CAWTHRON

Behaviour of the Low-salinity-layer in Doubtful Sound under Experimental Increases of Tailrace Discharge

Cawthron Report No. 1273

March 2007

CAWTHRON

Behaviour of the Low-salinity-layer in Doubtful Sound under Experimental Increases of Tailrace Discharge

Eric Goodwin
Mark Gibbs
Chris Cornelisen
Paul Barter
Kim Clark
Weimin Jiang

Prepared for

Meridian

Cawthron Institute
98 Halifax Street East, Private Bag 2
Nelson, New Zealand
Ph. +64 3 548 2319
Fax. + 64 3 546 9464
www.cawthron.org.nz

Reviewed by: _____ Approved for release by: _____

Dr Ross Vennell Dr Mark Gibbs

Recommended citation:
Goodwin E, Gibbs M, Cornelisen C, Barter P, Clark K, Jiang W 2007. Behaviour of the low-salinity-layer in Doubtful Sound under experimental increases of tailrace discharge. Prepared for Meridian Energy Ltd. Cawthron Report No. 44 p plus appendices.

© Copyright: Apart from any fair dealing for the purpose of study, research, criticism, or review, as permitted under the Copyright Act, this publication must not be reproduced in whole or in part without the written permission of the Copyright Holder, who, unless other authorship is cited in the text or acknowledgements, is the commissioner of the report.

EXECUTIVE SUMMARY

The Manapouri Hydroelectric Power Station operated by Meridian Energy Ltd. (Meridian) currently discharges freshwater into Doubtful Sound under a consent limit of 510 m^3s^{-1}. Meridian is investigating the possibility of increasing the discharge of freshwater from the Manapouri tailrace tunnels into Doubtful Sound to around 640 m^3s^{-1} at times. Whilst the ultimate throughput of freshwater is governed by its availability, which is determined under lake level operating guidelines and lake catchment inflows, it is possible that there are periods of time where more freshwater will be available to be used for generation. However, the influence of tailrace discharges exceeding 510 m^3s^{-1} on the near-surface oceanography of Doubtful Sound is currently unknown.

In order to better understand relationships between tailrace inflows of freshwater and the behaviour of the low-salinity-layer (LSL) in Doubtful Sound, Meridian carried out a high flow trial (HFT) that involved three separate controlled increases in tailrace discharge (610 m^3s^{-1}) for brief periods of time (2-4 hours). The three high discharge events were conducted during calm weather conditions, which allowed for better isolation of the effects of tailrace discharge on the behaviour of the LSL by minimising variability induced by other drivers (*e.g.* rain and wind).

Near-surface oceanography of the fiord was monitored during the two days preceding the discharge events, the three consecutive days that high discharge events occurred, and two days immediately following the HFT when the tailrace discharge was reduced to <400 m^3s^{-1}. Monitoring during this period was aimed at measuring physical attributes of the LSL that could potentially change with an increase in tailrace discharge, including current speed and direction, the magnitude of surface waves in Deep Cove, and the temporal and spatial structure of the LSL. Several tools were used to monitor these attributes, including GPS drogues, moored current and wave meters, Meridian's oceanographic moorings and vessel-deployed CTD's (Conductivity, Temperature, Depth sensors).

Key observations from monitoring during the HFT included the following:

- The stream of water discharged from the tailrace followed the main fiord channel, veering to the south of Elizabeth Island and either side of Bauza Island (through The Gut (Te Awaatu Channel) as well as Patea Passage).
- Transit time from the tailrace to the entrance of the fiord for water discharged through the tailrace was on the order of 16 to 20 hrs.
- Data collected within the inner region of the fiord suggest that increased discharge was accommodated by a roughly even partitioning between increased current speed and increased LSL thickness.
- Surface current speeds within Deep Cove during pulses of 610 m^3s^{-1} discharge were approximately 20 to 40% higher than during similar weather conditions and a lower discharge rate (330 to 370 m^3s^{-1}). Surface current speeds were lowest on the rainy day preceding the HFT when the LSL was thick and well stratified.

- Elevated current speeds during the high flow pulses were most evident within the first 10 km; however, were apparent over the length of fiord examined using the drogues (out to 15 km). Current speeds dropped as a function of distance from the tailrace and widening of the fiord.
- During periods of increased discharge, effective freshwater depth (EFD) and depth of the 28 psu isohaline increased (on the order of 0.5 to 1 m) in comparison to periods when the tailrace was discharging at a rate of 330 and 370 m^3s^{-1} on 18 and 19 July, respectively.
- An increase in tailrace discharge increased mixing between the LSL and underlying seawater, which in turn reduced stratification, slightly raised salinity in the surface waters, and increased levels of light attenuation within the top 5 m of water.
- Based on data collected at the oceanographic moorings, the effects of increased discharge on the LSL were most evident in Deep Cove during the first two events that coincided with a low tide.

Outcomes of the HFT demonstrate that the rate of tailrace inflow has a significant effect on physical attributes of the surface waters of Doubtful Sound. More specifically, an increase in discharge rate to 610 m^3s^{-1} during a calm period has measurable effects on surface currents and LSL characteristics, which in turn influences salinity stratification and light attenuation within the surface waters. Direct effects of increased discharge on these physical variables were largely limited to the inner region of the fiord (*i.e.* Deep Cove).

