Salt Lake Hydrology: Potential Impact of Drainage Schemes

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INTRODUCTION

"Salinisation of land and water is one of the most critical environmental problems facing Western Australia" (CEOs, 1996). In WA, salinisation is primarily a result of evaporation of brackish or saline groundwater in areas where the water table is close to or at the ground surface. High water tables have developed as a result of increased recharge to groundwater following clearing of native vegetation and other forms of land development that have altered natural hydrological systems. Salinisation is a global problem that is most frequently managed by installation of a drainage system designed to lower the water table. Drainage of agricultural land has been practiced for more than 2000years (van Schilfgaarde, 1974) and the technology of drainage is well established. Common constraints to installation of drainage schemes are costs and the disposal of drainage water. Discharge from a drainage scheme may be saline or contaminated with excessive concentrations of nutrients, agrochemicals or other chemicals.

Salt lakes (salinas) are a natural feature of the landscape in areas of southern Australia where salinisation is a problem. Other salt lakes have formed following European settlement and land development. One strategy for management of soil salinity is to improve drainage and to dispose of drainage water in a nearby salt-affected streamline or salt lake. Yet the salt lakes support fringing vegetation, and some of the lakes provide important habitats for birds and other fauna. Disposal of drainage water into such a lake may be detrimental to the existing environment.

This paper reports the development and application of a lake water and salt balance model designed to aid the hydrological evaluation of proposed drainage schemes. Impacts of the modified hydrology of a salt lake on fringing vegetation and dependent fauna are beyond the scope of the work reported here.

MODEL STRUCTURE

Any excess of inputs of water to a lake over outputs results in an increase of storage of water in the lake. This is represented by a mass-balance equation for a chosen interval of time. In practice, the density of liquid water is assumed constant and the following volume-balance equation is used:

$$F_{si} + F_{di} + P*A - E*A - G*A - F_o = DS. \qquad (1)$$

In this equation, F_{si} and F_{di} are volumes of streamflow and drainflow into the lake, P is rainfall on the surface of the lake of area A, E is evaporation from the lake surface, G is seepage to an aquifer beneath the lake bed, F_o is streamflow out of the lake, and DS is the change of water storage in the lake.

Salinity (total dissolve solids concentration; dimensions [M/L^3]) is linked to each of the volumetric flows, and to the volume of water stored in a lake for the salt balance model. Any gradients of salinity within the lake are neglected (i.e. the lake is assumed to be well-mixed).

If the lake should dry out, a mass of salt is assumed to remain on the bed of the lake. This overcomes anomalous salinity levels that have been indicated in some simulations. No allowance is made for salt accumulation on the bed of a lake by capillarity that may take place when there is no water in the lake, but the water level in an underlying aquifer is within about 2m of the soil surface.

In its present form, the lake salt balance model makes no provision for precipitation of salt from solution, which is known to occur in some lakes during periods of very high salinity.

The model is developed as an Excel workbook with separate but linked sheets for the water and salt balances. One row in a sheet represents the water or salt balance in each unit of time. In its current form, each row represents one month, but it could represent a day or a year. Two models of the salt and water balance are run in parallel, with one of each including a non-zero drainage input to allow comparison of lake hydrology with and without drainage.

A lookup table is used to determine lake water level and surface area from the volume of water in the lake at the end of the preceding time-step. The initial volume of water and mass of solute in the lake are guessed if not known, introducing possible error, particularly during the early stages of a period of simulation. For each time-step the water and salt balance equations are used to calculate increments of water and salt storage, and total water storage volume and solute storage mass in the lake are updated.

The lookup table defines relationships between lake depth, volume and surface area that depend on the shape of the bed of the lake. Ideally this is specified by survey data, but alternatives that form part of the model are to represent the bed of the lake as part of a cone, sphere or ellipsoid. Other geometric models are possible, but increasing complexity requires specification of an increasing number of parameters.

The parameters of a geometric lakebed model can be determined by matching the predicted surface area of a lake to observations at a number of depths of water in the lake. If available as additional information, the volume of water stored in a lake at a number of water depths enables better representation of the lakebed geometry.

MODEL INPUTS

Rainfall and Evaporation

Monthly rainfall records are available from many official stations and farm records. In the example of application to Lake Coyrecup (between Katanning and Nyabing, WA), rainfall data from the Badgebup station (No. 010508) was taken as representative of the lake and its catchment. The salinity of rainfall on this catchment was estimated from geographic information reported by Hingston and Gailitis (1976).

Pan evaporation is measured at few stations. In the example, maps prepared by the Bureau of Meteorology were used to estimate monthly pan evaporation from Lake Coyrecup. A pan coefficient of 0.65 was assumed, slightly less than usual as the pan factor is reported to decrease inland (Hoy and Stephens, 1979). The rate of evaporation was further modified by lake salinity using a relationship suggested by Coleman (personal communication, 2000).

