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Risk-based assessments of stormwater solutions for the poultry industry

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ABSTRACT

Australia's meat chicken industry is a strong contributor to our national economy. With production increasing to meet consumer demand, new poultry developments are a regular feature on the desks of local and state government development approvals teams. The protection of sensitive nearby environments is a key concern for these organisations and the broader community, and legislation, regulations and guidelines have been created to support these protection goals.

The many documents that support regulation of the poultry industry differ and overlap across jurisdictions, and these differences can cause uncertainty and confusion among development proponents and community. A lack of data on the true risks posed by poultry farm stormwater, and the effectiveness of the different management options available to treat it, further compounds this confusion, introducing uncertainty for the industry and development assessors.

This project aims to address some of the data and information gaps and develop a new innovative, risk based assessment process to satisfy both regulators and industry.

The poultry industry has taken significant steps to develop industry based standards for good environmental practice including the management of risk pathways for stormwater contamination. The Australian Government's National Environmental Management System for the Meat Chicken Industry, Version 2 (McGahan et al. 2015), developed in collaboration with the poultry industry, details a range of scientifically sound and practical risk avoidance and minimisation strategies and actions to protect surface waters and ground waters. These centre mostly on maintaining separation between stormwater runoff and operational areas such as broiler sheds, outside runs, load-out pads, spent litter stockpiles and litter applications areas, and composting areas with the effluent runoff from these areas to be managed in separate 'closed loop' systems (contain–treat–re-use/recycle). Correct application of the strategies and practices described in (McGahan et al. 2015) will significantly reduce residual stormwater risks and simplify the stormwater management regime required to achieve statutory compliance.

As this project is geared towards providing evidence based data and guidance for stormwater management on new poultry farm development applications and applications for expansion of existing operations, it is assumed that stormwater risk avoidance and minimisation strategies described in McGahan et al. (2015) will have been fully incorporated into farm designs and operating plans. To this end, this report does not attempt to re-state all of these risk avoidance and minimisation strategies. Rather, this report focuses on characterising, through analysis of field data, the typical constituents found in poultry farm stormwater and from this data assess the effectiveness and appropriateness of alternative stormwater management options available to the poultry industry.

This project collected and tested stormwater samples from 11 poultry farms in South East Queensland to identify the risks posed by different pollutants. It assessed the quality of the stormwater against relevant guidelines and made general comparisons with stormwater quality from other land uses as a benchmark. From the comparatively small number of stormwater samples collected and tested, initial indications show poultry farm stormwater is similar, in terms of concentrations of key environmental pollutants such as suspended solids and nutrients, to that typical of cropping and grazing land. The measured stormwater quality however did not generally meet the relevant national and state guidelines for protection of aquatic ecosystem values. Therefore, some level of stormwater treatment will typically be required before it can be discharged to a natural water course or wetland.

For this project, no stormwater samples were collected from poultry farms under new development or expansion and therefore construction phase stormwater quality has not been characterised. It can be expected, however, that stormwater runoff generated during the bulk earthworks and construction of shed pads, load-out pads and internal access roads will have elevated concentrations of suspended sediments and particulate bound nutrients, typical of any construction site. The management of construction phase stormwater from poultry operations should therefore employ temporary erosion prevention and sediment retention techniques as described in the relevant national and state guidelines for erosion and sediment control. Construction phase stormwater management is not discussed further in this report.

A review of the available published data on the performance of stormwater management options available to poultry farms identified that each option had different levels of effectiveness in treating the various pollutants.

The most successful treatment option is bioretention (vegetation and soil filter). Bioretention systems typically involve temporary shallow impoundment of stormwater over a prescribed soil filter media (layered soil matrix) that is planted with suitable grasses and sedges with dense fibrous root structures. The impounded stormwater percolates vertically down through the soil filter. Coarse sediments are retained on the surface of the filter media and aerobic and anaerobic soil conditions in the vicinity of the vegetation roots facilitates the retention and processing of nutrients. The bioretention vegetation also translocates some of the retained nutrients from the soil to plant biomass. The cleansed stormwater is collected at the base of the soil filter media within a sub-surface drainage system that discharges the cleansed water to the local drainage system or natural waterway.

Treatment options that impound stormwater to allow pollutants to slowly settle out of suspension (i.e. first flush basins, retention basins and constructed wetlands) can be effective for removal of suspended sediment and particulate forms of nutrients but are generally less effective in removing the more bio-available soluble forms of nutrients (the exception being constructed wetlands which can be effective for these pollutants). Treatment systems that impound stormwater for long periods (months) may however pose a potential bio-security risk if they were to attract waterfowl and other wild birds that can carry avian diseases. Use of these systems may require additional on-farm bio-security risk mitigation measures.

High Efficiency Sedimentation (HES) Basins, more commonly used for construction phase stormwater treatment, are an additional ‘impoundment type’ stormwater treatment system that can also be used for post-construction phase stormwater management. HES basins use an automatic coagulant dosing unit and mixing zone (pond) located at the stormwater inflow point to a small downstream retention (wet) basin or detention (dry) basin to enhance the process of colloidal sediment flocculation and sedimentation. HES basins can potentially treat more stormwater runoff to a higher standard than other types of ‘impoundment type’ treatment systems and typically require a significantly smaller overall land allocation. HES basins can also be fully drained (discharged to a receiving waterway or recycled for other uses) within hours of cessation of the rainfall event thereby mitigating bio-security risks.

Vegetative filter strips and swales are considerably less effective for most parameters than the abovementioned alternatives, however can form part of a treatment train (i.e. sequence of treatment elements) to contribute to the overall effectiveness of the selected stormwater treatment system (e.g. as a pre-treatment measure for bioretention).

Where poultry stormwater is intended to be discharged (directly or indirectly) to a natural waterway or wetland, it will be necessary, in most cases, to incorporate within the overall stormwater treatment system either a bioretention system, HES basin, First Flush basin,

retention basin or constructed wetland. The selection of these will be dependent on specific farm characteristics and the relevant environmental values and water quality objectives associated with the receiving waters.

To assist poultry farm operators and development assessors with the selection of the most appropriate 'fit for purpose' stormwater treatment solution a staged risk-based assessment framework was developed. The framework is provided in two formats: an overview as graphical decision trees, and a checklist that provides more detail for consideration at each step. This framework is suitable for use by developers during the early stages of planning. It supports both the assessment and communication of stormwater risk and management options appropriate for the location and nature of a proposed development. Assessors can also use the framework when reviewing applications, to ensure each step has been adequately addressed for appropriate outcomes in each development instance.

This report also makes recommendations for further research to continuously improve the evidence base available to the industry and regulators when making decision on poultry farm stormwater management. Key recommendations are:

- Broadening the collection of data on poultry stormwater beyond South East Queensland to ensure geographical representation of the industry across Australia;
- Conducting auto sampling of poultry stormwater in addition to grab samples to better quantify the variance with time of stormwater pollutant concentrations and to establish a more reliable evidence base for estimating pollutant event mean concentrations (EMC's).
- Developing further knowledge on the effectiveness of first-flush ponds and other innovative options such as HES basins;
- Assessing in more detail the stormwater pathogen risks posed by free range runs; and
- Testing of the risk-based framework developed in the project as a pre-cursor to the development of a streamlined National stormwater assessment process that can be uniformly applied across jurisdictions to reduce current conflict and uncertainty.

1 EXECUTIVE SUMMARY

Australia's meat chicken industry is a strong contributor to our national economy. With production increasing to meet consumer demand, new poultry developments are a regular feature on the desks of local and state government development approvals teams. The protection of sensitive nearby environments is a key concern for these organisations and the broader community, and legislation, regulations and guidelines have been created to support these protection goals.