TABLE OF CONTENTS

EXECUTIVE SUMMARY III
1. INTRODUCTION 1
1.1. Goal and objectives 1
1.2. Background on LSL behaviour and tailrace discharge 2
2. METHODS 4
2.1. Approach during the high flow trial 4
2.1.1. High flow discharge 4
2.1.2. Monitoring strategy 4
2.1.3. Performance indicators and maintaining compliance 5
2.2. Monitoring underlying drivers 7
2.3. Monitoring the LSL 7
2.3.1. Currents and waves 7
2.3.2. LSL structure in space and time 9
2.4. Data pre-processing 12
3. RESULTS 12
3.1. Performance indicators and maintaining compliance 12
3.2. Underlying drivers of LSL 13
3.3. Response of the Low-Salinity-Layer to high discharge pulses 14
3.3.1. Currents and waves 14
3.3.2. LSL structure in space and time 19
4. SUMMARY AND CONCLUSIONS 34
5. ACKNOWLEDGEMENTS 37
6. REFERENCES 38
7. APPENDICES 39

LIST OF FIGURES

Figure 1. Time series of rain, wind speed, tailrace discharge, equivalent freshwater depth (EFD) and salinity at M4 (mid-channel of Doubtful Sound) for the month of May 2005 3
Figure 2. Equipment deployed from vessels during the high flow trial 5
Figure 3. Chart showing monitoring zones and the table of performance indicator threshold values for each zone (see inset). 7
Figure 4. Schematic of the wave gauge mooring placed in Deep Cove during the high flow trial 8
Figure 5. Data from CTD casts collected along the main channel in Doubtful Sound 11
Figure 6. Site map with locations of physical moorings. 11
Figure 7. Wind speed, rain, tidal amplitude and tailrace discharge before, during and after the high flow trial. 14
Figure 8. Paths of 20 drogues released in Deep Cove during various levels of tailrace discharge 16
Figure 9. Average drogue speed (n = 20) with distance during deployments on days preceding (13 and 14 July), during (15–17 July) and following (18 July) high flow discharge. The solid black line represents the width of the main channel along the fiord. 17
Figure 10. Surface current speed (ms^{-1}) based on 20 drogues deployed during a 610 m^3s^{-1} discharge on 16 July (top panel) and during a 330 m^3s^{-1} discharge on 18 July. 18

Figure 11. Times series of current speeds recorded at 1 m depth with an FSI current meter attached to mooring M4 in mid-channel 19
Figure 12. Time series of wave frequency and energy during the high flow trial 20
Figure 13. Results from CTD casts collected from the Casteaux while the vessel drifted along the fiord on each day of the HFT. 21
Figure 14. Equivalent Freshwater Depth (EFD, blue) and depth of the 28 psu isohaline (red) along the main channel of Doubtful Sound. 23
Figure 15. Equivalent Freshwater Depth (EFD) along the main channel of Doubtful Sound derived from CTD surveys conducted during a rain event (13 July), two high flow discharges (15 and 16 July) and when the tailrace discharge rate was reduced (18 and 19 July) 24
Figure 16. Light attenuation coefficient (K_d) as a function of depth and distance along the fiord. K_d is calculated from the irradiance profiles collected with the CTD deployed from the Casteaux while the vessel drifted along the fiord on each day of the HFT 25
Figure 17. Vertical depth profiles of the average estimated K_d based on CTD casts collected between 0 and 5 km distance from the head of the fiord (Panel A). 26
Figure 18. Box plots representing means, quartiles and 95% confidence limits of K_d estimates made at each meter depth (1 to 10 m) based on CTD casts collected between 0 and 5 km distance from the head of Deep Cove. 27
Figure 19. Times series of temperature recorded at mooring M5 in Deep Cove over the course of the high flow trial. 28
Figure 20. Mean temperature (±1 SD) recorded during time intervals on each day of the HFT 30
Figure 21. Times series of salinity and temperature recorded at mooring M4 over the course of the high flow trial. 31
Figure 22. Mean salinity (±1 SD) recorded during time intervals on each day of the HFT 32
Figure 23. Box-and-whisker plots of salinity at M4 (mean, ± 1 SD) in Doubtful Sound. Boxes represent upper and lower quartiles. 34
Figure 24. Temperature and underlying drivers for each of the oceanographic moorings in Doubtful Sound. 35

LIST OF TABLES

Table 1. Description of the data collection methodology and trigger levels for the three performance indicators and the wave height measurements. 6
Table 2. Typical performance indicator results for a pre-HFT day during a period of heavy rain (13 July) and the three days during the HFT 13
Table 3. P values for pairwise Wilcox tests comparing K_d estimates at a given depth between different sampling days made from CTD casts of irradiance collected between 0 and 5 km distance from the head of Deep Cove. 27

LIST OF APPENDICES

Appendix 1. Roaming CTD casts collected within the main channel according to distance from the tailrace 39
Appendix 2. Roaming CTD casts collected within Thompson Sound according to distance from the tailrace 40
Appendix 3. Roaming CTD casts collected within Bradshaw Sound according to time of collection .. 41
Appendix 4. Roaming CTD casts collected within the junction between Doubtful and Thompson Sounds according to time of collection 42

Introduction

1. Meridian Energy Limited (MEL have applied to vary their discharge consents for the Manapouri tailrace discharge into Deep Cove. The recent construction of a second tailrace tunnel into Deep Cove has made it possible for MEL to increase the power output from the Manapouri system by increasing flows through the two tailrace tunnels. The result is generation of more power and using more of the water available to it especially at times of higher inflow rather than discharging all excess water into the Waiau River through the Manapouri Lake Control Structure (MLC).

