In the Matter	of the Proposed Central Plains Water Enhancement Scheme
To	Environment Canterbury and Selwyn District Council
Submitter	Te Runanga o Ngai Tahu

BRIEF OF EVIDENCE OF DAVID PHILIP HAMILTON

For

TE RUNANGA O NGAI TAHU

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1. QUALIFICATIONS AND EXPERIENCE

1.1 My full name is David Philip Hamilton. I am a Professor employed by the University of Waikato as the Environment Bay of Plenty Chair in Lakes Management and Restoration.

1.2 I hold a Bachelor of Science (B.Sc.) and Ph.D. (Otago), 1984 and 1991, respectively.

1.3 A component of my Ph.D. involved research into water quality of Te Waihora (Lake Ellesmere), particularly the effects of wind resuspension of bed sediments. This research was also published in peer reviewed scientific publications (Hamilton and Mitchell, 1996, 1997).

1.4 I have conducted research and teaching in the field of limnology (studies of inland waters) and aquatic ecology for the past 25 years. My specific research interests and expertise are in modelling of water quality in lakes and reservoirs, nutrient fate and transport in lakes and bloom-forming algae, particularly blue-green algae (cyanobacteria).

1.5 I have authored more than 75 peer-reviewed scientific papers and book chapters, 40 contract reports and 150 conference papers. I serve on international advisory or editorial boards for three scientific journals, have edited two special issues of international journals, have given several keynote talks to international and national conferences, have consulted in the water industry in New Zealand, Australia, Asia and USA, and have provided expert advice and evidence to central, regional and local governments.

1.6 I have read the Code of Conduct for Expert Witnesses (Rule 330A, High Court Rules and Environment Court Practice Note) and agree to comply with it. I confirm that I have complied with it in the preparation of this statement of evidence.

2. SCOPE OF EVIDENCE

2.1 I have been asked by Te Runanga O Ngai Tahu to:

- assess potential impacts of the Central Plains Water Enhancement Scheme (CPWES) on water quality of Te Waihora (Lake Ellesmere).
- provide information on how the Central Plains Water Enhancement Scheme might affect the potential for restoration of Te Waihora.

2.2 Ngai Tahu are concerned that changes in nutrient loading to Te Waihora may affect future efforts to restore the lake. Ngai Tahu has initiated measures that aim to protect the lake, including:

- obtaining ownership of the lake bed through the Ngai Tahu Claims Settlement Act 1998;
- development of water management policies with Environment Canterbury;
- development of Te Waihora management policies in a Department of Conservation - Te Runanga O Ngai Tahu Joint Management Plan; and
- development of a Ngai Tahu policy on fresh water.

3. SUMMARY OF SUBMISSION

3.1 My examination of effects of the CPWES and potential impacts on restoration of on Te Waihora by Te Runanga O Ngai Tahu focuses on three main aspects. First is that the restoration of turbid, eutrophic shallow lakes often requires extraordinary constraints on nutrient inputs and related management actions due to the relative stability of the turbid state. This turbid stable state is reinforced by wind resuspension of the lakebed sediments in Te Waihora, which are now denuded of vegetation. The alternative stable state of abundant weed (macrophyte) beds and relatively high water clarity tends to be reinforced naturally by the sheltering effects of the weed beds, but was disrupted in the 'Wahine' storm in 1968. It is my opinion that for this reason restoration of Te Waihora by Te Runanga O Ngai Tahu is extremely challenging.

3.2 Second, I have constructed water and nutrient budgets for Te Waihora to support the modelling work undertaken as the third component of my statement. The budget under current nitrogen loads indicates that in Te Waihora more than 550 tonnes per year of nitrate is lost as nitrous oxide and nitrogen gas via denitrification. This figure equates to an areal denitrification rate of 0.0081 g m^{-2} day^{-1}. I do not know how this rate might be altered under a scenario of increased nitrogen loading equating to the CPWES flows to Te Waihora. Until more information is available on denitrification rates, it is my opinion that it would be unwise to deliberately increase nitrogen loading to Te Waihora, particularly as the modelling indicates that phytoplankton production in the lake may be nitrogen-limited for considerable periods of time. The phosphorus budget indicates that the bottom sediments contribute a large mass to the lake water column, 8.3 tonnes each year, which equates to a net areal release rate of 0.00127 mg m^{-2} day $^{-1}$. This figure is consistent a major contribution of resuspended sediments to water column phosphorus concentrations.

