PLOVER 2*k*: Planning Openings and Values for Ellesmere's Resilience

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1 Overview of PLOVER

The PLOVER model is a deterministic Excel-based simulation which attempts to measure some changes in ecological and economic values as a function of the lake opening schedule. The purpose of PLOVER is to help choose lake opening regimes, to find a balance between farming, fishing, recreation, flora, and fauna. This report describes generally how PLOVER works, and partially documents the spreadsheet. The spreadsheet itself is heavily documented with comments.

Wherever possible, I have attempted to use other people's information, and I have tried to rely on quantitative effects rather than qualitative judgement. Further, I have generally included the source data within the spreadsheet. Most importantly, PLOVER is based heavily on a water balance model developed by Graham Horrell at NIWA. This version of PLOVER is most valid for water levels that are in the historical range, roughly 0.3 to 1.5 meters, and would be less and less valid further away from that range. Quality of data is designated at three levels:

Model is strong, based on a causal relationships and considerable data. This should provide reliable results. Example: water flows are based on the NIWA water balance model.

Model is okay, based on a correlative relationships and a reasonable quantity of data. This should provide reasonable results. Example: salinity was calculated as a function of water depth, using Environment Canterbury temperature information.

Model is hazy, based on anecdotal data or speculative relationships. This will provide only indicative results at best. Example: blue-green Nodularia algae are a "threat" formula based on a few reported events and general scientific data on likelihood of algae.

2 Model components

Components have been selected in lengthy consultation. Ideally, PLOVER would contain more components, such as more types of birds and fish, and in greater detail. However, the components and their detail are limited by data availability. Further, some components may actually be misleading, due to shortcomings in PLOVER. For example, I have modelled ruppia only in sprouting, not in growth, because I have a plausible model of sprouting, but none for growth. Thus, maximising sprouting results in September and October openings, which may hinder ruppia growth.

The model is organized generally in left-to-right and top-to-bottom order, except that summary totals appear at top. The objects below are given in order that they appear in the PLOVER spreadsheet. In the spreadsheet formulas have grey backgrounds, while constants and inputs have no shading.

Date follows the NIWA water model, which starts 5 Jan 1970 and ends with 31 Dec 2007. PLOVER uses date arithmetic heavily.

Hours of sunlight drives seasonality. I obtained hours of sunlight from sunrise and sunset times, from http://aa.usno.navy.mil/data/docs/RS_OneYear.php, 172:45 east, 43:30 S, 12 hrs E of Greenwich.

Temperature data came from ECan 2009. I ran a linear regression of temperature to day of year.

Lake depth is calculated directly by the NIWA water model.

Opening. This is the "decision variable," the part of the model that the user decides. An opening regime is defined with date and depth pairs at which to start an opening attempt. PLOVER uses three dates and three associated water levels. PLOVER treats each water level as the depth trigger at which an opening should be attempted, for the period between the dates. The lake is inherently a chaotic system – a small change early in the planning horizon can result in large changes later in the planning horizon, and the NIWA water model reflects that chaotic behaviour.

Because an opening attempt does not always succeed, we must define what we mean by "opening". The definition which best matches the associated costs of opening is the number of first-day openings at least 30-days apart, i.e., a 30-day continuous attempt to open the lake. For example, if we select 1 May as an opening date, with a threshold of 1,000 mm, then PLOVER will not open the lake in May if depth is below 1,000 mm. PLOVER will try to open the lake if depth is above 1,000 mm. If the lake does come below 1,000 mm, PLOVER relies on the NIWA water model to decide when the opening stops. If during May the lake comes below 1,000, and the NIWA water model closes the lake, but the depth again exceeds 1,000 mm, PLOVER will try to open the lake again, for 30 days. PLOVER may try to open the lake on the last of these days, and the NIWA water model may allow the lake to stay open until after that. An opening may take several days to initiate due to rough weather, so opening dates may need to be set somewhat earlier, and the decision depths may need to be set somewhat lower, to achieve the desired policy.

The baseline values in the model correspond to the opening regime as modelled by the NIWA water balance model. The following shows the baseline status quo values:

Lake depth, mm
1-Apr
1,130
1-Aug
1,050
1-Sep
1,050
FALSE

The first input indicates that from 31 Mar until 1 Aug, the lake is to be opened if depth >= 1,130.

From 1 Aug until 1 Sep, the lake is to be opened if depth >= 1,050.

Finally, from 1 Sep until 31 Mar, the lake is to be opened if depth >= 1,050.

The "TRUE" value indicates that the opening regime lasts only for 30 days, starting from the input date; an additional 1,200mm "circuit breaker" trigger is maintained year round. The "FALSE" value indicates that the opening regimes last beyond 30 days, continuing to the next date. This means that the status quo is really a depth-based regime, not a date based regime.