2. In order to analyse the effects of the increased tailrace discharge into Deep Cove, MEL has used a computer model to simulate the current generating conditions using existing discharge rules and lake operating levels. It has then extended this model by changing the tailrace discharge rules to allow more generation through the power system. A consequence of this is higher flows of fresh water entering Deep Cove and less water flowing into the Waiau River.

3. This report provides a review of:

   - The model used to generate current and future discharge, lake level and water transfer flows;
   - The resultant information used by MEL to compare the derived current and proposed future scenarios;
   - What extra information should be provided to assist in this water permit application accompanying report that would make it more complete and readable and assist in the processing of the consent.

The Model

4. The model used by MEL employed Stochastic Dynamic Programming and was named SoDaPop. The model "... takes historic daily inflows to the lakes and optimises the daily settings of the TLC (Te Anau Lake Control Structure), MLC and power station flow so that all environmental requirements are met and maximum electricity output is achieved while aiming to avoid the risk of future breaches of the environmental requirements." (Section 2.2 paragraph 1 of Final Report Manapouri Tailrace Amended Discharge Project (MTAD): Hydrology Assessment).

5. The model appears to be sophisticated enough to provide realistic outputs which can be reviewed and compared with some confidence. For this analysis, SoDaPop was run under the current environmental and permit constraints (maximum tailrace discharge 485 cubic metres per second (cumecs)) over a record period that extended from 1947 to 2006. It was then re-run using the same inputs but changing the tailrace discharge constraint to one with a maximum discharge of 550 cumecs. Two sets of results were produced, one for the current scenario and one for the proposed future scenario with a greater tailrace discharge.

6. While the model is obviously quite sophisticated it still has some shortcomings that may have affected the results of the analyses. These included:

   (a) The model uses daily lake levels and daily discharges and is unable to handle anything less than a 24 hour period. As a result, some of the flow, lake level

and generation changes will not be picked up. There is no real issue with the daily values in terms of environmental inflows and lake levels because these usually change only slowly over 24 hours but there are likely to be issues with controlled flows, with discharges at MLC which are to some extent determined by flows in the Mararoa River which can have rapid flow changes during the 24 hour period and also with power demand which fluctuates during the day depending on the time of day.

(b) The model operates in isolation from all the other hydro generation plant operated by MEL. That is, it operates assuming it is the only source of power than can meet the demand. It does not take into account other MEL storage and generating plant on other rivers such as the Waitaki and this is an issue. There are times when inflows are low and the Manapouri system cannot meet the demand. The shortfall is made up from the Waitaki hydro stations and wind energy. A recent example of this was the summer/autumn season of 2007/2008 when inflows to the South Island hydro lakes were some of the lowest ever recorded. Te Anau and Manapouri levels were low and the Manapouri system could not meet the demand. As a result, high summer flows occurred in the Waitaki as water was released for generation purposes in the Waitaki system to make up the shortfall in demand. The consequences were that the Manapouri/Te Anau permit conditions were met and the levels in Lakes Tekapo and Pukaki were lower leading into winter. At other times, power generation may be reduced due to high storage levels in the Waitaki system which need to be used or spillage may occur.

(c) Short term prediction is often undertaken by the system operators. This may be anticipation of a heavy rainstorm or a high unexpected demand that needs more generation. System operators can make adjustments during the day but SoDaPop cannot.

7. The model was calibrated using the measured inflow data, lake level and power generation data for the period 1997 – 2006. This was the period when the permitted minimum flow regime was operating and the second tailrace came on stream. The correlation between the actual and modelled outputs for the lakes, TLC and MLC flows were in the range of 0.88 – 0.93 while that for the tailrace was 0.79. While the report states that the correlation is very high, I would not be so optimistic and I believe it is not as good as the report writer thinks. In addition we are not told if the correlations are correlation coefficients (a measure of how well the predicted values from a forecast model "fit" with the real-life data) or if they are coefficients of determination (used in the context of statistical models whose main purpose is the prediction of future outcomes on the basis of other related information. It is the proportion of variability in a data set that is accounted for by the statistical model. It provides a measure of how well future outcomes are likely to be predicted by the model). Whichever it is, it is likely to be the best available and in this case it can be accepted as there is no alternative provided or available to assess the changes to flows and lake levels with the proposed new tailrace flows.

8. A major focus of the report is the scheme water balance, how it behaves under the present operational regime and how it is likely to change under the proposed new tailrace maximum flow. As part of the water balance, the Mararoa River flows needed to be taken into account. Records for this site began in 1974 but the modelling period is 1947-2006 so for the period 1947 to 1973, a synthetic daily flow record

needed to be derived for the Mararoa River. The best derivation was with lagged Lake Te Anau inflows but the coefficients of determination of 0.44 was very poor although the report writer stated it was "moderately good." The only thing that it was likely to do was maintain the statistics of the Mararoa River's contribution to Lake Manapouri inflows but beyond that, it is not likely really to resemble the actual flows in the river. It is fortunate that the Mararoa River contribution to the overall water balance for the Lake Manapouri system is quite small and will have little impact on the overall analysis.