Rainfall input and evaporation loss are dependent on lake surface area, which is computed from the volume of water in the lake and lakebed geometry. There is provision in the model for additional rainfall input to a lake as runoff from those parts of the bed of a lake that are exposed when the water level is low.

Streamflow and Saltflow to the Lake

Ideally, streamflow information would be available for a point close to the lake, but this is rarely the case. In the example, monthly streamflow is estimated from Badgebup rainfall and the parameters of a simple rainfall-runoff model for the nearest similar catchment where flow data are available. The streamflow model used is of the form:

$$F_{si} = R*A_c \qquad (2)$$

where R is monthly runoff per unit area and A_c is catchment area. In any month, runoff per unit area is assumed to be related to rainfall in that month (P_o) and the preceding month (P_{-1}), and pan evaporation (E) by:

$$R = a_1 + a_2*(P_o - a_3) + a_4*(P_{-1} - a_3) + a_5*E \qquad (3)$$

In the Lake Coyrecup example, runoff model coefficients a_1, a_2, a_3, a_4 and a_5 were determined by matching this flow model to data for the Bibkin stream gauging station (No. 6009021).

Where there are no streamflow data, it is unlikely that stream salinity will have been recorded. Stream salinity in any month can be estimated by:

- Assuming a catchment salt balance to calculate an annual salt load in streamflow. For the Lake Coyrecup catchment, the ratio of salt outflow in the stream to inflow in rainfall was assumed to be 4, based on data from the Bibkin stream gauging station.
- Assuming that the salt load is dominated by salt seepage from the ground, which is at a constant rate.
- Assuming that in months of no streamflow, salts accumulate on the ground surface.
- Assuming that all salts accumulated on the ground surface are washed off to contribute to saltflow in the next month when there is flow in the stream.

These rules provide an approximation to observations of the variation of stream salinity through the year with maximum load in flows at the beginning of winter, low salinity in high flows during the winter, and increasing salinity in lower flows at the end of winter.

Drainflow to a Lake, and the Associated Salt Load

The amount of discharge from a drainage system will depend on drain dimensions and soil type. Moreover, water will be lost from the drainage system by evaporation, and possibly by seepage into the beds of drains in areas where the water table is below the drain invert.

No reliable data on drain flows in southwestern Australia are known. In the Lake Coyrecup example, drain discharge was assumed to be at a constant rate of 40000m³ per month on the basis of reported estimates by a drainage contractor.

The salinity of drainage water is expected to vary through the year in response to rainfall and evaporation, and there may be a long-term decreasing trend as the drains leach soluble salts from part of the catchment. In the Lake Coyrecup example, the salinity of drain discharge was assumed to be a constant 20000mg/L. This is likely to be conservatively high.

Seepage from or to the Lake

Some natural lakes in southwestern Australia are fresh indicating outflow of liquid phase water by seepage losses through the bed of the lake, or surface flow from the lake.

The lake model represents seepage flow per unit area (G) from or to the lake at a rate dependent on a lakebed conductance (C) and the difference of water levels in the lake (h) and an aquifer beneath the lake (h_a):

$$G = C*(h - h_a). \qquad (4)$$

The water level in the lake is computed from the volume of water in the lake at the end of the preceding time-step. Provision is made in the model for h_a to vary both seasonally and over the long-term.

When water seeps from the lake, the salinity of the water is that of the lake, but when the direction of seepage reverses, the salinity of seepage is the groundwater salinity, which is assumed to be constant.

Streamflow from Lake

The model provides for streamflow from the lake through a stage – discharge relationship entered as a lookup table. This relationship could be estimated using channel survey data and the Manning equation. In the Lake Coyrecup example, anecdotal evidence is that there was no outflow during the period of simulation.

As the lake is assumed to be well mixed, the salinity of stream outflow from the lake is the same as lake salinity.

MODEL OUTPUTS

Water Levels and Salinities

Primary output from the model is predicted variations of lake water level and salinity through time. The sensitivity of these outputs to lakebed geometry and other parameters can be examined. Where observations of water level and salinity are available, they can be used to calibrate the model by variation of parameters that have not been measured.

Figures1 and 2 show predicted and measured water level and salinity in Lake Coyrecup over the period 1980 to 2000. A log scale is used for salinity, because of the wide range of values. Over this calibration period, there was no artificial drainage into the lake.

In this example, the lakebed geometry was assumed to be conic with a base angle of 179.81°. This result was obtained by matching lake surface area at only two water levels (0 and 2m). Output is sensitive to the assumed geometry. Clearly it would be preferable to characterize lakebed geometry by survey.