3.3 Third, simulations with a coupled hydrodynamic-ecological model were used to reproduce the observed variations of temperature, dissolved oxygen, dissolved reactive phosphorus (DRP), total phosphorus (TP), nitrate, ammonium and total nitrogen (TN), as well as light penetration, in the water column of Te Waihora. Simulation results were consistent with the observed highly turbid, eutrophic nature of Te Waihora. They indicated that phytoplankton in Te Waihora are light-limited for 51% of the year, phosphorus-limited for 12% of the year and nitrogen-limited for the remaining 37% of year. Under a scenario of increased water and nitrogen loading to Te Waihora, consistent with the CPWES inflows, chlorophyll *a* concentrations increased only marginally, most likely not outside of the bounds of model error, but concentrations of dissolved inorganic nitrogen, predominantly nitrate, increased more than 10-fold over concentrations simulated under present conditions. Given the magnitude of this increase and uncertainty in the physiological parameters that characterise phytoplankton responses to light and nutrients in Te Waihora, I consider that it would be unwise to risk this magnitude of increase in dissolved inorganic nitrogen concentrations with CPWES inflows, without more information. I consider that this increase in dissolved inorganic nitrogen is likely to be counter-productive in efforts by Te Runanga O Ngai Tahu to restore Te Waihora.

4. WATER QUALITY OF TE WAIHORA

4.1. Te Waihora is highly turbid and eutrophic. These conditions have persisted since a major storm (the 'Wahine') brought about the destruction of weed (macrophyte) beds in 1968. This storm was highly destructive and likely contributed to losses of macrophytes as a direct result of the effects of wave-generated turbulence on the plants themselves, as well as the subsequent poor light climate, which hindered the capacity for plants and seed beds to regenerate, and the greater mobility of bottom sediments.

4.2 It is my opinion that weed beds in Te Waihora may have already been susceptible to the effects of a destructive storm event because of the combined effects of managed water levels and greater nutrient inputs to the lake, both of which may have decreased the resilience of the weed beds to natural perturbations such as storms.

4.3 Since the Wahine storm event, macrophytes have failed to recolonise the lake bed to any significant extent. The water has remained turbid due to wind-generated wave action which resuspends bottom sediments. These bottom sediments are no longer subject to the sheltering effects of the plants. Correspondingly, water column concentrations of suspended solids, nutrients and chlorophyll *a* are very high, reflecting an adequate supply of nutrients, mostly from the bottom sediments, which contributes to maintaining high phytoplankton biomass.

4.4 Te Waihora conforms to the alternative stable state hypothesis for two readily identifiable states of water quality. The first is a state where abundant macrophyte biomass reinforces water column conditions of high water clarity and relatively low levels of nutrients and phytoplankton biomass. I consider that this state characterised Te Waihora prior to the Wahine storm. It is my opinion that the resilience of this state was reduced prior to the storm, due to management of water levels and increasing nutrient loads to the lake. The Wahine storm brought about a catastrophic switch to the alternative stable state of few or no macrophytes, low water clarity and high levels of nutrients and phytoplankton biomass. The terms used above of 'alternative stable state', 'catastrophic switch', 'resilience' are not mine; they have been adopted by ecosystem ecologists to describe the way in which natural ecosystems respond to anthropogenic and natural stressors, and especially the way in which shallow lakes can be partitioned into two readily identifiable alternative stable states (e.g. Scheffer, 1998; Scheffer et al., 2001).

4.5 It is my opinion that it will be difficult to change the current turbid, eutrophic state of Te Waihora to the pre-Wahine storm state. Ecosystem ecologists have recognised this difficulty and indicate that to achieve a switch back to a clear-water state often requires greater control of anthropogenic stressors (e.g. nutrient loads) due to the loss of relatively high levels of resilience of the original clear-water state prior to the switch to a turbid state. It is my opinion, therefore, that Te Runanga O Ngai Tahu will have a major challenge in attempting to restore water quality of Te Waihora. Nevertheless, there are examples both in New Zealand (Mitchell et al., 1988) and overseas (Jeppesen et al., 2002) in which shallow lakes alternate naturally between alternative stable states or where nutrient loads, water levels and fish populations have been managed to re-establish the clear-water state.