9. As stated earlier, the model was run using the data from 1947 – 2006 firstly with a peak tailrace discharge of 485 cumecs and secondly with a peak tailrace discharge of 550 cumecs. From these, current and future lake levels and flows for both Te Anau and Manapouri were derived for each scenario. Lake levels were categorised as being in the high, main and low range as stated in the current water permits and flows were categorised as occurring in wet years (annual mean daily inflow greater than 507 cumecs), typical years (annual mean daily inflow 367-507 cumecs) and dry years (annual mean daily inflow less than 367 cumecs). Of the 60 year record analysed, there were 10 wet years, 39 typical years and 11 dry years.

10. The model outputs allows a comparison to be made between the current and proposed hydrological regime which included:

- Flow and lake level durations
- Mean maximum and minimum flows and lake levels
- Flow and lake level events
- Seasonal patterns of flows and lake levels.

11. All of the above were derived from the 60 year record period 1947 – 2006 with the exception of MLC discharges to the Lower Waiau River. The latter was treated separately because it needed accurate data for the Mararoa River because of the rapid changes that can occur in this river within 24 hours. As was noted earlier, very little confidence could be had in the derived 24 hour average flows for this river for the period 1947-1974 so only the recorded data could be used. However, even using the actual data for the 1974 – 2006 period, the model output was still 24 hour average flows. For the Mararora and Waiau Rivers, this did not give information on the instantaneous peak flows and the possible changes to these peak flows if the proposed permit changes are accepted. Given that most of the major floods in the Waiau River will be due to flooding in Lakes Te Anau and Manapouri which do not have the same rapid response time as the Mararoa River, the peak discharge during the day may not be significantly different to the average 24 hour peak discharge so it may not be a significant issue.

12. Some other questions that are raised in this section on model development are as follows:

(i) <u>Section 2.4.2</u>

- What is meant by "the calibration for the period of overlap is exact."?
- Does it have any relationship to the R^2 value of 0.44?

- Is the correlation made more difficult in that the derived Mararoa flows are calculated from Lake Te Anau inflows which are also derived flows?

(ii) Section 2.5.1 There is a discussion of mean daily flows in the minimum flow bands of 12, 14 and 16 cumecs at MLC. The report states "...the maximum flow recorded was 65 m^3/s when the mean flow for the day was 14 m^3/s. Thus a brief peak flow 51 m^3/s greater than the reported mean daily flow had occurred. Overall 3.2% of reported mean daily flows in the minimum flow bands obscure brief actual peak flows of 26-65 m^3/s."

- How are these flows missed in the data collection process?
- Is it due to ½ hour flow reporting?
- Where are these brief flow increases coming from and why?
- How many days and how many events?

For daily mean flows above the minimum the magnitude of the effect is greater. "...1% of greater than minimum flow days had peak flows more than 100 m^3/s above the reported daily mean flow, and 5% of days had peak flows more than 50 m^3/s above the mean daily flow. The maximum difference between a reported mean daily flow and the maximum flow on that day was 326 m^3/s". "Some flood events with reported peaks about 30 – 300 m^3/s below the actual maximum, particularly in the 100-250 m^3/s flow band."

- How are these flows missed?
- What is being done to ensure these data are picked up?
- What is the impact on flood frequency for the Upper Waiau and subsequently the Lower Waiau River?
- If these floods were missed, how is it that they can be reported here?

A more thorough explanation of Section 2.5.1 is needed to answer the above questions. Flood frequency is important for the Waiau River and the above discussion may have some implications for it.

Model Output Results for the Current and Proposed Tailrace Flows

13. It needs to be noted here that the results being compared are between the outputs from a model and are not a comparison of the proposed operation of the Manapouri scheme with the current operation of the scheme. In addition, all inflow data used are also derived flows and not measured.

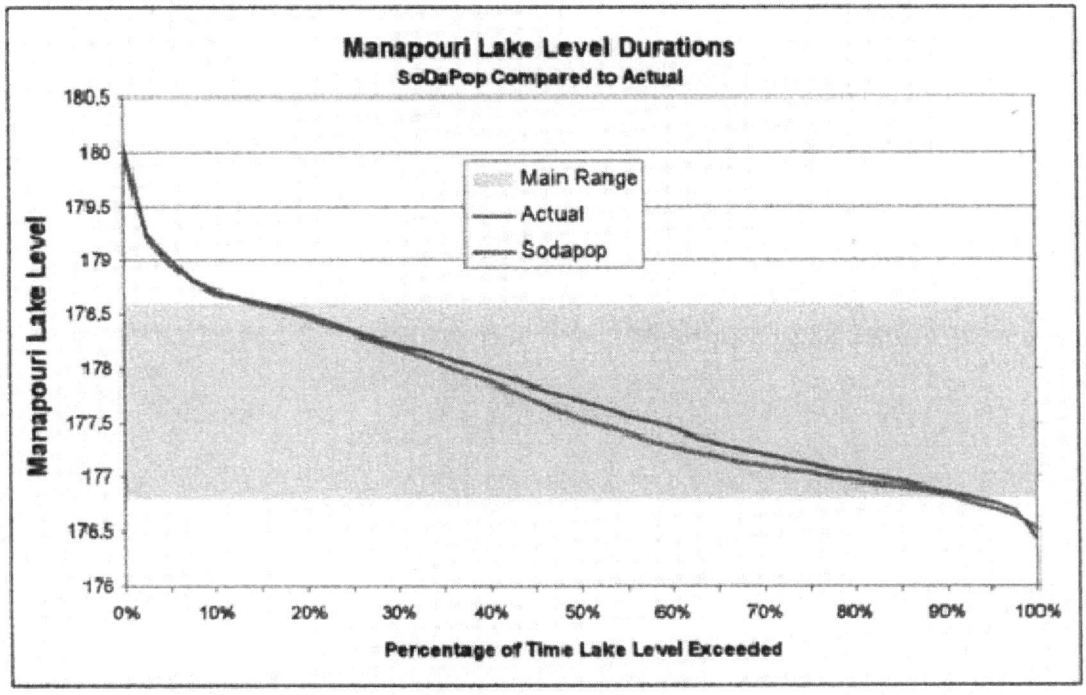
14. The problem with this is that the derived current operation is based on the statistics already discussed and the errors associated with the derivation will mean that there is a degree of uncertainty with both the existing and proposed scheme operation.