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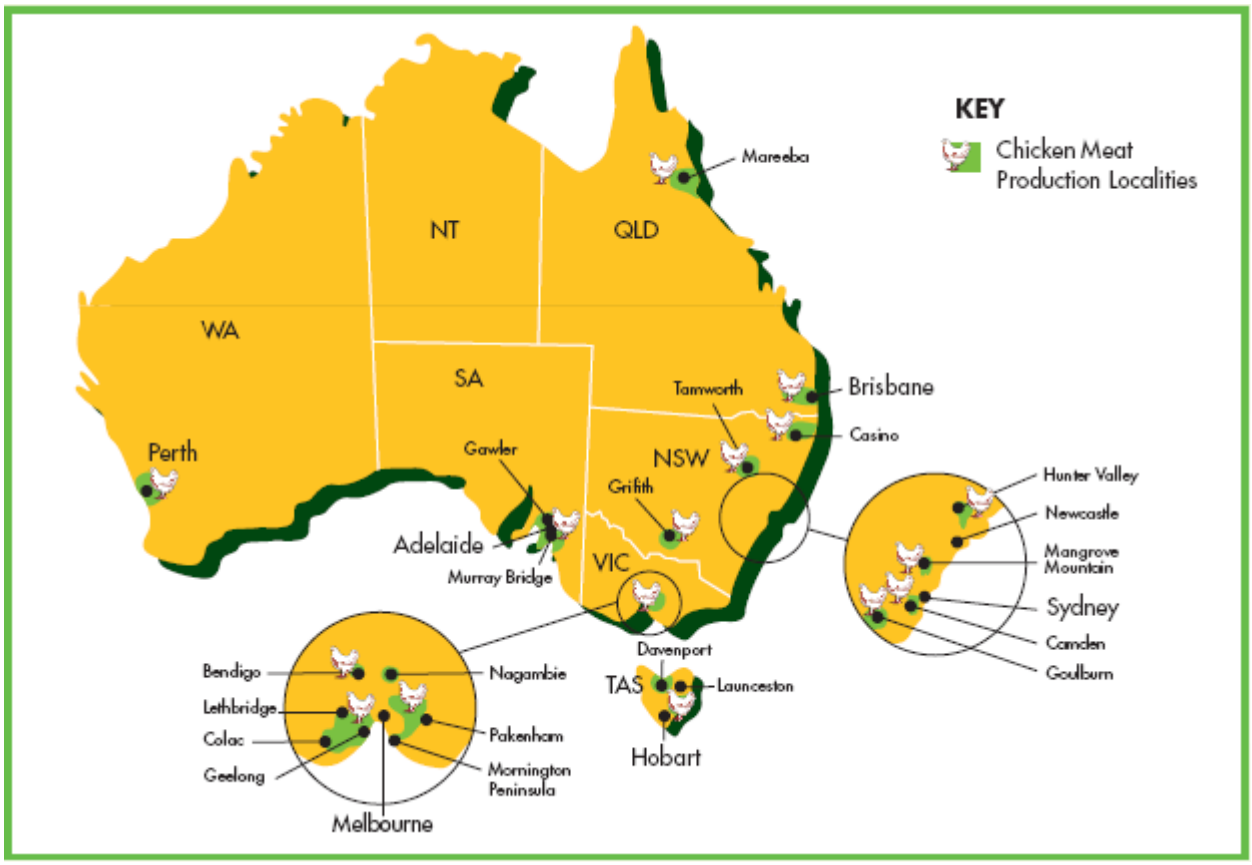
2 INTRODUCTION

> "Australia has one of the most efficient chicken meat producing and processing industries in the world. The chicken meat industry's gross value of production per year is estimated at A$2.2 billion, with Australian consumers spending approximately A$5.6 billion each year on chicken meat products." (ACMF nd-b).

Australia's chicken meat industry houses over 80 million meat chickens in more than 700 farms across Australia (ABS 2013), mostly in the eastern states. Chicken meat production is steadily increasing (ACMF 2013b), requiring new developments to sustain the industry's growth.



(Source: ACMF 2013c)

FIGURE 1- LOCATION OF AUSTRALIAN POULTRY FARMS

2.1 POULTRY FARMING

Poultry farming in Australia is undertaken using two different systems: conventional and free range. The key difference between these systems is that the free range farms include a small area around the sheds for the birds to range in addition to the sheds. Both systems have very similar operational procedures.

2.1.1 TYPICAL LAYOUTS

Conventional broiler farms are those where the chickens are constantly housed in specially designed sheds that have hard packed earthen floors and tailored ventilation systems, and are isolated from the natural stormwater system—usually by bund walls with recessed doors to keep out stormwater, and sills to keep in any washdown water.

Similar to conventional farms, free range farms have sheds available for the chickens to escape the weather and to roost at night. The free range areas utilise fenced-off areas close to the sheds for the chickens to range.

The shed layouts used in broiler farms of both types are similar, and typically around 150 m long and 15 m wide, housing about 40,000 chickens (ACMF 2013a). The number of sheds varies across farms but is typically 8 sheds for new farms—i.e. around 320,000 chickens (ACMF 2013a).

Other key features of broiler farms include storage areas for feed and may include storage and disposal areas for waste such as used litter.

2.1.2 Poultry Sheds

All broiler sheds have a range of integral systems in place to ensure the safety and productivity of the farm; including the health of the chickens, the farm workers and the surrounding environment. The key systems include waste, ventilation, feed and watering systems.

Waste systems are those that manage spent litter, carcasses, and shed washdown water. Management of these systems is described in Section 2.1.3.

Ventilation systems are either natural or use 'tunnel' ventilation. Natural ventilation usually involves open shed sides that allow air to flow through, sometimes assisted or controlled by fans, curtains or roof vents and using water misting systems to reduce the temperature when necessary. Tunnel ventilation systems uses fans to draw fresh air through cooling pads in the walls at one end, to be expelled at the other end. These tunnel systems have built-in heating and cooling facilities that can be adjusted frequently to maintain the temperature necessary for the chickens' stage of life.

2.1.3 Farm Processes

The Australian Meat Chicken Federation Inc. (ACMF 2013a) provides information on broiler farm processes, a brief summary of which is provided in this section.

The key components of the management of broiler farms in addition to the structural aspects outlined above, include processes for managing inputs (including feed, water, chickens, fresh litter, temperature and light), outputs (harvesting), and waste (including carcases, washdown water, and used litter). As the cycle of processes usually follow the life cycle of the chickens, each of these processes will be discussed below across a rearing cycle.

In preparation for receiving a new batch of chicks, shed floors are spread with fresh litter (e.g. sawdust or rice hulls) that provides bedding. The sheds are heated to an appropriate receiving temperature for the young birds (usually between 31 and 32°C). As the birds typically arrive when they are one day old, they are initially housed in a smaller area than the full shed space with additional heating, feed and water appropriate for the density of young birds. The temperature of the sheds is managed over the life of the birds to match their requirements (i.e. gradually reducing to around 23°C by final harvest).

FIGURE 2 – SHED WITH NEW BATCH OF CHICKS

(Image courtesy of the Australian Chicken Meat Federation)

As the chickens grow, the additional heating is removed and the floor area available to the birds is increased until they have full run of their shed. Feed is generally offered either 24 hours a day, or at defined meal times. Water is always available, and light is managed to be dimmer than natural light (to promote calm), and includes dark periods for the birds to rest. The overall temperature and humidity of sheds is controlled using the ventilation system, which helps keep the litter clean and dry. The birds themselves are also regularly checked for health and any unwell, injured or deceased birds removed. Usually only about 4% of the chickens are lost during this period. Dead birds are removed daily and stored in a refrigerated cold room prior to regular removal from the farm by a suitably licensed waste removalist for off-site disposal or processing. Some poultry farms manage dead birds on-farm using one of the following techniques: burning or incineration; composting; or burial in pits and trenches. McGahan et al. (2015) describes appropriate management practices for on-farm management of dead birds to avoid contact with stormwater.

Depending on the market and its need for light or heavy birds, harvesting of the birds may happen selectively as many as four times from each batch. These harvests may occur at any time between 30 days and 60 days after arrival of the birds. Harvesting often occurs at night when the birds are most calm and lighting is low so there is minimal disturbance to the flock. Harvested birds are manually collected and transported in light crates that have good ventilation and will keep the birds safe from bruising during transport. The crates are transported by truck to the processing plants.

Once all the flock has been harvested, the sheds are cleaned and made ready for the next batch of chickens. Cleaning involves removal of the used litter; washing and sanitising the floor; and cleaning water lines, fans and other equipment.

Spent litter is often heaped inside the shed, then loaded onto trucks for removal offsite in enclosed vehicles to avoid spillages and emissions. Some farms reuse their spent litter as fertiliser for other areas of the farm (e.g. turfed areas), while litter removed from farms may be sent to approved landfill, or used as fertilisers by market gardens, crops and pastures, or domestic gardens (Scott et al. 2009).

Shed floors are washed down using low-volume, high-pressure water that is kept within the shed confines. Due to the low volume of water used, any water remaining on the shed pad is evaporated by the ventilation system.

Disinfectants and insecticides required for cleaning and maintenance are stored offsite (at the farm's head office) and brought in when required. Chemicals brought in for maintenance is stored within the shed and removed from the site after completion of the day's maintenance tasks.

As well as providing appropriate food, water and shelter for the birds, the farm also maintains the health of the chickens by guarding against disease. Biosecurity issues are managed through implementing system designs and policies that aim to mitigate possible disease transfer to the chickens from contact with contaminated sources such as humans (e.g. service providers moving between farms), vehicles and equipment, and other birds (chickens or wild birds).

2.2 REGULATION OF POULTRY FARM DEVELOPMENT

All Australian poultry operations require development approval, and one of the functions of this regulation of poultry farms is to ensure the protection of nearby water quality. The regulation of poultry developments differs by state/territory as shown in Table 1.