5. WATER AND NUTRIENT BALANCES FOR TE WAIHORA

5.1 I calculate a water balance for Te Waihora as follows:

- Current inflow volume from tributaries at 12.265 m^3 s^{-1}, (Horrell, 1992);
- Current inflow volume from groundwater seepage at 0.44 m^3 s^{-1}, (Ettema & Moore, 1995);
- Current inflow volume from rain at 3.585 m^3 s^{-1} (Horrell, 1992);
- Current inflow volume from sea incursions from artificial openings of Kaitorete spit at 2.353 m^3 s^{-1} (Horrell, 1992);
- Current inflow volume from sea incursions from rough weather surges over Kaitorete spit at 1.258 m^3 s^{-1} (Horrell, 1992);
- Current outflow volume through evaporation at 6.078 m^3 s^{-1} (Horrell, 1992);
- Current outflow volume through artificial openings of Kaitorete spit at 12.893 m^3 s^{-1} (Horrell, 1992);
- Current outflow volume through groundwater seepage at 1.01 m^3 s^{-1}, (Horrell, 1992);
- A water level decrease of 0.013 m based on a residual term in the water balance of -0.079 m^3 s^{-1}. This change is considered small and has been ignored in subsequent considerations.

5.2 I calculate a nitrogen balance for Te Waihora using the flow rates from 5.1 and concentrations as follows:

- Nitrogen concentrations in tributaries of 3.325 mg L^{-1}, equating to an input of 1287 tonnes per year (White, 2008);
- Nitrogen concentrations in groundwater seepage of 0.460 mg L^{-1}, (White, 2008) equating to an input of 6.387 tonnes per year;
- Nitrogen concentrations in rainfall of 0.124 mg L^{-1}, equating to an input of 14.0 tonnes per year (Larned and Schallenberg, 2006);
- Dry deposition rates of nitrogen of 70 kg km^{-2} $year^{-1}$ and a water surface area of 189 km^2, equating to an input of 13.2 tonnes per year (Newman, 1995);

- Nitrogen concentrations in sea incursions from artificial openings of Kaitorete spit of 0.5 mg L^{-1} (Pinet, 2000), equating to an input of 37.1 tonnes per year;
- Nitrogen concentrations in sea incursions from rough weather surges over Kaitorete spit of 0.5 mg L^{-1} (Pinet, 2000), equating to 19.9 tonnes per year;
- Nitrogen inputs from faecal deposition by lake birds of 1.7 tonnes per year, calculated by assuming that there are the equivalent of 27,000 swans which have faecal nitrogen output rates of 0.17 g $swan^{-1}$ day^{-1} (Mitchell & Wass, 1995; O′Donnell, 1985; NWASCA, 1988). This figure was determined as approximate numbers of each major bird species breeding at Te Waihora and adjusting each figure to an equivalent swan number based on relative sizes.
- Nitrogen concentrations in outflows from artificial openings of Kaitorete spit with a mean lake water concentrations of 1.871 mg L^{-1} (Hamilton & Mitchell, 1997), giving a nitrogen output of 761.3 tonnes per year.
- Nitrogen concentrations in seepage through Kaitorete spit with a mean lake water concentrations of 1.871 mg L^{-1} (Hamilton & Mitchell, 1997), giving a nitrogen output of 59.6 tonnes per year.
- A difference between inputs and outputs of nitrogen of -557.9 tonnes. This term is considered in further detail below.

5.3 The loss of nitrogen of 0.0081 g m^{-2} day^{-1}, which is not accounted for by other terms in the nitrogen balance, is likely to be mostly due to the net effect of sedimentation/resuspension and to denitrification. I consider that the net sedimentation/resuspension term is likely to be small or even positive because of a) the dominance of the resuspension term shown in the phosphorus mass balance (see below) and b) similar concentrations of nitrogen and phosphorus in sediments from the lake, with the contribution (Hamilton & Mitchell, 1997). On this basis it is possible that the denitrification term might be higher by around 87 tonnes, the figure for release of phosphorus from the lake bed (see calculations below).