15. Appendix A of the hydrology report contains a brief review and 5 graphs showing the comparison of the derived current operations on lake levels and flows. These are

reproduced here but unfortunately the copy is not so good. Nevertheless the diagrams do show the comparisons based on flow or level duration curves between the existing actual current regime and the SoDaPop derived current regime.

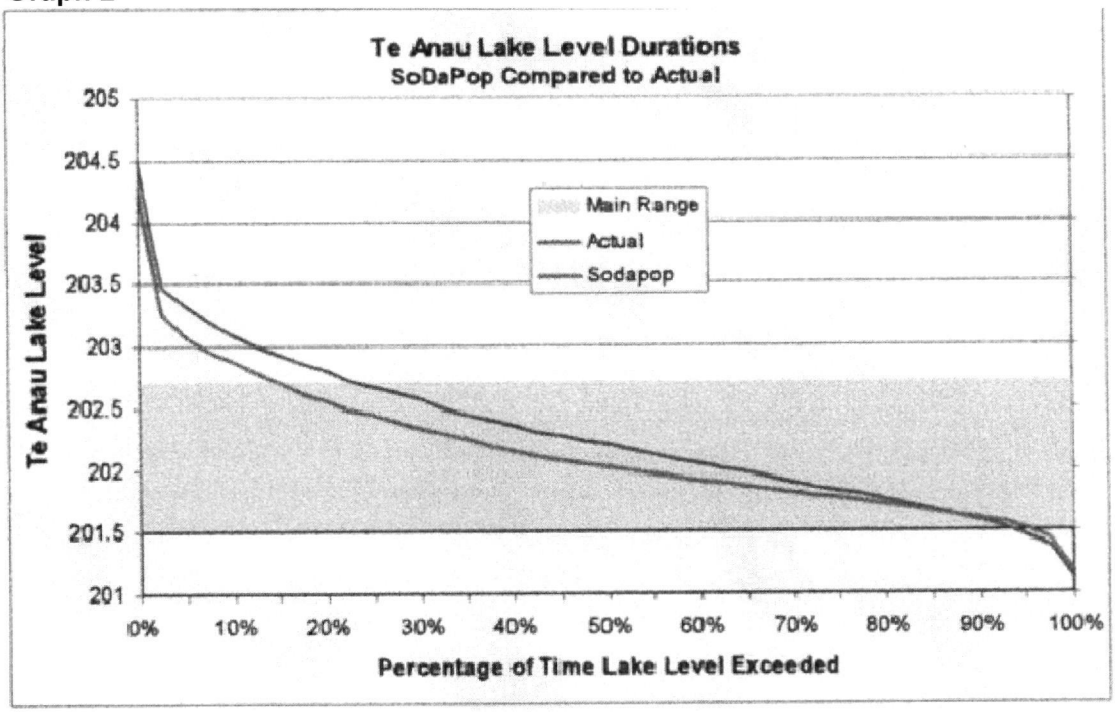
16. Flow/level duration curves in this case are a summary of 10 years of actual or derived flows and any individual events are masked. The first graph (Graph 1 from Appendix A Manapouri Tailrace Amended Discharge Project (MTAD) Hydrology Report) shows the level duration curves for Lake Manapouri (correlation 0.911) and it indicates the model is good for the highest and lowest levels but there is a difference in the main range between the actual and derived levels. The report states "SoDaPop keeps Manapouri in the high, main and low ranges almost exactly the same proportions of the time as was done in reality."