TABLE 1- AUSTRALIAN POULTRY (STORMWATER RELATED) REGULATORY AND GUIDANCE DOCUMENTS BY STATE/TERRITORY

Jurisdiction	Regulatory and Guidance Documents	Specific to Poultry
New South Wales	Poultry Meat Industry Act (1986)	Yes
	Water Management Act (2000)	No
	Environmental Planning and Assessment Act (1979)	No
	Protection of Environment Operations Act (1997)	Yes
	Guidelines for Managing Risks in Recreational Waters (2008) (NHMRC 2008)	No
	Best Practice Management for Meat Chicken Production in NSW Manual 1 – Site Selection & Development (2012) (NSW DPI 2012)	Yes
	Environmental Management on the Urban Fringe (2004) (OEH 2004)	No
Northern Territory	Not applicable	-
Queensland	Sustainable Planning Act (2009)	No
	Environmental Protection Act (1994)	No
	Water Act (2000)	No
	Environmental Protection Regulation (1998)	Yes
	State Planning Policy—state interest guideline: Agriculture (2014) (DILGP 2016a)	Yes
	State Planning Policy—state interest guideline: Water quality (2014 (DILGP 2016b))	No
	Environmental Protection (Water) Policy 2009 (Environmental Protection (Water) Policy 2009)	No
	Eligibility criteria and standard conditions for poultry farming (ERA 4) (DEHP 2015)	Yes
	Queensland Water Quality Guidelines (2009) (DEHP 2009)	No
	Stormwater guideline: Environmentally relevant activities (2014) (DEHP. 2014)	Yes
	Queensland Guidelines: Meat Chicken Farms (2012) (DAFF 2012)	Yes
	Best Practice Technical Guide for the Meat Chicken Industry in Queensland (2005) (FSA Consulting 2005)	Yes
South Australia	Environment Protection Act (1993)	No
	Environmental (Water Quality) Protection Policy (2003)	No
	Guidelines for the Establishment and Operation of Poultry Farms in South Australia (1998) (SAFF 1998)	Yes
Tasmania	Environmental Management and Pollution Control Act (1994)	No
	Land Use Planning and Approvals Act (1993)	Yes
	Water Management Act (1999)	No
	State Policies and Projects Act (1993)	No
	State Policy on Water Quality Management (1997)	No
Victoria	Environment Protection Act (1970)	No
	Environment Protection (Scheduled Premises and Exemptions) Regulations 2007 - S.R. No. 77/2007 (2007)	No
	State Environment Protection Policy (Waters of Victoria) (1988)	No
	Victorian Code for Broiler Farms (2009 (DPI VIC 2009))	Yes
Western Australia	Waterways Conservation Act (1976)	No
	Environmental Protection Act (1986)	No
	Planning and Development Act (2005)	No
	Waterways Conservation Regulations (1981)	No
	State Planning Policy 2.9: Water Resources (2006) (Western Australian Planning	No

Jurisdiction	Regulatory and Guidance Documents	Specific to Poultry
	Commission 2006)	

Jurisdiction	Regulatory and Guidance Documents	Specific to Poultry
Western Australia (continued)	State Planning Policy 2.7 Public Drinking Water Source (2003 (Western Australian Planning Commission 2003)	No
	Water Quality Protection Note: Land use compatibility in Public Drinking Water Source Areas (2004) (Department of Water 2016)	Yes
	Public Drinking Water Resource Policy: Protecting Public Drinking Water Source Areas in Western Australia (2005) (Department of Water 2009)	No
	Environmental Guidance for Planning and Development (2008)	No
	Environmental Code of Practice for Poultry Farms in Western Australia (2004) (Department of Environment 2004)	Yes
National	Environment Protection and Biodiversity Conservation Act (1999)	No
	National Water Quality Management Strategy (2014)	No
	Australian and New Zealand guidelines for fresh and marine water quality - 2000 (often referred to as the ANZECC (2000) guidelines)	No
	Australian Drinking Water Guidelines (2011) - (NHMRC & NRMMC 2011)Updated March 2015	No
	Water Quality Guidelines for the Great Barrier Reef Marine Park Authority (2010)	No

[A] Intensive livestock listed as cattle and pigs only.

Some areas also have local guidelines, such as the following examples:

- nationally driven local guidelines—for example the *Water Quality Guidelines for the Great Barrier Reef Marine Park* (2010) (Great Barrier Reef Marine Park Authority 2010), which supports international obligations for protection of the World Heritage Area.
- those provided by non-statutory expert groups like the Healthy Waterways Partnership—for example the *Water Sensitive Urban Design Technical Design Guidelines for South East Queensland* (2006) (Moreton Bay Waterways and Catchments Partnership 2006), and *Seqwater Development Guidelines: Development Guidelines for Water Quality Management in Drinking Water Catchments* (2012) (Seqwater 2012).
- those provided by some local governments for developments in their jurisdiction—for example Gladstone City Council's *Poultry Solutions, Poultry Farms: Operator's Environmental Guide for Environmentally Relevant Activity* (2000), which was developed from work by Brisbane City Council (2000).

2.3 Stormwater Quality Knowledge and Policy Gaps

Multiple issues arise from the policy approaches outlined in Table 1. Firstly, there are multiple guidelines and regulations to meet in each state, often with different objectives and targets. Secondly, many of the guidelines and regulations are not specific to the poultry industry; with generalised information and guidance intended to cover many different sectors and situations. Subsequent to these two, many poultry-specific guidelines were developed without detailed information on typical poultry stormwater quality.

2.4 IMPLICATIONS FOR NEW POULTRY DEVELOPMENTS

Each of these three issues impact on developers, their advisors, and those assessing development applications. They provide room for conflicting interpretations and can lead to expensive court cases.

2.4.1 MULTIPLE GUIDELINES

The existence of multiple policies and guidelines in a single jurisdiction requires interpretation by developers and assessors of which are relevant, and in what order of importance, in each situation.

This lack of clarity and potential for opposition to the interpretation applied to these policies and guidelines by developers and their advisors, can lead to significant uncertainty in the application process requirements and how best to address them. Developers must identify which objectives to target and the level of investment required to plan and implement measures to meet these, without knowing if they have fully addressed any issues of potential opposition. Application assessors and potential objectors are also left with uncertainty in deciding if proposals meet their own interpretation of the objectives and whether or not opposition is appropriate—and to what level.

2.4.2 NOT SPECIFIC TO POULTRY

The lack of specific relevance to the poultry industry of some policies and guidelines, requires interpretation by each party involved in the approvals process. Without specific knowledge of the poultry industry, non-specific guidelines can be interpreted based on experience of other industries' stormwater qualities and management approaches that may not be as relevant for poultry farms. Even with poultry-specific guidelines in place (e.g. the *Victorian Code for Broiler Farms 2009*) (DPI VIC 2009) conflict can still occur over the acceptability of compliant developments; particularly as residential uses expand in rural areas (Scott et al. 2009).

2.4.3 LOW EVIDENCE BASE

The lack of data on typical poultry stormwater quality further compounds the issues above by reducing confidence in the suitability of proposed assessments and solutions. Without this key information, it is unclear if the targets or management options proposed by the various guidelines can achieve the objectives of the relevant legislation. For developers and their advisors, this means that they may be unsure if their proposal is under or over-designed, and leaves them open to opposition. Assessors also face this issue, and without sufficient experience with the poultry industry, may be guided by past experience in other sectors (e.g. urban or mining). This can lead to extensive and expensive management requirements that may not be required, may not meet the legislation's objectives, and may not be suitable for rural application.

2.5 INCREASING CERTAINTY

It is outside the scope of this project to address the issue of multiple policies, but the project aims to contribute toward addressing the remaining two issues of guidelines that aren't poultry-specific, and lack of knowledge of typical poultry stormwater quality. The project tested stormwater quality on a range of poultry farms (including control sites away from poultry for comparison with general rural runoff). Then used this data to assess the suitability of a range of stormwater management options for use by poultry developments, and developed recommendations for risk-based stormwater management guidelines for poultry developments.

The recommendations from this project will be suitable for use by developers early in planning and for documenting decision around making stormwater management decisions. It will also provide a structure suitable for use by assessors when reviewing proposals to confirm the appropriate consideration of risks. One potential barrier to the use of risk-based stormwater management guidelines, is resistance of regulators to changing away from the familiar, prescriptive urban stormwater solutions. Risk-based approaches have been successfully introduced to development assessment in other areas, such as coastal hazard management (e.g.DEHP 2013).

3 METHODS

The key components of this project include:

- Stormwater quality and current management approaches data collection.
- Analysis of relevant guidelines and comparison with collected stormwater data to identify likely treatment needs.
- Review of stormwater management options for suitability to rural environment and identified stormwater treatment needs, and
- Development of recommendations for risk-based approach to poultry stormwater planning.

The project focuses specifically on broiler chicken (free range and conventional) farms in the summer rainfall region. As the project was required to be completed within 12 months, the geographic focus required restriction to areas expected to receive rainfall for sampling. The location of the sampled farms is discussed in Section 4.3.

3.1 CURRENT STORMWATER QUALITY AND MANAGEMENT APPROACHES

The first step in understanding the stormwater risks posed by broiler farms involved sampling stormwater runoff and identifying the management approaches currently adopted by the industry, and specifically those associated with the sampled stormwater. Connecting the quality of runoff to the management approaches used is a critical component for assessing the effectiveness of management approaches for recommendation in any guideline.