5.4 I calculate a phosphorus balance for Te Waihora using the flow rates given in 5.1 and concentrations as follows:

- Phosphorus concentrations in tributaries of 0.0390 mg L^{-1}, equating to an input of 15.1 tonnes per year (White, 2008);
- Phosphorus concentrations in groundwater seepage of 0.005 mg L^{-1} (White, 2008), equating to an input of 0.069 tonnes per year;
- Phosphorus concentrations in rainfall of 0.0097 mg L^{-1}, equating to an input of 1.1 tonnes per year (Horrell, 1992);
- Dry deposition rates of phosphorus on the water surface of 10 kg km^{-2} $year^{-1}$ (Newman, 1995), a water surface area of 189 km^2, equating to an input of 1.9 tonnes per year;
- Phosphorus concentrations in sea incursions from artificial openings of Kaitorete spit of 0.07 mg L^{-1} (Pinet, 2000), equating to an input of 5.2 tonnes per year;
- Phosphorus concentrations in sea incursions from rough weather surges over Kaitorete spit of 0.07 mg L^{-1} (Pinet, 2000), equating to an input of 2.8 tonnes per year;
- Phosphorus inputs from faecal deposition by lake birds of 0.14 tonnes per year, calculated by assuming that there are the equivalent of 27,000 swans which have faecal phosphorus output rates of 0.02 g $swan^{-1}$ day^{-1} (Mitchell & Wass, 1995). This figure was determined as approximate numbers of each major bird species breeding at Te Waihora and adjusting each figure to an equivalent swan number based on relative sizes.
- Phosphorus concentrations in outflows from artificial openings of Kaitorete spit with mean lake water concentrations of 0.259 mg L^{-1} (Hamilton & Mitchell, 1997), giving a phosphorus output of 105.4 tonnes per year.
- Phosphorus concentrations in seepage through Kaitorete spit with a mean lake water concentrations of 0.259 mg L^{-1} (Hamilton & Mitchell, 1997), giving a phosphorus output of 8.3 tonnes per year.
- A difference between inputs and outputs of phosphorus of -87.4 tonnes per year or a loss of 0.00127 mg m^{-2} day $^{-1}$ considering a lake area of 189 km^2. This term is considered in further detail below.

5.5 The loss of phosphorus of 0.00127 g m^{-2} day^{-1}, which is not equated for by other terms in the phosphorus balance, is likely to be due mostly to the net effect of sedimentation/resuspension. Therefore, a large mass of phosphorus is resuspended from the lake bed sediments and is in suspension at any given point in time.

5.5 The estimated rate of denitrification in Te Waihora is extremely high for a lake that in which there is no evidence of severe deoxygenation. Denitrification is the major factor responsible for the low concentrations of inorganic nitrogen in the lake compared with levels in tributary inflows. Denitrification requires the presence of anoxic conditions in order to achieve reduction of nitrate to nitrous oxide and nitrogen gas, as well as an adequate supply of carbon. I consider that anoxic conditions may be provided in regions near the sediment-water boundary and possibly in microzones associated with organic particulates within the water column, as noted by Pinckney and Paerl (1996), and that the eutrophic state of Te Waihora provides an adequate supply of carbon to also support denitrification. Additional nitrogen loads associated with the CPWES could compromise the occurrence of nitrogen limitation in Te Waihora (see below) as areal rates of denitrification, which likely exceed 0.0081 g m^{-2} day^{-1}, are unlikely to increase proportionately to maintain the current low levels of inorganic nitrogen in the lake.

6. ECOLOGICAL MODEL OF TE WAIHORA

6.1 An ecological model has been set up for Te Waihora. The model consists of a hydrodynamic component, DYRESM, and a water quality component, CAEDYM. The combination of DYRESM-CAEDYM is arguably the best tool available worldwide with which to simulate water quality in lakes. The CAEDYM model includes a relatively complete water column representation of interactions amongst phytoplankton, nutrients and dissolved oxygen. I initiated the development of CAEDYM and have worked with DYRESM-CAEDYM and its predecessor DYRESM-WQ for more than 15 years.

6.2 Input data have been sourced with which to run the DYRESM-CAEDYM model for a period of one year, starting from 19 January 2000. The input data comprise daily average meteorological data sourced from Lincoln Broadfields station (latitude 43.6262^o, longitude 172.4704^o), daily inflow and outflow data sourced from the water and nutrient budget information above (section 5), and hypsographic information comprising of wetted area for different lake water levels.

