# Non-effluent water storage modelling using MEDLI

## Agri-Science Queensland Innovation Opportunity

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# Summary

MEDLI (Model for Effluent Disposal using Land Irrigation) is a Queensland Government-owned model (now managed by DES) that is the benchmark water balance model for wastewater reuse applications in Australia. MEDLI lends itself to further investment as a vehicle for delivering other research outcomes and new modelling capabilities. There is a need for MEDLI to be supported and maintained, and there are opportunities to expand its capabilities with reasonable additional investment.

MEDLI is designed for agricultural wastewater reuse applications but can, and has been, ‘tweaked’ to perform other tasks that have demonstrated MEDLI’s versatility and potential. Modelling of freshwater storages is an application well-suited to MEDLI. The most cost-effective and intuitive way to accommodate non-effluent water (freshwater) storage modelling is to program the feature into MEDLI.

Freshwater storage modelling requires additional inputs, algorithms and outputs, depending on the objective. Nutrient loading rates from different catchments and faecal deposition from livestock and wildlife (especially waterbirds) may be required for irrigation and water quality scenarios. Catchment modelling can be adapted from the MEDLI feedlot model. Nutrient loadings can be predicted from published values.

For biosecurity and pathogen risk assessment applications for the poultry industries, habitat attraction for waterfowl and prediction of waterfowl abundance will be required i.e. modelling when waterbodies will dry up during drought and waterfowl will flock to permanent water supplies on or near poultry farms, increasing the risk of disease transmission, including Avian Influenza.

DAF needs MEDLI as a research and regulatory tool and a vehicle for delivering outcomes, and DES needs DAF’s commitment and support to ensure MEDLI remains operational long-term. External funding for MEDLI is more justifiable once the freshwater storage framework is in place.

# Table of contents



# Table of figures



# Table of tables

## Background

MEDLI (Model for Effluent Disposal using Land Irrigation) was a QDPI initiative in the mid-‘90s that was developed collaboratively under the umbrella of the CRC for Wastewater and Pollution Control and released in 1997. MEDLI brought about consensus and transparency in designing sustainable effluent reuse areas for intensive livestock operations, abattoirs, sewage treatment plants, and other agricultural wastewater producers. This solved the problem of consultants and regulators using different models and having decisions being challenged in court.

Collectively, MEDLI has been used by consultants, regulators and researchers on thousands of jobs. As MEDLI is essentially a daily time-step water balance model (with nutrient balance modelling added), it could be potentially used to model ’non-effluent’ water usage scenarios too.

Presently, MEDLI assumes an unlimited freshwater supply (and solely for the purposes of ‘shandying’ effluent when required), and has no ‘multiple paddock’ capability to irrigate different crops/pastures with different levels of shandying. Some MEDLI users need more options and flexibility. In some instances, MEDLI users ‘tweak’ the model to perform an atypical task, but that was never the intent of MEDLI; transparency is lost when users have to resort to workarounds that may be unsound within the current limitations of the model.

Reliability of freshwater water supply is crucial in all livestock production systems, both extensive and intensive. Decision support modelling can be misleading if it assumes that a production system can be maintained at 100% carrying capacity (unlimited freshwater supply). For example, the increasing frequency and severity of droughts could render some production systems economically unviable.

Modelling freshwater dynamics is therefore important, particularly, for scenarios involving water restrictions and use of permanent, semi-permanent or temporary water storages for irrigation and drinking water. Freshwater ponds also create problems because they attract waterbirds that can foul the water. Waterfowl also harbour avian influenza viruses so are a threat on poultry farms.

For irrigation purposes, reuse of effluent is dictated by availability of effluent and nutrient concentrations. A ‘clean’ water balance running in parallel with the effluent water balance is needed to model some irrigation applications, e.g. to ‘shandy’ effluent. Other applications may need to have the effluent component ‘turned off’, and the ‘clean’ water on, e.g. storm water runoff dam being used to irrigate vegetables.

Including a separate non-effluent pond option in MEDLI is relatively simple and will provide more options and flexibility for users. This will help justify further investment in the model to improve and most importantly keep it operating in the future. The DES modelling team rely mainly on proceeds from sales and training to support MEDLI. Additional funds are required to improve and update MEDLI.