3.1.1 STORMWATER QUALITY

Environmental risks posed by poultry farms' stormwater quality were identified based on the nature of the known potential pollutants from activities typically undertaken during the development and implementation of these farms, and by considering the potential receiving environments for poultry stormwater. These risks are addressed in development approvals, and include:

- Sediment, nutrients and chemicals released during construction of sheds and free range runs.
- Manure, dust and feathers released through open shed access doors.
- Dust and feathers released through shed exhaust systems, and
- Manure and feathers from free range runs.

Risks excluded from this analysis are those that are mitigated by standard procedures, including:

- Isolation of shed and equipment washdown water from contact with stormwater.
- Isolation of spent litter piles, compost areas and land application areas from contact with stormwater.
- Isolation of dead bird carcass management areas from contact with stormwater.
- Isolation of fuel and chemical storage areas from contact with stormwater, and
- Sediment control measures during construction.

While it is recognised that load-based water quality analyses provide the most effective measure for consideration of impact of pollutants such as suspended solids and nutrients on most receiving waters (ANZECC 2000, Water by Design 2007), this approach requires significant investment in monitoring across events and was not within the scope of this study. The collection of grab samples as an initial screening "snapshot" process to characterise poultry stormwater and to identify issues requiring further investigation is an accepted

approach for preliminary studies (Geosyntec Consultants & Wright Water Engineers 2009), and was adopted for this exploratory project.

Initially, poultry farms within 2 hours drive of Brisbane were identified using satellite imagery and pre-existing industry networks. Of the 20 farms that indicated interest in participating, final participation included 11 farms due to a combination of lack of rain and reduced capacity or interest for involvement throughout the project.

For each farm, stormwater samples were collected from a single event at each of three separate locations. The sites were selected to allow comparison of stormwater with different levels of contact with the risk areas of poultry farms, including one sample each:

- Upslope of the sheds/forage area (to check the quality of water coming on to the property) - referred to as upstream (A) sites.
- Immediately downslope of the sheds/forage area (to check the quality of water coming off the sheds/forage area) - referred to as poultry shed (B) sites, and
- Immediately downslope of the runoff treatment system or at the downstream property boundary (to check if there is any change to water quality before it leaves the site or after it has been treated - if the treatment system is a retention basin or detention basin, the sampling point was from the basin/pond) - referred to as downstream (C) sites.

As the two key contaminants of concern from the variable risk points above are faecal matter and feathers in washdown water and in dust and manure on runs, it is expected that the primary pollutants to poultry stormwater would be nutrients, sediments and pathogens. Parameters for analysis were selected to best represent these potential contaminants using representative indicators (e.g. *E. coli* to represent pathogens). The selected stormwater quality parameters and their testing methods included:

- Total suspended solids dried at 104 ± 2°C (method EA025).
- Total nitrogen as N (TKN + NOx) by discrete analyser (method EK062G).
- Total phosphorus as P by discrete analyser (method EK067G), and
- E. coli by membrane filtration (method MW006).

Due to the testing systems of the laboratory used, additional parameters were tested for each sample, but were not included in the analysis. The additional parameters tested were Calcium, Potassium, Magnesium, Sodium, Nitrite + Nitrate, and Total Kjeldahl Nitrogen.

Stormwater samples were collected during or immediately after a single rainfall event at each farm in the site order listed above (Sites A, B and C) by FSA Consulting staff members or landholders. Where possible, rainfall data was provided by farmers for the sampling event. Where this information was not available, data from the nearest rainfall gauge was sourced. Data on the event runoff flow rates and volumes was not available, and is likely to have differed across farms. Three samples were collected at each site, one each with the following preservatives as appropriate for the parameters being assessed: sodium thiosulphate, sulphuric acid, and no preservative. Samples were kept refrigerated and delivered for analysis by a NATA accredited laboratory within 24 hours.

A review of sampling conditions at each site was undertaken to confirm that the samples were appropriate for use and not contaminated or non-representative due to no-flow conditions, nearby erosion or other confounding factors. The results of these checks are discussed in Section 4.3.

Control (Site A) and poultry site (Sites B and C) data were compared against each other for the different production systems and stormwater management approaches using R statistical

analysis software (version 3.2.3, R Core Team (2015)). The data were tested for equal variance using Bartlett's tests, then either t-tests or ANOVA tests were applied (depending on data variance equality) to test hypotheses about differences across groups. Follow-up Tukey multiple comparisons of means tests were undertaken for significant ANOVA tests, to identify group differences. The key hypotheses tested include:

- Water upstream of poultry sites is of better quality than stormwater from poultry sites.
- Poultry site stormwater quality differs across production systems, and
- Treatment by different systems (e.g. vegetated filter strips and basins) provides different levels of quality improvement.

Correlations between the different pollutants were also tested to identify relationships that might simplify stormwater management decision-making.

Data from each site type were also compared against ranges for other industries for relative context (e.g. stormwater from grazing land).

The guidelines used to assess the sampled water quality were those that could reasonably be expected to be relevant to poultry farms in the study area, and include guidelines for the following receiving environments or downstream uses:

- aquatic ecosystems
- irrigation water (by downstream users or on farm)
- stock drinking water
- poultry drinking water (i.e. reuse of clean runoff)
- urban water supply catchment, and
- human drinking water.

Note that the human drinking water guidelines are least likely to be applicable as few domestic supplies come directly from untreated stream water.

3.1.2 Stormwater Management

Information on the stormwater management approaches used on the 11 participating poultry farms, as well as related contextual data, was collected by FSA consulting staff members through telephone interviews, including:

- number of sheds
- number of birds per shed
- total number of birds on farm
- production system (free range or conventional)
- stormwater system
- reason for choice of stormwater system
- date of approval of farm/commissioning of stormwater system
- stormwater system maintenance regime
- soil type on-site
- ground cover
- other potentially influencing factors such as run-on water from neighbouring farms, grazing on property, and application of litter on farm.

It was initially intended to compare field effectiveness of management approaches across the different production systems through statistical analysis using R software, however, the final samples included insufficient data for such analyses (refer to Section 4.3 for more information). As discussed in Section 3.1.1, the key hypothesis regarding management approaches considered the differences in their effectiveness. With insufficient data for statistical analyses, field data were compared qualitatively with the effectiveness value data

provided in the research literature to identify how practical application of the various methods might differ from the outcomes achieved under research conditions.

3.2 Stormwater Quality Requirements Review

Regulatory documents (including legislation, regulations and policy) and guidelines relevant to the design of stormwater management systems for poultry farms were identified by reviewing individual State government web sites and sites recommended for potential new poultry farmers by the Australian Chicken Meat Association Inc. (ACMF 2013a), see http://www.chicken.org.au/page.php?id=244.

Each guideline document was reviewed to identify contents specific to the poultry industry, provision of quantitative targets/guidelines, and provision of management solution recommendations for comparison and contextual purposes.

Quantitative stormwater quality target guidelines were separated out from management option recommendations and the quantitative guidelines relevant to the study area were compared against the stormwater quality test results from this project, to identify the range of water quality treatment gaps likely to require management by poultry developments in this area.

The median and 80th percentile values of each parameter for each group of sites (A, B, and C) were calculated from all farm samples. These values were used for comparison against the identified quantitative guidelines based on the recommended compliance approach outlined in the ANZECC and Queensland water quality guidelines (DEHP 2009).

3.3 Assessment of Recommended Management Options

A literature review was undertaken to capture efficiency data for each stormwater management option as identified in relevant research and in recent industry documents that included such analyses in their development (e.g. Water Sensitive Urban Design Technical Design Guidelines for South East Queensland, 2006 and Moreton Bay Waterways and Catchments Partnership 2006).

Stormwater management option recommendation guidelines were separated out from quantitative stormwater quality target guidelines and the management guidelines relevant to the study area were compared.

Management options were reviewed to identify their effectiveness for maintaining stormwater quality within the guideline quantitative target ranges.

4 POULTRY STORMWATER QUALITY

While one recent study exists that examined stormwater quality on two poultry farms (Brown and Gallagher 2015; see Section 4.2 for more on this research. The study became available after this project began), prior to this, little data was available on stormwater quality from poultry farms so a range of approaches were used by developers to address this knowledge gap when considering stormwater quality risks. The two alternative approaches used include: qualitative approaches that consider the risks based on intuitive expectations and past experience, and modelled quantitative approaches that integrate assumptions and available contextual data using mathematical formulae.

4.1 PAST APPROACHES

Prior to this study, only isolated samples of stormwater quality were known to have been collected from poultry farms, with no collective analysis available for comparison. Development approvals for new poultry farms typically applied qualitative approaches based on assumed stormwater quality, although some cases used modelling to predict likely impacts.

4.1.1 QUALITATIVE APPROACH

As stormwater from poultry broiler farms does not typically come into direct contact with contaminants, its quality has been assumed to be similar to that of the surrounding farmland. The minimal potential for contamination by particulate matter released by ventilation fans, and the increased runoff volumes caused by additional impervious areas, has been addressed by the use of vegetated filter strips between the source and receiving environment and in some cases by inclusion of dams, particularly for free range farms where manure is found outside the isolated shed system.