Area of the lake is calculated from detailed GIS data supplied by ECan (Hill, 2009). This GIS data is a combination of AgriBase and NIWA LIDAR data. The model is uncertain only due to wind lash, which has not been included. That is, the inundated area assumes calm weather. Except for wind lash, this is excellent data.

Volume of the lake is calculated from the ECan GIS data.

Dissolved oxygen also came from ECan 2009. I ran a multiple linear regression of hours sunlight, ocean swell height offshore from Lake Ellesmere (Horrell 2009), lake level, and temperature. This is probably overkill, as sunlight and temperature are correlated, so one of those could be dropped to have a more concise model, but no more predictive.

Salinity depends on openings. I approximated salinity as a function of volume, based on data from ECan 2009. If we suppose the lake has a constant amount of salt S as a result only of mixing during opening, salinity may be approximated as S/volume. I examined other models of salinity, including salinity as a linear function of depth, and salinity as a power function of depth. The power function has a slightly better fit, but doesn't make as much sense physically. The function is given as salinity = $2,407/\text{volume} - 1.2$, where volume was calculated as above, in millions of cubic meters. Taylor (1996, p. 18) says "mean salinity of 8.5 ppt," and ECan 2009 indicates a mean of 6.9; PLOVER is showing about 7.0.

Nodularia algae risk is based on Taylor 1996 and Taylor & Hughey 2009, indicating that this microbe, Nodularia Spumigena, blooms under high heat and high salinity. Taylor 1996, mentions three specific blooms, in autumn 1971 (p180), March 1981 (p180), and autumn 1990 (p180). From that, I created a pseudo-time series, and observed that ocean swell height (Horrell 2009) was never over 5,000 mm when there were algae. Taylor 1996, p180, also states that the optimum growth occurs "in the range of 5-20 ppt". I therefore created a multiplicative function of these two, = (if (wave height >=5,000, 0, MAX(0,(hours sunlight – 8:55)*(salinity –

5))*10), multiplying by 10 simply to have a nice scale. Hence, blue-green algae are likely to grown under conditions of light wind, long daylight and high salinity. This produces values between 0 and about 1.2.

Turbidity was calculated as a multiple regression, based on depth, temperature, and ocean-wave height, using data from ECan 2009 and Horrell 2009. Turbidity is not used elsewhere in the model. The macrophyte calculations, in particular, could be improved by taking turbidity into account, but sufficient data is not immediately available.

Submerged macrophytes, sprouting should be interpreted as the expected hectares with sprouting macrophytes. It is a qualitative measure of the opportunity of macrophytes to sprout.

Sprouting time. Taylor 1996, Taylor & Hughey 2009, and Jellyman et al 2009 indicate that macrophytes sprout in "the spring," but do not specify what that means. Hammer (1986, p. 347) writes of Wakaw Lake in Saskatchewan, "Growth of *Ruppia* and *P. pectinatus* began in the middle of May at temperatures of 10°C. Seeds sprouted at 8°C. Flowering began by the middle of June and produced fruit by the middle of July…By October visible plants were senescent…" He refers to Ruppia Maritima, while Lake Ellesmere has Ruppia megacarpa and Ruppia polycarpa. I decided to use the values 8°C and 10°C. The Lake Ellesmere temperature data indicates that the lake reaches 8°C about 17 August, and it reaches 10°C around 11 September.

Sprouting conditions. Taylor 1996, p. 182, indicates that growing is best when salinity is between 0 and 8. If Ruppia sprouts in late August and requires low salinity, then Ruppia prefers **no openings** between 15 June and 15 September, because the increased salinity will slow sprouting. A paper by da Silva & Asmus (2001) develops a detailed simulation model of Ruppia Maritima in Brazil, which uses an exponential function of control by salinity on germination velocity. I have used it here: the probability that sprouting occurs depends on $e^{-0.048*salinity}$.

I therefore created a distribution function that returns a normal density value, implying a *centre* of sprouting on 29 Aug, with a distribution of 4 days around that, so that sprouting began just when average temperature became 8°C. I then multiply this value by $e^{-0.048*salinity}$; the function returns 1 if salinity is 0, 0.68 if salinity is 8. Next, I assumed a given fraction, e.g., 10%, of the area is of correct depth for sprouting. Finally, I multiply by the lake area. This value may be interpreted as the expected hectares with sprouting macrophytes. Available light is known to strongly affect growth, but I did not attempt to take account depth or turbidity in sprouting.

Shortfin eel is the fraction of ideal migration. It was computed with a distribution function that returns a normal density value centred at the maximum days of ingress and egress. Since both dates are considered to help the eel population, the two values are summed and divided by 2. Thus, the function conveys the fraction of ideal migration for eel.