To keep MEDLI relevant for DAF’s business purposes requires a vision and commitment to its evolution. It also requires a commitment to gather data to validate MEDLI and justify the model’s continued usage as the vehicle for delivering research and regulatory outcomes that support sustainable intensive livestock production in Queensland.

This research maps to the following ASQ impact areas: livestock protection, production systems, environmental sustainability and business management.

## Project Objectives

The overarching aim was to increase freshwater and wastewater modelling capabilities, either in MEDLI or by utilising other available models. This is needed to dynamically account for the amount of freshwater still available, on any given day, for the purposes of meeting shandying, irrigation, drinking water, and other requirements, for assessing sustainability and risk depending on the situation.

We aim to identify the additional inputs and modelling required to capture the water usage, water quality dynamics, and biosecurity risk dynamics, particularly those attributable to waterfowl. The attractiveness of water storages to waterfowl is related to the pond morphology, features and current water depth.

These capabilities are needed to support defensible decision-making relating to sustainable agricultural production. A further aim was to identify knowledge gaps that required further research.

The specific objectives were to:

- conduct a literature review of 'freshwater' storage models
- develop a prototype Fortran model for potential inclusion in MEDLI.

# Methodology

As a case study and basis for narrowing the literature search, we used the hypothetical scenario of modelling the storage volume and water quality of a freshwater dam on a poultry farm, which may attract waterfowl that can potentially introduce avian influenza viruses to the system.

A catchment modeller (David Waters, NRM) was consulted and a literature search was conducted. We searched for pond models and catchment models. We also searched for models to predict water quality to estimate nutrient loading rates attributable to waterfowl because they can contribute to water quality problems.

We discussed the WaterBal 5 model with its developer (Alan Skerman, DAF), and the HowLeaky model with its developer (David McClymont) and a regular user (David Freebairn) with a view to adapting their water storage modelling approaches for MEDLI.

Based on these findings and his knowledge of MEDLI, Michael Atzeni identified code from the MEDLI feedlot model and effluent pond model that could also be adapted for the purpose.

# Results

## Water storage models

The search was limited to Australian models that we could access and evaluate.

HowLeaky developed by DNRM and DSITIA (McClymont et al, 2010) is used to explore water balance and water quality (salt) implications of alternative land uses and management practices. The HowLeaky pond accommodates the linked simulation of an inflow (constant or time series) to a storage pond connected to an irrigation area. Unlike MEDLI, HowLeaky is not a nutrient balance model as well.

WaterBal 5 developed by DAF (Skerman & Simpson, 2014) performs a daily water balance for dairy applications, accounting for pond inflows from wash-down, rainfall, runoff from several different catchments; and pond outflows from evaporation, irrigation and recycling for wash-down. Waterbal 5 offers flexible pond design options with sloping sides. Nutrients are not modelled in Waterbal 5.

The MEDLI model already allows for catchment, pond and nutrient modelling, so is a more suitable model for this application.

All three models rely on climate files from the SILO database. SILO is an enhanced climate database hosted by the Department of Environment and Science (DES, https://data.qld.gov.au/dataset/silo-climate-database).

## *Poultry scenario modelling*

Hamilton et al. (2017) suggested that there where almost 750 000 dams or ponds in the Murray Darling Basin alone providing drinking water for stock or to meet irrigations requirements. Farm dams are also often important waterbird habitats in Australia (Hamilton et al., 2017). For the poultry industry, dams present a biosecurity risk because waterfowl are the main source of avian influenza viruses. This risk is greater for free-range farms where waterfowl come into contact with commercial flocks. Waterbirds also foul dam water through faecal deposition. No suitable models were found to assess these problems.

Australian chicken meat farms are mostly centralised and are able to utilise treated water facilities. However, commercial layer operations are more likely to use alternate water sources such as bore water and/or surface waters (fam dams) due to their distance from main water supplies (Government, 2009). It is estimated that almost half of Australian poultry production sites rely on surface water supplies for drinking water, cooling and washing purposes.