6.3 The model simulated accurately the observed annual fluctuations in water temperature from 5 to 21 ^{o}C. Simulations also indicated no major departures from oxygen saturation in the water column.

6.4 The model was calibrated to reproduce concentrations of chlorophyll and nutrients in Te Waihora based on levels typically observed in the lake. The observed levels were a mean chlorophyll *a* concentration of 87 mg m^{-3} and typical concentrations of dissolved reactive phosphorus (DRP) < 10 mg m^{-3}, total phosphorus (TP) c. 180 mg m^{-3}, dissolved inorganic nitrogen (DIN; nitrate + ammonium) c. 20 mg m^{-3} (see Fig. 1 from Larned and Schallenberg, 2006) and total nitrogen of 1,870 mg m^{-3} (Hamilton and Mitchell, 1997). The euphotic depth, indicative of where photosynthetically active radiation is 1 % of the surface water value, was estimated by Larned and Schallenberg (2006) to be around 0.4 m.

6.5 The calibrated model gave annual mean values derived from the daily output of the model of 83 mg m^{-3} chlorophyll *a*, 3.3 mg m^{-3} DRP, 149 mg m^{-3} TP, 19 mg m^{-3} DIN and 1938 mg m^{-3} total nitrogen, and a euphotic depth of 0.43 m.

6.6 During the calibration procedure, particular attention was placed on key physiological parameters for phytoplankton, including responses to light and nutrients. The selected parameter values reflected high sensitivity of phytoplankton to light and low sensitivity to available nutrients, as might be expected in a turbid, eutrophic lake. Values of these parameters were also set to be well within bounds of reputable literature sources (e.g., Reynolds, 1997). The calibrated model can be considered to be conservative with respect to nutrient limitation (i.e. nutrient limitation likely to occur at lower frequency than in reality). The values of selected parameters in the model should not be regarded as fixed at this stage and additional studies to measure phytoplankton responses to light and nutrients should be undertaken under controlled environmental conditions. At the present point in time the simulation results and any trends in model scenarios should be regarded as indicative rather than being used for quantitative values.

6.7 The model output indicated that phytoplankton in Te Waihora were light-limited for 51% of the year, phosphorus-limited for 12% of the year and nitrogen-limited for the remaining 37% of year. Light limitation occurred more frequently in winter, when nutrient levels were elevated, compared with summer.

6.8 These results demonstrate that light, phosphorus and nitrogen can, at different times, impose significant constraints on phytoplankton production in Te Waihora. The results suggest that if tributary concentrations are altered relative to concentrations in lake water, then there are likely to be changes in nutrient limitation.

6.9 The results of the model simulations of nutrient and light limitation of phytoplankton production differ slightly from assessments of nutrient limitation in previous studies (e.g., Larned and Schallenberg, 2006). I consider that they provide the best basis by which to assess the temporal and spatial occurrence of nutrient limitation in Te Waihora in the absence of direct measurements of nutrient limitation. The model simulations suggest that the large phytoplankton biomass supported within the water column is quite regularly constrained by light limitation, followed by nitrogen limitation and then by phosphorus limitation. I consider that it is incorrect to have used total phosphorus concentrations to support previous assessments of nutrient limitation in Te Waihora as much of the phosphorus in the lake is 'bound' to particulates, i.e., inorganic particles with high adsorptive capacity for phosphorus, and which effectively compete with phytoplankton for bioavailable phosphorus in the water column. It is for this reason that I consider previous studies have underestimated the occurrence of phosphorus limitation in Te Waihora.

7. MODEL SIMULATIONS OF CPWES EFFECTS ON WATER QUALITY

7.1 Simulations have been set up with DYRESM-CAEDYM for different scenarios related to increases in tributary discharges to Te Waihora of 10.235 m^3 s^{-1} due to the CPWES. The phosphorus concentrations associated with the additional inflow are considered to increase slightly, from 0.039 to 0.045 mg L^{-1}, on the basis that approximately 80% of the phosphorus load from the Central Plains area occurs as 'quick flow', with a concentration of 0.2 mg L^{-1} and 20 % of the load occurs as 'base flow' with a concentration of 0.02 mg L^{-1} (Moore and Borrie, 1987). The simulations are as follows:

a. CPWES and current tributary nitrogen concentrations at a lower range of 4.42 mg L^{-1}, and phosphorus concentrations of 0.042 mg L^{-1} based on a volumetrically average concentration for the inflow and the CPWES.

b. CPWES and current tributary nitrogen concentrations at an upper range of 5.66 mg L^{-1}, and phosphorus concentrations of 0.042 mg L^{-1} based on a volumetrically average concentration for the inflow and the CPWES.