From Chisholm (2009), pp. 36-37:

> …the SIEIA's preferred times for the lake to be open and for it not to be open are as follows:
>
> • One or two openings during spring/summer (October – mid December)
>
> • No further openings during the summer months (mid December – mid April), with lake levels preferably kept high
>
> • One or more openings during late April/May

As the Chisholm report was developed by the eel fishing industry, I assume that this is what they want. Centre-of-ideal dates were therefore taken as 1 Nov, with a standard deviation of 12 days, and 1 May with a standard deviation of 7 days. I then multiplied this distribution function by 1 if the lake were actually open, else 0.

Butcher (2009) suggested that the baseline value of the eel fishery is $430,000. However, a recent news article (Dominion 2009), which indicates the earnings (not profit) of the eel fishery at $360,000/year. Chisholm (2009) does not give a value, and the Ministry of Fisheries website shows blanks for data. I have used the lower value. I multiplied the total $ by the change in average area from mid-December to mid-April.

Chisholm also states, "A high lake during the mid-summer months (mid-December – mid April) is desirable, as it allows eel access to the (more desirable) riparian feeding grounds. A low lake during the mid-summer is detrimental to the fisheries, as it can lead to algal blooms and high water temperatures. Both these events can lead to fish dying." None of these components were included, thus the measure given for eel may actually be detrimental to them.

3

Flounder is the fraction of ideal migration. It was computed with a distribution function that returns a normal density value centred at the maximum days of ingress and egress. Taylor (1996, p. 211) indicates migration is "August to November," so I have used a mean centre-of-ideal day of 1 October, with a large standard deviation of 20 days. I then multiplied this by 1 if the lake were actually open, else 0. The dollar value from Butcher (2009) is scaled to the baseline percentage. This value will go up with more openings, because flounder have a greater chance to migrate. The large standard deviation implies that 30 continuous days of opening, even at the peak migration season, would get only a fraction of the flounder. Flounder could appear to have a greater gain if this standard deviation were smaller, because a larger fraction would be modelled as entering over a shorter period. Note that this measure ignores the size and quality of the habitat.

Duck hunting is the (daily bag limit)*depth. Thus, hunters are assumed to prefer a deeper lake during hunting season. The measure will be higher to the extent that the lake is high during hunting season. This measure does not put any special weight on the May opening day.

Duck hunting, opening day avg depth is the depth on the first Saturday of each May. This puts all the weight on opening day. The Lake Ellesmere workshop participants indicated that duck shooters liked to have the lake at a depth between 800mm and 1300mm on opening day. I have assumed that higher is better.

Hectares of quality-adjusted wader habitat indicates total wader habitat over the growing season. The "raw" area was calculated as the lake area for the current depth, minus the lake area for the current depth minus 100mm. Hence, this provided the area at the margin of the lake. For each GIS land type, Ken Hughey provided a % quality of habitat. This quality was multiplied by the "raw" area of each land type at the margin of the lake, to provide the hectares of quality-adjusted habitat.

Indigenous waders is population, scaled by habitat area: (wader population on day t) = (observed population on day t)*(wader habitat area on day t)/(baseline habitat area on day t). Thus, this indicator is highest when both habitat and birds are at high levels together. Taylor & Hughey (2009) contains 1986-7 population by month. I interpolated those values by day.

Hectares submerged by land type are look-up values based on the ECan GIS data. The most important of these is "SNB Mixed Sheep and Beef farming," because this is the largest area. The areas were scaled by a cost per hectare per day of inundation, and also adjusted by "tolerance depths" from Hearnshaw (2009). I estimated the cost of inundation in several ways. If the opening regime were considerably higher on average, so high that farm land became inundated most of the year, the land would be devalued somewhat. It would retain some capital value, but the portion of capital value from production would be lost. Thus, we need to examine the productive value of the land. Anecdotal information from a workshop participant: "…[A]round 2 years ago a block of 200ha on the true right of the Selwyn mouth was up for sale with an asking price of $1.2m…" This puts the price of land at about $6,000/hectare during a very high value period for commodities. Assuming a 6% return on investment, this works out to $6,000*0.06/365 = $0.99/hectare/day. This is clearly an upper bound. In a discussion with Lake Ellesmere participants, it was reported that DOC leased 100 hectares of land for $5,300, implying $5,300/100/365 = $0.15/hectare/day. This value was used in the model.

3 Measures of overall effectiveness

Dollar improvement: only commercial components. This measure sums the opening costs, costs to farmers of inundation, and increased profits to flounder and eel fisheries. It does not attempt to add dollar values to any other component.

Percentage improvement: commercial and environmental components. For each component, this measure calculates the % improvement from the base case. The overall measure is simply the sum of the % improvement. Note, however, that farming and opening are costs, and appear as negatives.