4.1.2 MODELLED STORMWATER QUALITY

Some development proposals have included modelling of the site using eWater's *Model for Urban Stormwater Improvement Conceptualisation* (MUSIC) software (see http://ewater.org.au/products/music for more information on the model). While this software was developed (and named) specifically for use in urban design, the flexibility it offers in how information is entered into the model and its inclusion of 'agriculture' and 'forest' node types, provides capacity for use in rural situations. The SEQ Healthy Waterways Partnership's *MUSIC modelling guidelines* (2010) (Water by Design 2010) provides guidance on parameter value ranges expected for use in their catchment areas, including the treatment of agricultural and forested land. This guideline also highlights the difficulties that can be associated with calibration and validation of the model. This may be particularly difficult in rural instances where limited data may exist (as is the case for the poultry industry).

The MUSIC software is a conceptual design tool (i.e. it does not allow for detailed design of interventions) that uses nodes and optional routing protocols to provide probabilistic estimates of the stormwater and pollutant loads across a modelled area at source, treatment and receiving nodes (CRC for Catchment Hydrology 2005). It is suitable for modelling a broad range of temporal and spatial scales with default values provided based on available research, however, its user manual emphasises the need for calibration of the model (of both rainfall-runoff and pollutant concentration components) for each modelled situation to ensure appropriateness of the parameters used (CRC for Catchment Hydrology 2005).

Site parameters used in the MUSIC model include climate, land and use characteristics:

- rainfall amounts
- evapotranspiration rates

- runoff characteristics by land use, including amount of impervious area and infiltration rates
- pollutant export characteristics by land use, including TSS, TP and TN values from roof and ground sources
- presence and characteristics (as model nodes) of any intercepting/treatment structures such as rainwater tanks, wetlands, swales, bioretention ponds, buffers, pollutant traps, sediment basins, infiltration zones, and sand or other media filters.

The characteristics included in this last point allow for the testing of a variety of stormwater management options through the estimation of the changes in the probabilities of pollutant load that each offers.

A review of MUSIC modelling in three stormwater management example reports (each prepared by a different consulting company) for poultry development approvals, identified a range of issues facing modellers in the case of poultry developments. These issues include reliance on limited research data from other locations (for a variety of parameters), inconsistent application of node characterisations, and limited options for selection of appropriate rainfall period. While urban applications of the model are sufficiently established that the default values are well accepted as appropriate by regulators, rural applications are less established, and uncertainty over the typical quality of poultry stormwater and associated selection of parameters (including defaults) make further research and model calibration desirable. Intensive agriculture default values could be assumed as conservative estimates for poultry farms, but there is limited data to confirm how representative these may be of poultry farms. This chapter discusses the findings of recent research and this project's sampling results in this context.

The *MUSIC Modelling Guidelines* (Water by Design 2010) provide pollutant export values for use in modelling stormwater runoff from a range of land uses, but do not specifically provide values for poultry farming. While this project aims to further understanding of poultry stormwater quality, several approaches have been used in the past to address this gap. One approach was the application of the *MUSIC Modelling Guidelines* values for other industries (e.g. intensive agriculture or residential areas). Estimates developed from research by Brown and Gallagher (2015) on a two free range poultry farms in Queensland have also been applied. As have estimates based on nutrient deposition rate data collected from a development site's existing poultry areas.

The characterisation of nodes within poultry farms has also been variable, with different modellers using different default values for characterising the same nodes. For example, applying any one of residential, agricultural or commercial default values for shed roof nodes. As each node type includes standard parameterisation of certain characteristics, this variability may result in inconsistent and inappropriate results - especially without appropriate data for calibration.

The selection of rainfall period with which to run the model is specified in the guideline, and is selected by modellers based on the nearest rainfall station to the development. These datasets range in decency, with periods ranging from 1961–1970 to 1997–2006, and may require review to incorporate the impacts of climate change on rainfall patterns. Due to the model's need for 6-minute rainfall data, considerable work will be required to develop new datasets for all areas where the model may be applied.

Collectively, these uncertainties pose issues for modellers and development assessors in rural areas, which must be overcome in ways that maintain confidence in model outputs should modelling be considered a desired approach into the future.

4.2 OTHER RESEARCH

Research by Brown and Gallagher (2015) for the Rural Industries Research and Development Corporation (RIRDC) measured nutrients in runoff from both free range and control areas on two Australian poultry farms from December 2011 to April 2013. From the range of small and large storm events sampled, they found no statistical difference between nutrient levels in stormwater from the free range areas than the control areas for Farm A, but significant differences for all nutrients at Farm C. Across both farms there was more variability in both total nitrogen and total phosphorus levels from the free range areas. Figure 2 and Figure 3 show the distribution of measured nutrients across range and control sites at each farm. A key difference between the two farms, however, was the quality of the control sites. Farm C control sites had much better stormwater quality than that of Farm A. Brown and Gallagher identified this as being due to different upstream soil types which reduced the amount of runoff reaching the control gauge at Farm C and with lower potential to collect and carry pollutants. Overall, Brown and Gallagher determined that "the runoff from free range areas would generate less load on the environment than, for example, a commercial golf course" (p. iii), and that soil type strongly influenced the amount of nutrient mobilised in runoff.

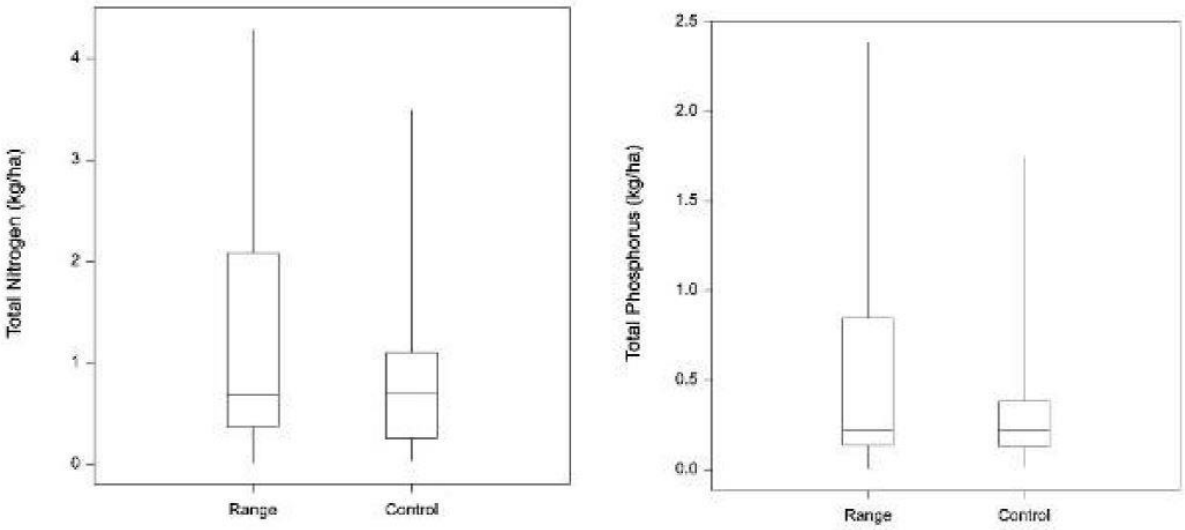


FIGURE 2 – FARM A NUTRIENT LEVELS (RANGE AND CONTROL SITES)

(Source:Brown and Gallagher (2015), p. 37)

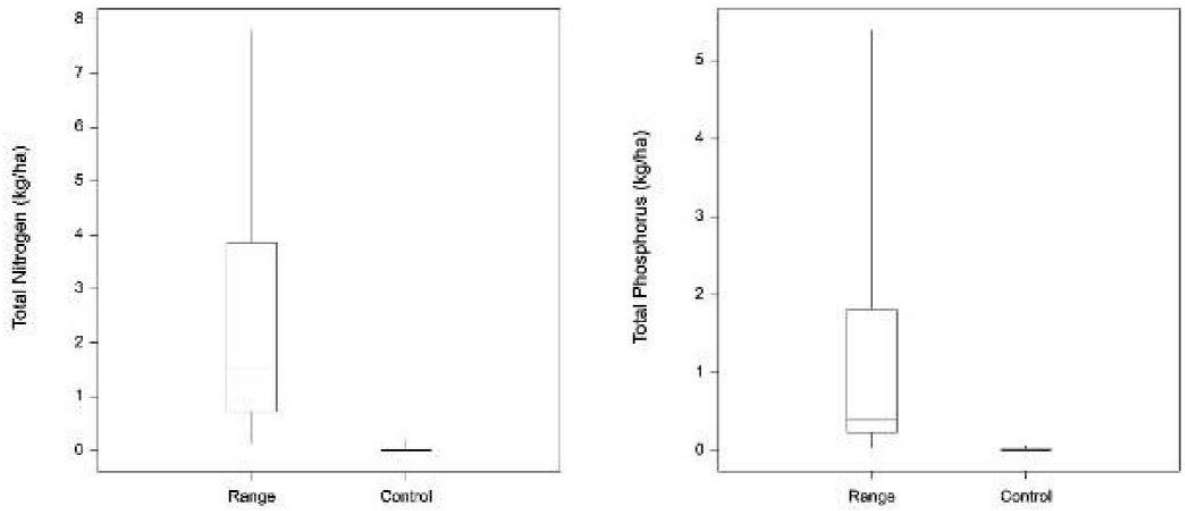


FIGURE 3 – FARM C NUTRIENT LEVELS (RANGE AND CONTROL SITES)

(Source:Brown and Gallagher (2015), p. 39)

While development approvals and stormwater modelling often focus on nutrient loads based on considerations surrounding chicken manure, two reports provide insight into another area of concern that is less frequently addressed: pathogens.