Graph 1



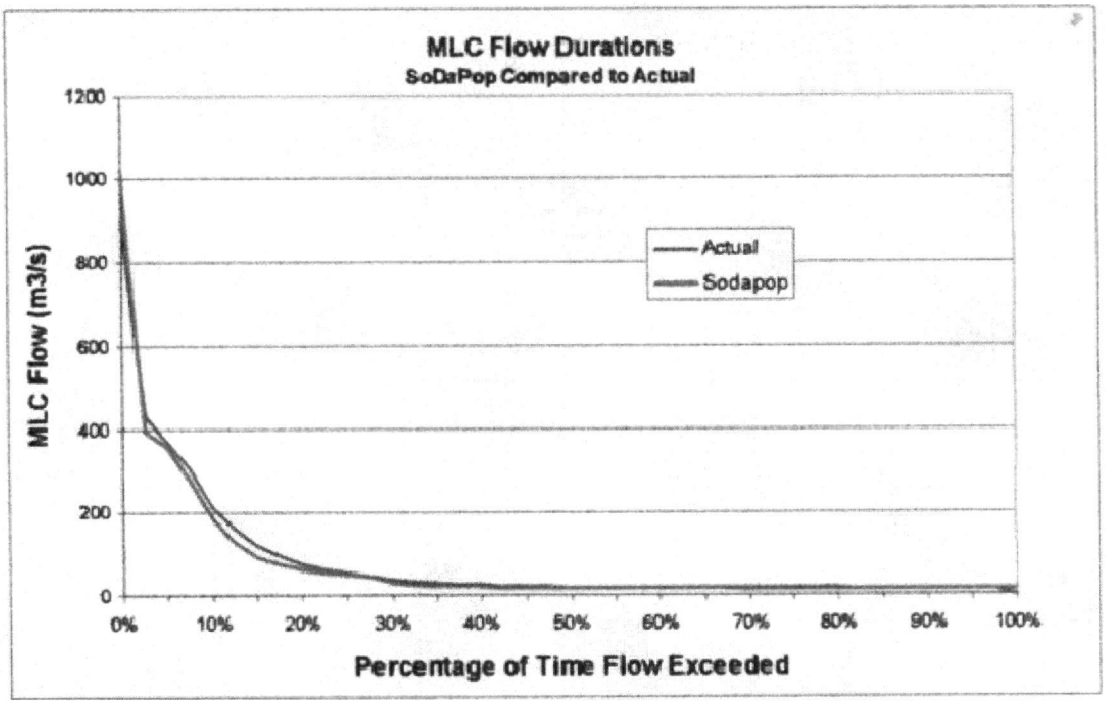
17. The second graph is that for Lake Te Anau levels (correlation 0.934). There is a difference between the two curves mainly because the model does not show Lake Te Anau at the highest stages for the period of time it was actually in this range. The report states "SoDaPop takes Te Anau into the high range about 15% of the time compared with 25% of the time in reality." While this may be important in the water balance of the system, it may not be so important in the overall context of increasing the outflow through the tailrace as is being applied for.

Graph 2



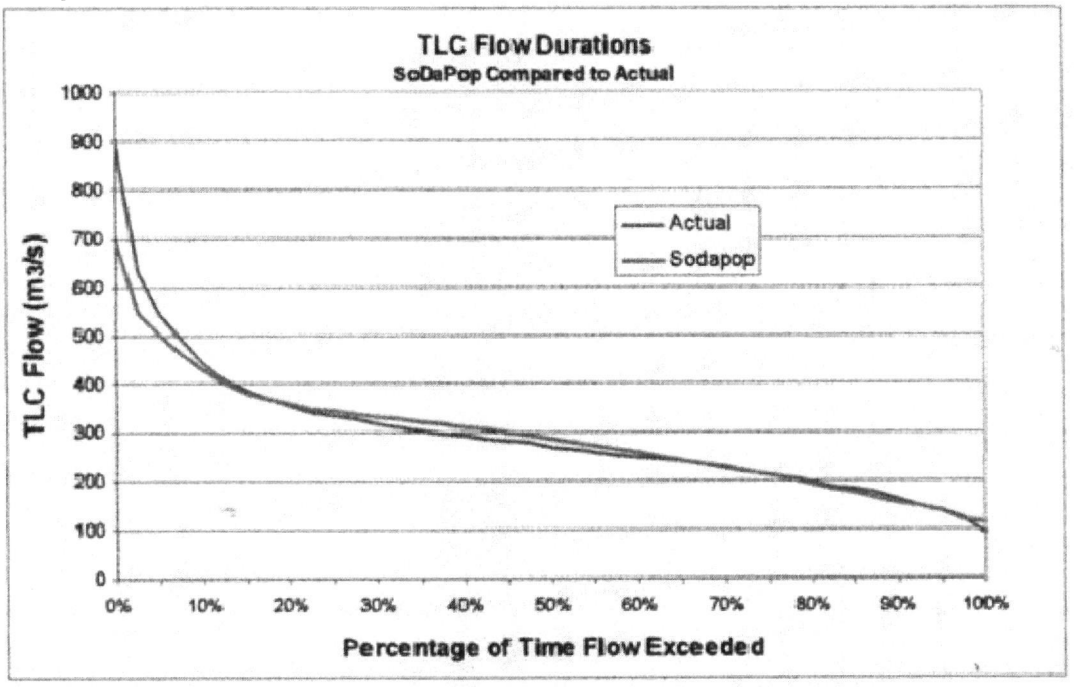
18. The third graph is a flow duration curve comparison for MLC discharges (correlation 0.92). The graph shows a quite close and good relationship between the actual and derived flows. This one is important as changes to flows into the Waiau River may create issues in that river.