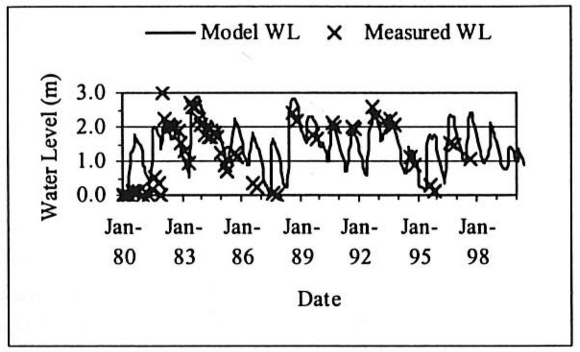

Figure1: Water Level in Lake Coyrecup

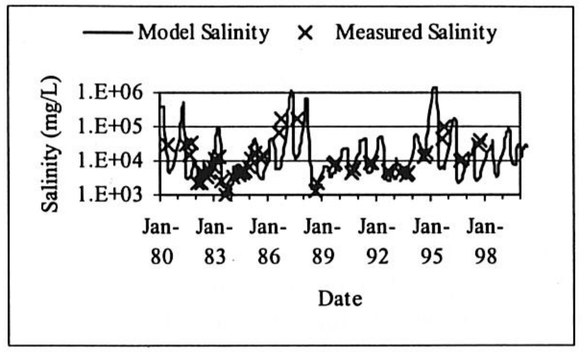

Figure2: Salinity in Lake Coyrecup

The level of water in the aquifer beneath Lake Coyrecup is not known, and neither is the conductance of the bed of the lake. These parameters were varied to improve the fit of predicted to observed water levels. Some improvement to fit was obtained by assuming that the water level in the underlying aquifer varied seasonally with amplitude 2.5m and no long-term trend.

The salinity of water in the aquifer beneath Lake Coyrecup was assumed to be 18000mg/L. This parameter is irrelevant in the example, because during the period simulated, water did not flow from the aquifer to the lake.

In view of the simple models of lake-bed geometry and streamflow into the lake, the water and salt balance model is considered to provide a reasonable fit to observed water level and salinity for Lake Coyrecup with minimal adjustment of parameters.

Probability of Exceedence

To facilitate comparison of effects of drainage on lake hydrology, model output is also expressed as the probability that the water level, lake surface area or lake salinity will exceed a given value in any month with and without operation of a drainage scheme. Figures3, 4 and 5 (next page) present output in this form for the Lake Coyrecup example.

In-so-far-as the salt and water balance model presented here accurately simulates the hydrology of Lake Coyrecup, these figures show that inflow to Lake Coyrecup from a drainage scheme at the rate considered would have the following effects:

- Increase the probability of water levels in the 0 to 0.5m range.
- Slightly increase the probability of lake area exceeding a given value, throughout the range of lake areas.
- Significantly reduce the probability of lake salinity exceeding a given value throughout the range.

An assessment of the impacts of these hydrological changes on flora and fauna associated with the lake is beyond the scope of this work.

It is emphasised that drainage to Lake Coyrecup at a different rate would have different hydrological impacts. Moreover, drainage at the rate considered for the Lake Coyrecup example may have very different hydrological impacts if directed to another lake.