## *Waterbird abundance*

The largest problem with nutrient loading/biosecurity risk factor is estimating bird numbers that are utilising a dam (Manny et al., 1994). In order to achieve this, the factors that attract various bird guilds need to be incorporated, including dam morphology. In Australia, there have been limited studies undertaken on farm dam structures (Hamilton et al., 2017; Kingsford, 1992; Markwell and Fellows, 2008). Markwell and Fellows (2008) studied eight farm dams in southeast Queensland.

Hamilton et al. (2017) examined waterbird occupation of farm dams in south eastern Australia's Murray Darling basin (MDB), on a number of guilds (shorebirds, long legged wading birds, swamphens and coots, pursuit predictors diving, dabbling, filtering and herbivorous birds) as well as a wide range of pond parameters that could potentially affect a bird's use of a water resource including:

1. Water depth.
2. Total water surface area.
3. Steepness of shoreline.
4. Fringing and emergent vegetation.
5. Logs / dead trees.
6. Agro pollutants.
7. Stock use.
8. Surrounding crop and pasture.
9. Visibility.
10. Biomass of invertebrate communities.

Studies also need to take into account spatial and seasonal variations in waterbird populations. Australia is known to have massive year-to year fluctuations in abundance of waterbirds due to large scale breeding events resulting from water reaching the central lakes. Annual waterfowl survey data collected by UNSW indicate spatial abundance and prevailing conditions (Figure 1). These could be incorporated as historical data and used towards verifying predicted abundance of waterfowl on dams.


***Figure 1. Ten aerial survey bands (each 30 km in width), every two degrees of latitude, crossing eastern (UNSW, 2018)***

### *Faecal contamination*

The nutrient load contributed by birds through faecal deposition has been examined in a number of international studies (Guilfoyle and Schultz, 2017; Hahn et al., 2007; Hoyer and Canfield, 1994; Manny et al., 1994; Scherer et al., 1995) and has been shown to have a significant impact on nutrient levels in lakes and water reserves (Guilfoyle and Schultz, 2017).

High nitrogen (N) and phosphorus (P) loadings occur particularly during roosting, over wintering, flocking and colony breeding (Hahn et al., 2007). Table 1 shows a wide range in the contribution of N and P loading rates directly attributed to birds, some studies showing a low nutrient load (Hoyer and Canfield, 1994) while others show substantial nutrient loading by birds (Hahn et al., 2007; Manny et al., 1994; Scherer et al., 1995). In some cases, concentrations were high enough to result in algal blooms (Manny et al., 1994) as well as increased coliform bacteria loads (Klimaszyk and Rzymski, 2014).

For N, the surrounding land use was seen to have a larger impact on dam N concentration. However, the results in Table 1 indicate that for P, the impact seems significantly higher. Scherer et al. (1995), however, noted that 87% of the P found to be deposited by birds may have come from internal sources such as food generated in the lake in which the birds are a link in the cycle, resulting in a low net nutrient addition. However, the bird wastes alter the rate and pathways of nutrient cycling in the lake from its previous form. Bird droppings increase the nutrient content of sediment, which stimulates the productivity of aquatic macrophytes resulting in a long term impact on water quality (Carpenter and Lodge, 1986).

Numerous research studies have noted the potential for birds such as waterfowls to serve as mechanical vectors for transport of viable diseases (Alderisio and DeLuca, 1999; Girdwood et al., 1985; Graczyk et al., 1996; Guilfoyle and Schultz, 2017; Klimaszyk and Rzymski, 2014).

Factors could be used to assess pathogen risk from wild fowl species such as studies by Guilfoyle and Schultz (2017).

*Table 1. N & P contributions from different sources*

| Rain | Soil/Groundwater | Birds | Notes | Reference |
|---|---|---|---|---|
| 19% N<br>7% P | 64% N<br>20% P | 17% N<br>73% P | External sources<br>Protected area/ duck feeding common | Chaichana et al. (2010) |
| 18% N<br>24% P | 59% N<br>63%P | 15% N<br>12% P | External / internal sources<br>Protected area/ duck feeding common | Chaichana et al. (2010) |
| 2% N<br>1%P | 63% N<br>Watershed runoff – 58<br>Fertilizer runoff - 9<br>Other - 4<br>29% P<br>Watershed runoff – 1<br>Fertilizer runoff -16<br>Other -12 | 27% N<br>70% P | Wintergreen lake – known for large flocks of Canadian Geese | Manny et al. (1994) |
| | | 27% P<br>87% of this P originated from food items found in the lake representing internal cycling<br>Water birds account for 99% of this P loading | Green Lake Seattle | Scherer et al. (1995) |
| | | 2.4% P | the total annual phosphorus load contributed to 14 Florida lakes by bird populations | Hoyer and Canfield (1994) |
| | | 59-62% N<br>2-36% P | Carnivorous waterbirds | Hahn et al. (2007) |