7.2. Annual mean concentrations of chlorophyll *a* and nitrate were calculated from daily values from model simulations for the two cases above. In case (a) chlorophyll *a* concentrations increased to 0.087 mg L^{-1} from 0.083 mg L^{-1} in the 'present' (2000) case, and dissolved inorganic nitrogen concentrations increased to 0.241 mg L^{-1} from 0.019 mg L^{-1} in the present case. In case (b) chlorophyll *a* concentrations were identical to those for case (a), increasing to 0.087 mg L^{-1} from 0.083 mg L^{-1} in the present case, while for dissolved inorganic nitrogen, concentrations increased to 0.349 mg L^{-1} compared to 0.241 mg L^{-1} in case (a) and 0.019 mg L^{-1} in the present case. Almost all of the increase in dissolved inorganic nitrogen was attributable to increases in nitrate concentrations.

7.3. Changes in chlorophyll *a* for the three different simulation cases (present with no CPWES and for two CPWES scenarios with different nitrate concentrations) are likely to fall within the error bounds of the model output. I emphasise the need for a cautionary approach in assessments of model chlorophyll *a* output, however, as there is almost no information adapted into the model that is specific to Te Waihora in relation to phytoplankton physiological responses to light and nutrients.

7.4. Changes in nitrate concentrations for the three different simulation cases are less equivocal and indicate that there will be marked increases in concentration with CPWES inflows. The size of these increases indicates that nitrate limitation of phytoplankton biomass will decrease markedly in Te Waihora and that limitation by other factors (e.g. phosphorus) is likely to increase as a result.

7.5. Model simulations that show that there is little or no change in chlorophyll *a* concentrations with the different CPWES inflow nitrate concentrations suggest that in each case concentrations of dissolved inorganic nitrogen had already increased above levels that induce limitation. This finding is not surprising given the large increases in concentrations of dissolved inorganic nitrogen in each simulation scenario. Bioassays should be used to examine how phytoplankton respond to increases in nitrate concentrations ranging from the present case (0.019 mg L^{-1}) to a projected upper range (0.349 mg L^{-1}) with the CPWES inflow.

7.6. It is my opinion that with the current projections of increases in nitrate concentrations in Te Waihora in simulations of effects of CPWES inflows, there is a strong possibility that lake water quality will become further degraded. To refine model projections, however, carefully controlled bioassays are required to assess the extent of phosphorus and nitrogen limitation, the interactions amongst inorganic sediments and phytoplankton for available phosphorus, and the responses of phytoplankton to increases in nitrate concentrations corresponding to those projected in the model simulations with the CPWES. These results will help to refine the extent to which phytoplankton biomass might change with CPWES inflows and should be used in further model simulations to assist with predictions of water quality under a range of scenarios.

7.7. The model simulations indicate the importance of assessing additional nutrient loads from CPWES inflows using comparisons of concentrations in tributary inflows against lake water concentrations, not against existing tributary concentrations; nitrogen concentrations in CPWES inflows are high compared with those in the lake while phosphorus concentrations are low. The net effect in model simulations is a substantial increase in nitrate concentrations with CPWES inflows but relatively little change in concentrations of chlorophyll *a*.

7.8. My preliminary assessment is that the CPWES inputs to Te Waihora will impede the objective of Te Runanga O Ngai Tahu to initiate restoration of the lake and improve mahinga kai resources. Given the paucity of information about phytoplankton responses to light and nutrients in Te Waihora, a precautionary approach should be adopted in which these responses are carefully gathered. CPWES inputs to Te Waihora should not be initiated in the interim because of high probability for increases in nitrate concentrations that may stimulate phytoplankton productivity, to an extent that cannot be predicted with certainty at this stage.

DATED this day of 2008

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D P Hamilton

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