Graph 3



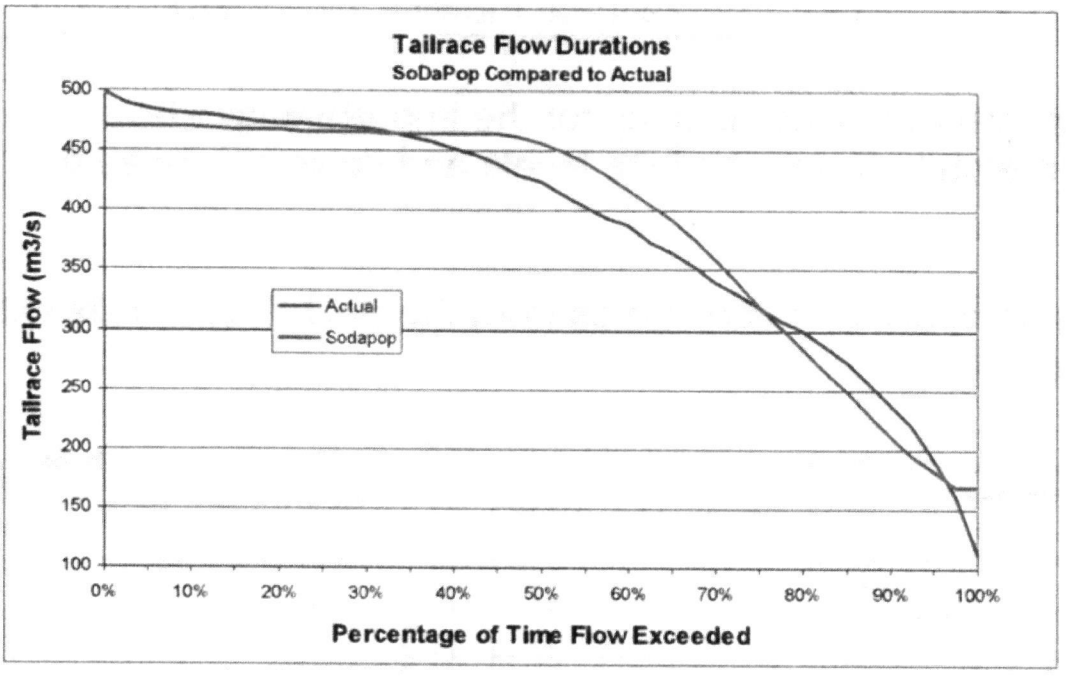
19. The fourth graph is a flow duration curve comparison for TLC discharges (correlation 0.884). Like the level duration curve for this lake, the model does not produce the very large TLC flows that actually occurred.

Graph 4



20. The final graph is the tailrace flow duration curves and these curves are quite different (correlation 0.787). The tailrace discharges are important in this proposed permit change because increased tailrace discharges will increase the amount of fresh water being discharged into Deep Cove.

Graph 5



21. While the flow level duration curves in Appendix A of the report provides an overall review of the actual operation compared to the SoDaPop version, a ten-year average masks the real variations that occur but which are subdued in any averaging process. What is needed at least for flows is a series of annual hydrographs as shown in the main part of the report which would show the actual and modelled flows on a daily basis to give an idea of the real differences between the two current series. In addition, some tables of flow comparisons, especially floods and low flows, would also be helpful in deciding how good the SoDaPop modelling is in predicting daily flows. Annual plots of lake levels would also assist in defining the differences between the two current series.

22. I believe the extra requirements detailed in the previous paragraph are needed because of the unique nature of the data provided in support of the requested tailrace discharge permit change. It is difficult to learn how good the base data are compared to a modelled future dataset when the base dataset that it is compared to is also a synthetic dataset.

Analysis of Current Regime

23. The data available for the current operation is included in Section 2 of the hydrology report and Section 3 analyses inflows into the Manapouri Power Scheme. This inflow analyses includes a review of rainfall and the calculated inflows (calculated from lake level data using the relationship between lake levels, lake area and lake volume) including their duration at various flows and their seasonal and annual variability. There is also a review of short term and long term climate change theory including the Interdecadal Pacific Oscillation and anthropogenic climate change.

24. There are some questions that relate to Section 3 that do require further explanation. These include:

    i. In Table 3.1, the Te Anau catchment area multiplied by the mean annual rainfall (3082 km^2 x 2900mm) is equivalent to a total annual volume of $8.9378x10^9m^3$ which when divided by seconds in a year, equates to a flow of 283 cumecs. The man inflow is calculated to be 282 cumecs (Table 3) . On this basis, there is no allowance for evaporation or groundwater loss. If it is assumed that evaporation would be at least 600mm/year, this would equate to a flow of about 50 cumecs. Therefore the mean annual rainfall is likely to be underestimated since the calculated annual rainfall volume as a flow is the same as the calculated inflow.

       For Manapouri, the total annual volume from catchment area and average annual rainfall is $4.455x10^9m^3$ which equates to a flow of 141 cumecs. If evaporation is at least 500 mm/year (equates to a flow of about 24 cumecs), then 141-24 = 117 cumecs which is close to the calculated flow. It is possible the mean annual rainfall is also underestimated in this catchment but not to the same extent as that for Te Anau.

       Applying the same calculations to the Mararoa catchment, the rainfall inflow would be 52 cumecs, the evaporation 23 cumecs and the mean annual discharge is 29 cumecs. Again the rainfall is likely to be underestimated.

    ii. What are the "totals" in Table 3.2?

What are some of the examples of the very large inflows to the lakes that are far in excess of the instantaneous maximum tailrace discharge limit of 510 m^3/s?

Is the 1986 calculated inflow of 7202 cumecs the largest on record?

iii. Section 3.3.4 Comparison of wet and dry years over record period "The overall increase in annual mean inflow resulted from the increased frequency of wet years and decreased frequency of dry years, not an overall increase in inflows" In reality, increased wet years and decreased dry years over the record period results in an overall increase in inflows.