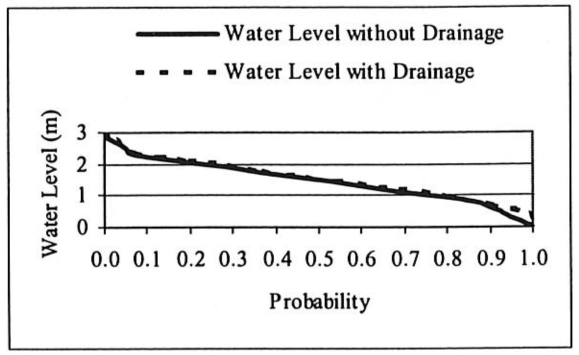

Figure3: Lake Coyrecup Water Level Probability

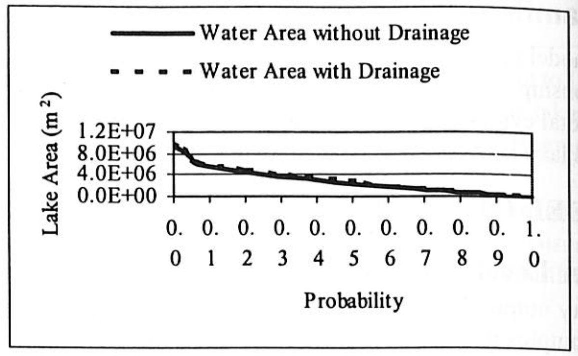

Figure4: Lake Coyrecup Surface Area Probability

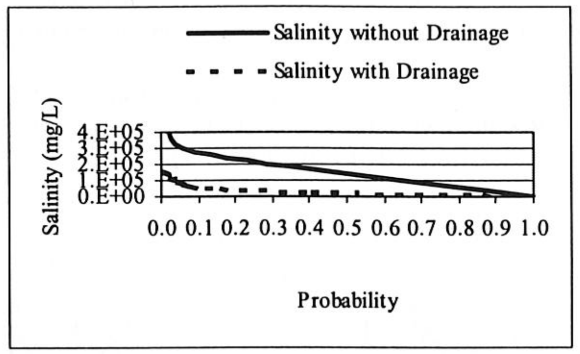

Figure5: Lake Coyrecup Salinity Probability

CONCLUSIONS

In many countries, land salinisation is managed by construction of drainage schemes, and such schemes may make an important contribution to salinity management in southwestern Australia. Commonly the installation of a drainage scheme is limited by economics and/or the disposal of saline drainage water.

In WA salt lakes are common and they are potential areas for disposal of drainage water. A modelling approach has been developed to aid the assessment of impacts of a proposed land drainage scheme on the water level, surface area and salinity of a salt lake. The model provides a reasonable match of predicted to measured water level and salinity for a lake in WA. An important input to the model is the shape of the bed of the lake, since this defines relationships between water level, lake surface area, and lake volume. In the application, the bed of the lake is modeled as part of a cone. Survey data would be expected to improve the match of predicted to observed lake water level and salinity.

The model is applied to predict that construction of a drainage scheme discharging saline water to Lake Coyrecup near Katanning WA would increase the probability of water levels in the 0 to 0.5m range and significantly reduce the probability of high salinity in the lake. There would be only a very slight increase of lake surface area at any time.

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An assessment of likely origins of the non-homogeneous shallow groundwater in a region of calcareous sedimentation

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ABSTRACT

Characterization of groundwater is an important element in the investigation of sedimentary systems and groundwater flow. Problems associated with the interpretation of groundwater sources in a contemporary study in the evaporative lake systems in the Coorong region of South Australia emphasize that the breadth and depth of sampling are significant factors in arriving at an appropriate assessment of the groundwater environment. Variation in measured salt concentrations raised questions about the homogeneity of groundwater in the Coorong region. Since 1985 piezometer water levels, isotope data and salt concentrations have been determined for surface and ground waters of one lake, Bird Lake. Four categories of groundwater have been distinguished across the 1600 metre transect of Bird Lake and its environs. These data, combined with the piezometer data, have been examined in the light of a geographical and geological assessment of the locality to substantiate arguments that there is more than one source of the groundwater. Our conclusion is that in areas of extensive calcareous sedimentation, where the migration of groundwater is inevitably slow, a simplistic notion that the groundwater is homogeneous is not necessarily correct. Waters from distinct ages, origins and sources can coexist as virtually discrete systems.

INTRODUCTION

The work discussed here was initiated in the context of an ongoing study of contemporary dolomite sedimentation in the Coorong region of South Australia (Ahmad 1991, Ahmad & Hostetler 1994). Ahmad (1991) reports that, since the 1950s, studies of carbonate mineralization in the Coorong, based on little or no detailed hydrological and hydrogeochemical data, have been undertaken at mainly localized sites. Ahmad (1991) concluded that a clear understanding of the processes involved could be had only through an extensive study of the region, but that such a study must include a thorough investigation of the isotope geochemistry of the sediments as well as the coexisting water bodies. Subsequently, the ion chemistry and isotope geochemistry of the surface and groundwaters implicated in the genesis of the dolomites and other carbonate sedimentary components at one lake in the evaporative lake system of the Coorong were documented over ten years from 1985. The hydrogeochemistry data set for Bird Lake and environs, together with the 1985-1995 isotope data and pre-existing geological and hydrological data, from regions to the southeast of Bird Lake, have informed our assessment of the likely origins of the groundwaters discussed in this paper.

Simple assumptions about the homogeniety of the shallow ground waters and the direction of flow based on the geology of the Coorong region were contradicted when concentrations of dissolved salts were first measured. Ahmad (1991) collected aerosol and sea spray fallout and analyzed their ion concentrations. Subsequent isotope work confirmed the marine origin of these salts (Batts *et al.*, 1997a) but pointed up variations in the isotope composition of the waters from different sites and depths (Batts *et al.*, 1997b). Consideration of precipitation and evaporative effects did not reconcile these isotope data with the notion of an homogeneous source. Over the longer term of this ten-year study, observed variations in isotope and piezometer data introduced further complexities that were contrary to the effects expected in a simple homogeneous system (Batts *et al.*, 1999).

THE STUDY SITE

The shallow groundwater of this study underlies Bird Lake, one of some 120 evaporative lakes in the Coorong region. Throughout the region, contemporary calcareous sedimentation leading to the formation of dolomite is under investigation. The Coorong is a long narrow lagoon which runs southeast for some 80 km from the mouth of the Murray River, separated from the sea by the Younghusband Peninsula. This peninsula is an