Pathogens are disease-causing organisms (including bacteria, viruses, protozoa etc.) and can be harmful to both humans and poultry to varying degrees depending on the pathogen. They can be transported by humans and poultry alike, as well as through faecal matter, feathers, and dust. International research in poultry facilities has reviewed a range of different pathogens, including bacteria, viruses and protozoa (Sobsey et al. 2006), although not all of these are present in Australia. The first report discussed in this section addresses pathogens in animal wastes more broadly, with a focus on America (Sobsey et al. 2006), while the second study was undertaken by the RIRDC in Australia, and addresses pathogens in litter and dust (Blackall et al. 2010).

Table 2 provides a list of the pathogens discussed by (Sobsey et al. 2006) as relevant to poultry that also appear in the *Australian Drinking Water Guidelines* (NHMRC & NRMMC 2011). It highlights transport methods and persistence of these key pathogens.

TABLE 2 – PATHOGENS IN POULTRY FACILITIES

Pathogen[1]	Human infection	Transmission	Animal infection	Persistence
BACTERIA				
Aeromonas hydrophila	Yes, some	Water, wounds, food	Usually no	Commonly occurring in fresh and brackish waters (persistence not specified)
Campylobacter jejuni	Yes	Food and water	No	Survival in faeces and liquid manure 3-4 days (moist conditions), or minutes to hours (dry conditions).
Escherichia coli	Yes, some	Food and water	No	Survival in faeces 42-84 days at room temperature.
Mycobacterium spp.	Yes	Respiratory	Unknown	Persistence not specified
Salmonella species	Yes	Food, water, fomites	No	Survival in manure 14-35 days depending on temperature
Yersinia spp.	Yes, some	Direct contact, food, water	No	Commonly occurring (persistence not specified)
VIRUSES				
Adenoviruses	No[2]	Faecal-oral and respiratory	Some[3]	Persistence not specified
Enteroviruses	No[2]	Faecal-oral and respiratory	Some[3]	Persistence not specified
Hepatitis E virus	Maybe[2]	Respiratory and possibly enteric	Yes, but mild	Persistence not specified
Rotaviruses	No[2]	Faecal-oral and possibly respiratory	Some[3]	Persistence not specified
PROTOZOA				
Cryptosporidium parvum	Yes	Ingestion of water	Yes	Survival in soil and faeces for 4 weeks and in water for 10 weeks at 25°C
Giardia lamblia	Yes	Ingestion of water	Yes	Survival in water for 1 month at 21°C

[1] Only those pathogens listed in the Australian Drinking Water Guidelines are detailed here as not all are relevant to Australia.
[2] The source notes that there has been limited study of these and further is required.
[3] The specific animals at risk were not specified.
Source: Adapted from (Sobsey et al. 2006).

Sobsey et al. (2006) note that two key factors affecting the persistence of pathogens in the environment, are temperature and moisture levels, with higher temperatures and dryer conditions typically reducing persistence.

Strict hygiene protocols are implemented at broiler farms to protect both humans and birds from disease. Water-related biosecurity issues focus on the risks posed by standing water and its attraction of wild birds, which can transmit disease through contact with the water and through direct contact with the chickens (DAFF 2009b). Interactions between chickens and wild birds are minimised by a number of methods. These include exclusion of wild birds from sheds, sealing water and feed systems, cleaning spills as they occur, and feeding and watering birds inside sheds only (ACMF nd-a, Agriculture Victoria 2008, Lee & Macarthur 2014). Potential disease spread through water is minimised by filtering and treating water before using it to water chickens (DAFF 2009a), and by preventing chickens from accessing standing water used by wild birds (ACMF nd-a).

In contrast to this first report, the RIRDC project (Blackall et al. 2010) focused solely on pathogens that could pose risks for human health. A key set of experiments in the project

involved laboratory tests of the survival characteristics of salmonella species, campylobacter species, E. coli and staphylococci in litter and aerosols from litter. It focussed on these pathogens as they were deemed most likely to be present in Australian meat chickens and to pose a threat to humans.

Their key findings include:

- The levels of pathogenic bacteria in the dust emissions was linked with the levels in the litter.
- E. coli counts (refer to Figure 4) began to level out in both litter and aerosols after 3 days of decline, with litter levels consistently around 2 log counts/g higher than aerosols, and aerosols nearing zero after two days.
- Salmonella spp. (refer to Figure 5) were rarely present and then only at low levels. Comparison of litter levels with aerosols shows about 2 log counts/g difference with continual decline throughout testing.
- Campylobacter spp. (refer to Figure 6) did not survive well in the litter or aerosols despite initial high levels in the litter. While litter started around 4 log units/g higher than aerosols and declined rapidly over the first day, the aerosol levels remained consistently low throughout testing.
- A harmless species of staphylococci bacteria (refer to Figure 7) was easily detected and highly persistent, and may provide a useful indicator species for monitoring bacteria risk.
- Maintenance of low levels of pathogens in litter will ensure low levels of pathogens transported through the air.
- Birds with the highest dust particle emissions were those 4-5 weeks old, due to a combination of age and activity levels.

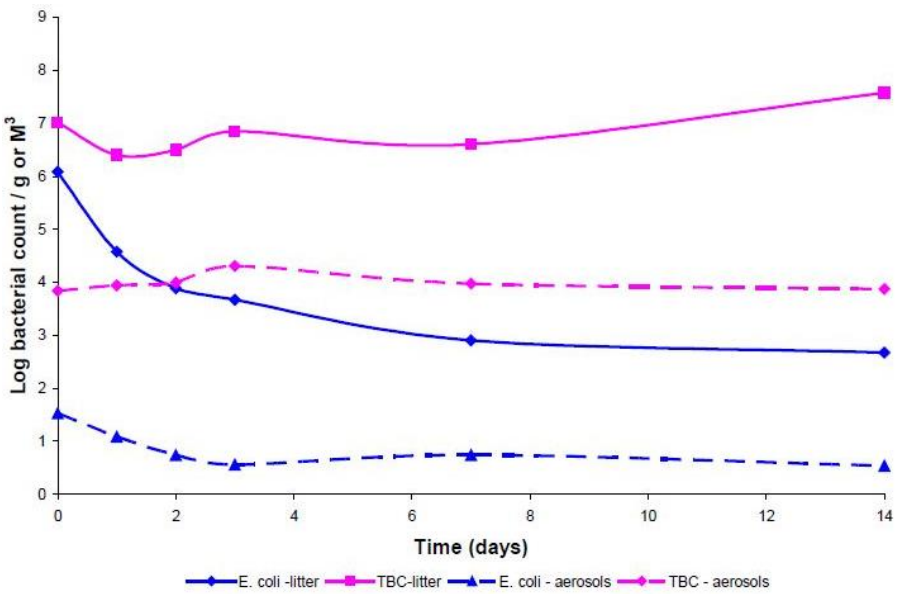


FIGURE 4 – E. COLI LEVELS IN LITTER AND AEROSOLS COMPARED WITH TOTAL BACTERIAL COUNTS

(Source: Blackall et al. (2010), p. 20)

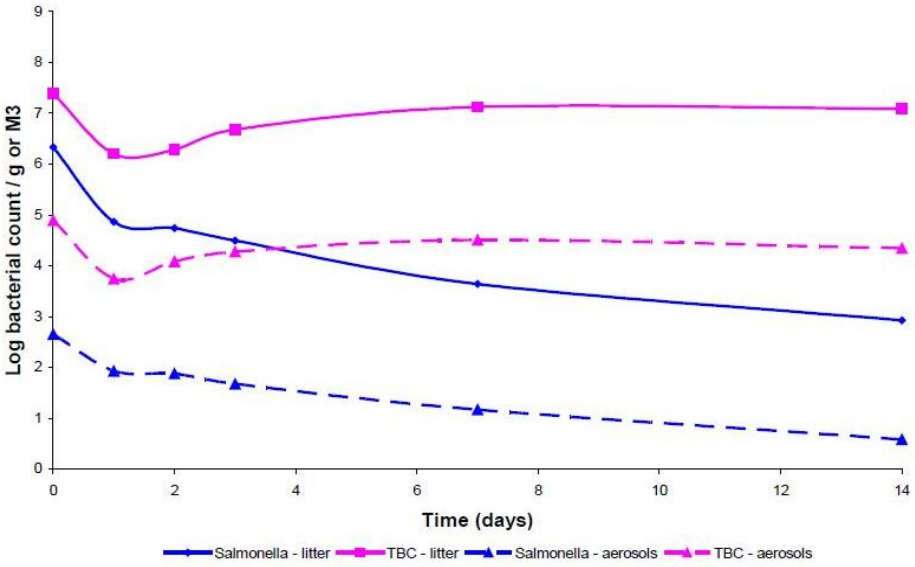


FIGURE 5 – SALMONELLA LEVELS IN LITTER AND AEROSOLS COMPARED WITH TOTAL BACTERIAL COUNTS

(Source: Blackall et al. (2010), p. 20)