Existing Regime as Derived By SoDaPop

25. This section provides that derived current flow and level regime and presents it in a series of graphs and tables which are all generally self explanatory.

26. There is a series of graphs that should be in this section and are not. The graphs are the seasonal variations in flows and levels for the following:

- 4.1.4 Seasonal lake levels Te Anau
- 4.3.4 Seasonal lake levels Manapouri
- 4.4.4 Seasonal Waiau Arm flows
- 4.5.4 Seasonal MLC discharges
- 4.6.3 Seasonal tailrace discharges
- 4.6.4 Seasonal Waiau Arm mean flows

27. These graphs suddenly appear in the next section (MTAD future regime) and show comparisons with the current regime. At present the current regime section (Section 4) has only a table representing the seasonal variation. The current regime graph for each flow or level needs to be introduced in the current regime section so that the new regime can be overplotted. The authors have presented all other graphs in this section that in the next section are overplotted with the future regime and the same should hold for the seasonal graphs.

28. The data are mainly presented as summaries of the 60 year record analysis with no daily or single yearly information provided. The daily and single yearly graphs would be useful to allow the reader to get a more realistic view of what is occurring in the Manapouri Power system. Mean monthly and mean annual data provide a smoothed view of the system and it eliminates the variation. The Manapouri system is all about variation on a daily basis so the smoothed average view does not provide the reviewer for the permit application with a picture of the real situation. The mean data are needed to be able to summarise the regime concisely but it smothers the real situation.

29. The tables in this section could be expanded to show the ranges of the various flows about the means that are provided. This includes:

- In Table 4.1, the ranges of the periods of time in each operating range should be included:

- In Table 4.3, range of the mean events, minimum days duration, minimum days between events

- In Table 4.4, similar comments as for Table 4.3 above

- A graph of seasonal wet, typical and dry years has already been recommended for Section 4.1.4. A further graph showing some of the variations within wet, typical and dry years would be useful. This would entail selecting some wet, typical and dry years which had different seasonal patterns

- In Table 4.14, the range of events about the mean number of events, duration, days per year and flows should be included to give a more complete picture of what happens in the Waiau Arm.

- A graph of seasonal wet, typical and dry years has already been recommended for Section 4.4.4. Another graph showing some of the variations within wet, typical and dry years would be useful. This would entail selecting some wet, typical and dry years which had different seasonal patterns.

- In Table 4.17, the range of frequency and duration of events could be provided

- Given the importance of flows contributions through MLC to the Waiau River since even at the most downstream end of the catchment (at Tuatapere) flows through MLC contribute 48% of the average flow and 50% of flood flows and must contribute a much greater percentage of the Waiau River flow at more upstream sites, a more comprehensive review of flow contributions to the Waiau River is needed. This should include actual hydrographs showing the relative contribution from the Mararoa River and Lake Manapouri and the differences that can occur in this contribution, especially during floods. It should also show the relative flow contributions when the river is not in flood. Sections 4.5 to 4.5.4 do provide some basic average information but it needs to be expanded. A review of flood frequency of the Mararoa River should be included and a review of the total flood frequency immediately downstream of MLC which would be a combined flood frequency of Mararoa River and Lake Manapouri floods.

- Table 4.18 should include the rang of events per year for Lake Manapouri floods and the same should occur for Mararoa River floods.

- A graph of seasonal wet, typical and dry years has already been recommended for Section 4.5.4. A further graph showing some of the variations within wet, typical and dry years would be useful. This would entail

selecting some wet, typical and dry years which had different seasonal patterns.

- Tailrace discharges are important because of the freshwater input to Deep Cove. Table 4.22 lists values for the number of high flow events and their duration. This table also needs to have the range of events per year for each type and the minimum duration for each high flow.

- A graph of seasonal wet, typical and dry years has already been recommended for Section4.6.3. A further graph showing some of the variations within wet, typical and dry years would be useful. This would entail selecting some wet, typical and dry years which have different seasonal patterns MTAD Regime.

MTAD Regime

30. This is the regime post the change to a maximum discharge of 550 cumecs through the tailrace instead of the current maximum of 485 cumecs.

31. A general comment is that while many of the tables show a comparison of the derived current regime and the derived MTAD regime and the differences are commented on, there is little explanation as to why they are different and the reader is left to draw their own conclusions. Again the tables need to be expanded to include more than just the means over the 60 year period. Similar comments apply as those for the corresponding tables in the previous section discussing the current regime. This would require expansion of tables 5.1, 5.3, 5.4, 5.6, 5.7, 5.9, 5.10, 5.12, 5.13, 5.14, 5.17, 5.18.

32. In addition, while the long term seasonal graphs are included in this section, for each of these the extra graphs required for the previous section should have the same yeas over-plotted with them being under the MTAD regime. It should be noted that some hydrographs for individual years are provided. More of these for each perhaps included in an appendix would also be useful.

33. The changes to MLC outflows are especially important in terms of Waiau River flows and a more in-depth review of the consequences in the Waiau River if the MTAD regime is permitted is needed. The MTAD regime suggests that there will be a measurable decrease in flows entering the Waiau River from Lake Manapouri and these need to be quantified clearly, and an explanation as to the overall impacts in the Waiau River as a result of the decreased flows.

34. The changes to the tailrace discharge also need to be more detailed. The extra water to be discharged into Deep Cove has implications for the low salinity layer in Deep Cove and the extra volumes of water being discharged need to be identified in more detail.