## *Nutrient loading models*

Numerous models on nutrient loading from bird life have been developed (Hahn et al., 2007; Manny et al., 1994; Scherer et al., 1995). Scherer et al. (1995) developed the following model for estimating the phosphorus loading rate into lakes by bird droppings:

$$P = (B)(D)(C_d)(p)$$

Where:

P= phosphorous loading rates (kg P $t^{-1}$)

B= Number of Bird days (bird-d $t^{-1}$)

D= dry weight of droppings produced each per bird per day (mg DW droppings bird-$d^{-1}$) (E.g. 2.25% of body weight)

$C_d$= total phosphorous content of droppings as a percentage dry weight (e.g. 1.87% of DW)

p= probability that the droppings will reach the lake (e.g. bird spending all time on lake = 1, non-water birds entering the lake =0.125, widgeons/Canadian geese 0.5).

One of the concerns surrounding the addition of bird faecal matter to dams is the potential for algal blooms to occur. Nutrient enrichment is known to simulate aquatic plant growth. For these systems, P is often considered as the limiting nutrient source in lakes, and external P loads including that from water fowl can change the trophic status of the dams. Manny et al. (1994) proposed the following formula to predict phosphorus concentration (mg P/$m^3$) in small lakes:

$$[P]=[L(P)/q_a] / [1+\sqrt{T}(w)]$$

Where:

[P], = mean annual concentration of total phosphorus in the lake (mg P m- 3)

L(P) = annual areal load of total phosphorus per unit area of lake surface (mg P m- 2 y- 1)

q = hydraulic load (m y- 1)

T(w) = water residence time (y).

## Modelling a generic farm dam

A conceptual model for a farm dam is shown in Figure 2. The Fortran model originally proposed was unable to be programmed due to unexpected and extended personal leave by the DAF programmer who was involved in his project. The conceptual model could also include a catchment for runoff entrained into the dam. For a poultry farm, pond morphology influences bird numbers and therefore nutrient loading rates. For other applications, these may not be relevant.