4 Comments

Changing an opening level or date can often produce surprising and counter-intuitive results. For example, making an intentional opening earlier can lower water levels in later months, because the 1,200mm "circuit breaker" limit could be reached in between, resulting in another opening. However, generally, delaying an opening date tends to delay the next opening.

"Lake Ellesmere/Te Waihora is one of the most important eel fisheries in New Zealand." – Chisholm 2009. Of all components in PLOVER, it appears that eel fishing could have the greatest increase in benefit, as measured by migrations in PLOVER. The current opening regime does not seem to favour eel, and an opening regime that does favour eel would appear to improve migrations by a large amount. By either % or $ measure of effectiveness, a regime which improves eel – *based on PLOVER in its current state* – significantly improves both measures of effectiveness for the lake overall. The reason is because eel fishing is larger financially than any other component, and appears also to have the largest % improvement. Lowering the opening trigger depth appears to help eel and flounder due to greater chance of migration, as the lake is open more often. Both of these measures ignore habitat, and may even be counter-productive. Chisholm (2009), for example, reports that eel fishing is easier in flood. Measuring the eel fishery only on migration ignores the habitat; switching to a "maximise eel migration" scenario, as given by PLOVER, could actually harm the eel fishery.

A separate issue is whether PLOVER is to be used for short term decisions or long term decisions. According to Chisholm (2009), "Commercial eel quota have been largely under-caught in all South Island Quota Management Areas, with the exception of ANG 13 (Lake Ellesmere/Te Waihora), which was 100% caught in 2003–04, 2004–05, and 2005–06." In the short run, the current quota limits any gain to eel fishing. However, if the modelled gains were valid, the eel quota for Lake Ellesmere could possibly be raised.
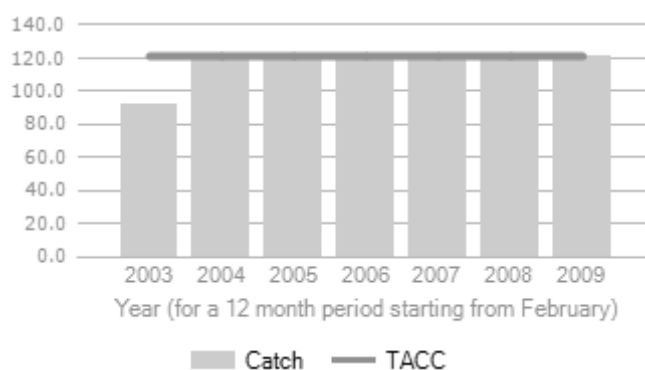
Freshwater Eels Lake Ellesmere (ANG13), commercial catch vs. allowance. Source: http://fs.fish.govt.nz/Page.aspx?pk=8&tk=41&ey=2009, 24 Oct 2009.

Openings are not the only option for the eel fishery. According to Chisholm (2009), "If a spring-summer opening is not possible, it is preferred that the bulldozers (used for lake openings) scrape back the shingle on the lake side to reduce the amount of beach between the lake and the sea. This will allow glass eels to crawl through the shingle from the sea to the lake." Scraping the beach is not modelled in PLOVER, and I found no data on its effectiveness.

5 Suggested future work.

PLOVER, and the understanding of Lake Ellesmere, could be improved by more focused science.

Eel. Because eel appears to be the largest dollar value associated with the lake, a simulation of eel growth, taking into account both openings and habitat, would be the largest-value research.

Ruppia. A paper by da Silva & Asmus (2001) develops a detailed simulation model of Ruppia Maritima in Brazil. Their model could be calibrated to the ruppia in Lake Ellesmere, and should be helpful in guiding macrophyte reestablishment.

Modelling. The PLOVER model could be improved in at least three ways.

First, Lake Ellesmere could be modelled with existing stochastic reservoir optimisation techniques. This should provide improved policies, such as conditional regimes, e.g., "if the lake depth is below D in week W then don't open". In another interesting paper, Estrada, Parodi, and Soledad (2009) developed a reservoir model specifically to manage algae growth and eutrophication.

Second, additional time series data, such as for water quality, would improve the strength of the regression relationships.

Third, PLOVER was improved every time another scientist reviewed it. PLOVER would benefit from additional peer review, especially for suggestions in better structures for the various components.

Fourth, Lake Ellesmere should be modelled as part of a larger area, taking in a significant portion of the catchment. This modelling should include water flows, nutrient run-off, and impervious cover, and include both economic and ecological components. This technology is available now, and probably could be done at reasonable cost.

Database. Information about Lake Ellesmere appears in many places. Future research would be considerably easier with a consolidated database, or even a web site, containing GIS data, regularly measurements, a bibliography, and models.

6 Acknowledgements

7 References

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