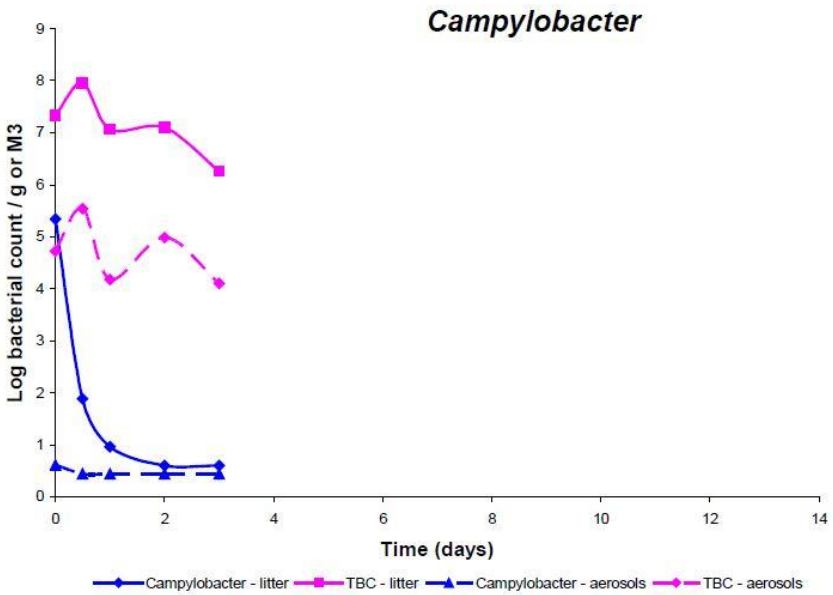


FIGURE 6 – CAMPYLOBACTER LEVELS IN LITTER AND AEROSOLS COMPARED WITH TOTAL BACTERIAL COUNTS

(Source: Blackall et al. (2010), p. 21)

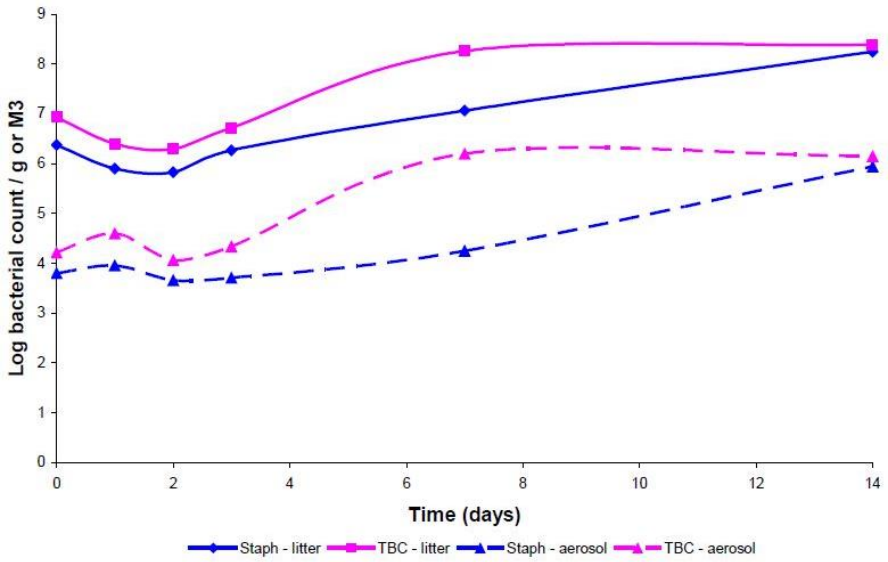


FIGURE 7 – STAPHYLOCOCCI LEVELS IN LITTER AND AEROSOLS COMPARED WITH TOTAL BACTERIA COUNTS

(Source: Blackall et al. (2010), p. 21)

These two studies collectively illustrate that of the many pathogens potentially present in poultry farms across the globe, very few are likely to be present on Australian poultry farms and to pose risks to humans. Of these more likely pathogens, their sensitivity to environmental factors is likely to affect their risk potential, and further investigation is warranted of their presence and longevity in relation to stormwater from poultry shed and free ranges areas.

4.3 SAMPLING RESULTS

A review of the stormwater quality laboratory results and the collection records for each sample identified several samples not considered representative of poultry farm stormwater:

- Data from one farm (No. 10) was excluded due to significant erosion in the area. The soils on this farm are sodic and the test results were confounded by soil influences not related to the poultry production areas of the farm.
- Farm No. 4 also experienced erosion below the farm at the time of sampling, but due to the soil type at this site, it did not significantly affect most parameters. Only the total suspended solids value was excluded from this site's samples, with total nitrogen, total phosphorus and E. coli values retained.
- The upstream site sample for a third farm (No. 1) was taken in an inappropriate location (a spring), and was excluded for all parameters as it was not representative of the surrounding upstream water quality.

Due to the removal of these samples and the lack of rainfall or farmer interest for acquiring samples from other sites, there were insufficient samples to compare in-situ differences in treatment effectiveness of specific stormwater management approaches. Qualitative discussion of the stormwater differences across management approaches will be included in Section 6 along with the research-derived performance data.

Note: Farm identification numbers are provided in brackets on parameter chart labels to allow readers to compare farms across parameters.

Table 3 provides a summary of the key characteristics of the farms with retained samples, and Figure 8 shows the location of the sampling sites.

TABLE 3 – CHARACTERISTICS OF RETAINED-SAMPLE FARMS

Production system	3 conventional farms 3 free range farms 2 mixed (conventional and free range) production farms				
Treatment approach		Treatment			
	Production system	Vegetative filter strip only	First flush dam + vegetative filter strip	Vegetative filter strip + retention pond	Vegetative filter strip + detention basin
	Conventional	-	1	1	1
	Free range	2	-	1	-
	Mixed	-	-	2	-
Size range	100,000 to 270,000 birds (2 to 8 sheds) per farm				
Shed bird density	24,000 to 52,000 birds per shed				
Geographic range	Latitudes: -26°59'43" to -28°13'53" and longitudes: 152°18'53" to 153°3'2"				
Year of development approval	1979-2015				

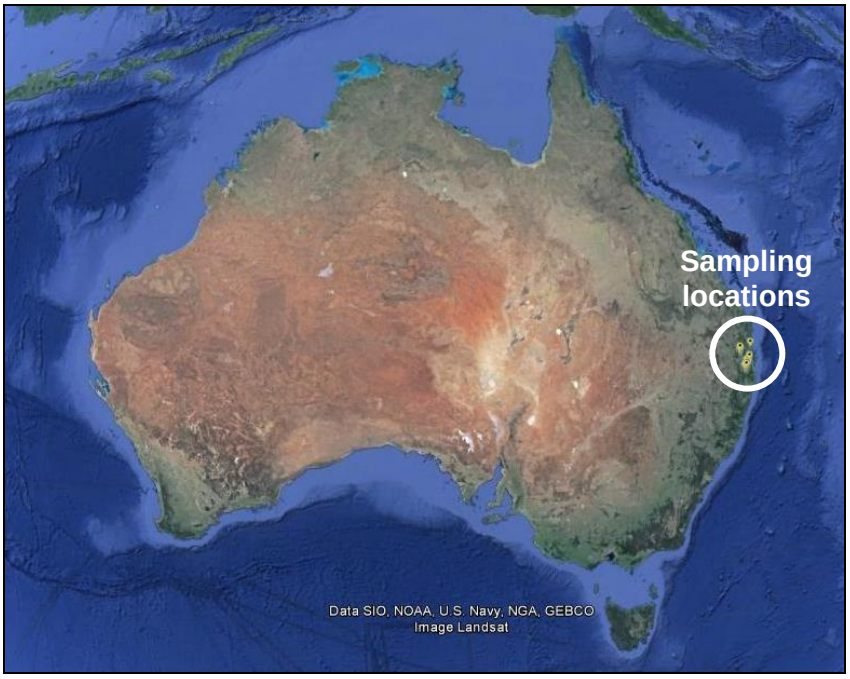


FIGURE 8 – MAP OF SAMPLING SITES

(Image created in Google Earth using Landsat imagery)

A summary of information for the retained samples is provided in Table 4. For some of the sampled farms, the rainfall events were localised, and did not register significant rainfall at the nearest rainfall station. The rainfall measured at other stations may also have been in excess of that received at sampled farms. As mentioned in Section 3.1.1, some farms were excluded from the study due to insufficient or no stormwater flow for sampling.