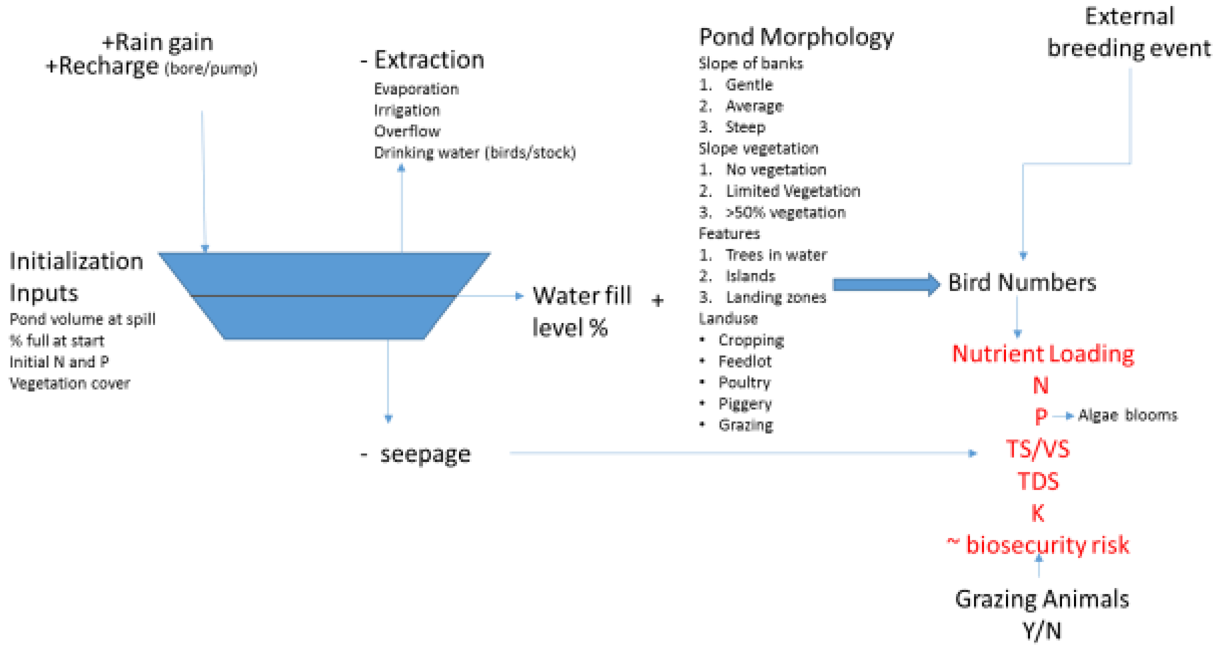


***Figure 2 Schematic of a dam model involving nutrient loading from waterfowl and other animals***

## Conclusions/Significance/Recommendations

MEDLI could be upgraded relatively easily to incorporate a functional 'non-effluent' containment that optionally receives runoff from a catchment. This can be done by combining the feedlot catchment runoff algorithms used to determine the amount of runoff from roofs, roads and grassed ('soft') areas of the feedlot model with the water balance modelling of the effluent pond. Other models that are currently available were found to be unsuitable for this purpose.

It is recommended:

- That the conceptual models reported in this study be programmed into MEDLI as a DAF–DES initiative, so that future studies (externally funded by agricultural industries) can be conducted to validate the model outputs, and ensure sustainable agricultural production.
- Additional modelling features, based on previous DAF R&D outcomes, be added to MEDLI including bio-solids, greenhouse gases and odour emissions.

## Key Messages

- Water availability is a limiting factor in the profitability and sustainability of intensive livestock enterprises. Non-effluent water mass balance modelling is a potential modelling need in order to make informed decisions about the long-term viability of the enterprises affected.
- A business case exists for upgrading MEDLI to an irrigation model that handles both non-effluent and effluent scenarios. It is a relatively straightforward exercise that DAF and DES could undertake.
- Adapting MEDLI for "non-effluent reuse, non-irrigation" scenarios is more difficult and not possible until the above irrigation capability is in place.
- MEDLI's feedlot hydrology model currently being implemented by DES in collaboration with Premise (MLA-funded) and pond model code can be used towards developing the non-effluent modelling.
- The MEDLI model is an undervalued and rare asset. It can and should be much more than an effluent reuse model moving forward. Frameworks could be added for other nutrients, solids reuse and emissions modelling.
- MEDLI modelling needs to be validated, especially for any new capabilities. Validation data needs to be collected towards achieving new functionality in the model.
- Machine vision (combined with other sensor technologies, e.g. chemical sensors) may provide an innovative way of collecting environmental data for model validation and could potentially be the source of input data files for future MEDLI applications.

## Where to next

Currently, MLA are funding the inclusion of the feedlot hydrology model developed by DAF and Premise (engineering, environmental and agricultural consultants) for MEDLI in 2006. Once this current project has been completed, DAF will be well placed to enhance MEDLI's feedlot modelling capability based on a backlog of DAF feedlot R&D outcomes (especially Matthew Redding's work) that have been left 'on the shelf'.

We propose a scoping study across all livestock sectors and probably an MLA-funded project that involves modelling and collection of data to validate the MEDLI feedlot model. Data required includes rainfall and runoff events; water levels in the runoff dams, sedimentation basin, and non-effluent dams; pen data such as stock numbers, manure harvesting and stockpiling events; and weather data (especially wind direction) when manure harvesting and turning compost.

# Budget Summary

There has been no external expenditure. The $2000 operating expenses allocated was intended for consultation fees with the MEDLI development (DES) but was not required.

The literature review was performed in-house by Jaye Hill. The modelling investigation and report was prepared by Michael Atzeni.

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