TABLE 4 – CHARACTERISTICS OF RETAINED SAMPLES

Farm Number	Sample date	Retained sites	Rainfall (mm)
1	19 February 2016	B	43
2	30 January 2016	A, B, C	62[A]
3	30 January 2016	A, B, C	62[A]
4[B]	9 November 2015	A, B, C	36[A]
5	3 February 2016	A, B, C	52
6	5 January 2016	A, B, C	46[A]
8	22 February 2016	A, B, C	70
9	7 November 2015	A, B, C	6
13	31 January 2016	A, B	20
14	1 February 2016	A, B, C	20

[A] Rainfall data taken from nearby Bureau of Meteorology station, reported as the sum of rainfall for the day of sampling and the previous day.
[B] Suspended solids data excluded for all sites as discussed above.

The hypotheses tested for each of the different categories of stormwater quality parameters (i.e. nutrients, sediments and pathogens) were:

- Water upstream of poultry sites is of better quality than stormwater from poultry sites.
- Poultry site stormwater quality differs across production systems.
- Treatment by different systems (e.g. vegetated filter strips and basins) provides different levels of quality improvement.

4.3.1 NUTRIENTS

The two nutrient parameters analysed across the sampled farms were total nitrogen and total phosphorus. The range of qualities sampled and results of hypothesis testing for each parameter is provided under the relevant headings in this section.

Total nitrogen

Table 5, Figure 9 and Figure 10 illustrate the distribution of total nitrogen values across stormwater samples. The median and 80th percentile total nitrogen levels across all farms at upstream (A) control sites are 2.1 and 2.7 mg/L; at shed (B) sites are 5.25 and 6.74 mg/L; and at downstream (C) sites are 3.15 and 3.82 mg/L. These values are used for guideline comparison in Section 5.5.

TABLE 5 –TOTAL NITROGEN DATA BY PRODUCTION SYSTEM AND SAMPLE SITE LOCATION

Production system	Sample Site Location					
	Control (Upstream A) Site Total Nitrogen (mg/L)		Poultry (Shed B) Sites Total Nitrogen (mg/L)		Downstream (C) Sites Total Nitrogen (mg/L)	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Conventional	2.35	0.71	5.73	0.83	3.23	0.21
Free range	1.77	0.87	6.43	5.42	2.33	1.59
Mixed	2.40	0.85	3.45	1.20	2.60	2.55
All farms	2.17	0.75	5.55	3.40	2.74	1.36

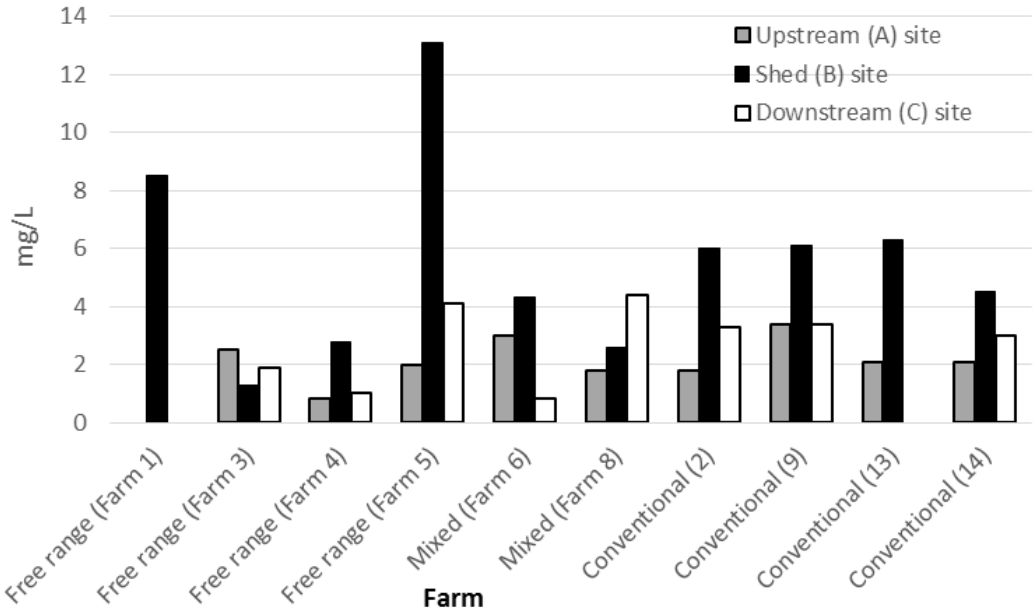


FIGURE 9 – TOTAL NITROGEN BY FARM AND SITE (ONE SAMPLE PER SITE PER FARM)

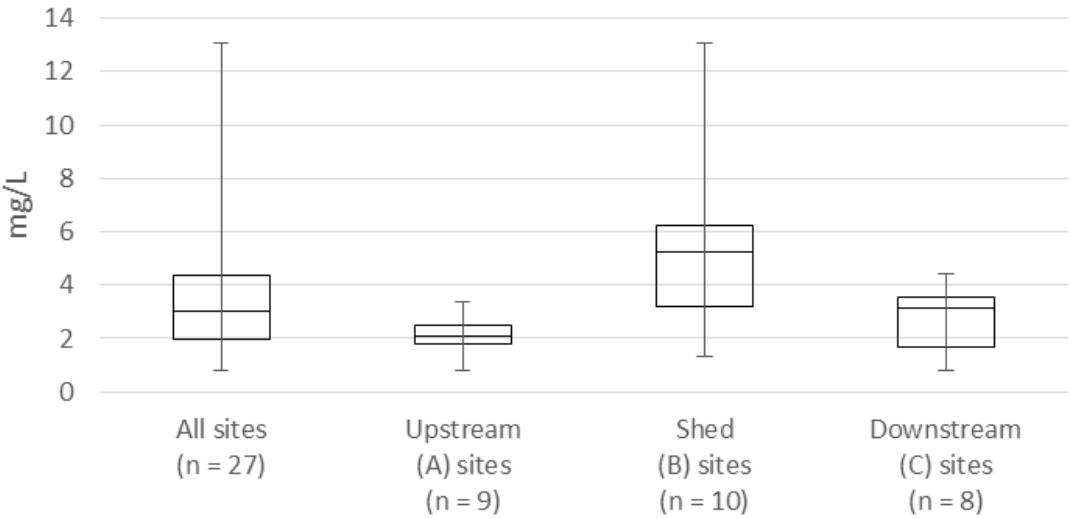


FIGURE 10 – TOTAL NITROGEN VARIABILITY ACROSS SITE LOCATIONS (ALL FARMS)

Shed (B) sites tended to have significantly higher total nitrogen levels than either upstream (A) or downstream (C) sites. The control and downstream sites' total nitrogen values, however, were not found to be statistically different, indicating that treatment practices were generally maintaining overall stormwater runoff total nitrogen levels to match the surrounding landscapes.

A comparison of total nitrogen across the different site types for each production system didn't find any statistical difference between the production systems, but a comparison of the mean and standard deviation values in Table 5 indicates that the variability in total nitrogen levels at the shed sites and downstream sites may be masking any actual differences. The total nitrogen levels at control sites across all production types were quite consistent (low variability and similar mean values) compared with the shed and downstream sites. The sampled conventional production farms showed the most consistent (lowest variability) total nitrogen levels of all production systems, with downstream site values similar to upstream

control site levels. The mean values at downstream sites across all production systems appeared similar to the control site means, but with larger variability for mixed and free range farms.

In summary, total nitrogen values in stormwater from tested poultry farms was higher at shed sites than upstream, but was generally returned to similar levels of quality to the surrounding landscape by the time it left the farm. There was higher variability in nitrogen levels at shed sites and downstream sites on free range and mixed production farms, which made statistical analysis of the data difficult. Further research is recommended to better understand the implications of this variability for management of nitrogen levels in stormwater.

Total phosphorus

Table 6, Figure 11 and Figure 12 illustrate the distribution of total phosphorus values across stormwater samples. The median and 80th percentile total phosphorus levels across all farms at upstream (A) control sites are 0.47 and 0.65 mg/L; at shed (B) sites are 1.39 and 2.97 mg/L; and at downstream (C) sites are 0.48 and 0.72 mg/L. These values are used for guideline comparison in Section 5.5.

TABLE 6 –TOTAL PHOSPHORUS DATA BY PRODUCTION SYSTEM AND SITE TYPE

Production system	Control Site Total Phosphorus (mg/L)		Poultry Sites Total Phosphorus (mg/L)		Downstream Sites Total Phosphorus (mg/L)	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Conventional	0.41	0.20	1.41	0.69	2.09	2.43
Free range	0.57	0.50	1.92	1.85	0.37	0.19
Mixed	0.41	0.18	1.85	2.11	0.18	0.20
All farms	0.46	0.30	1.70	1.36	0.97	1.61

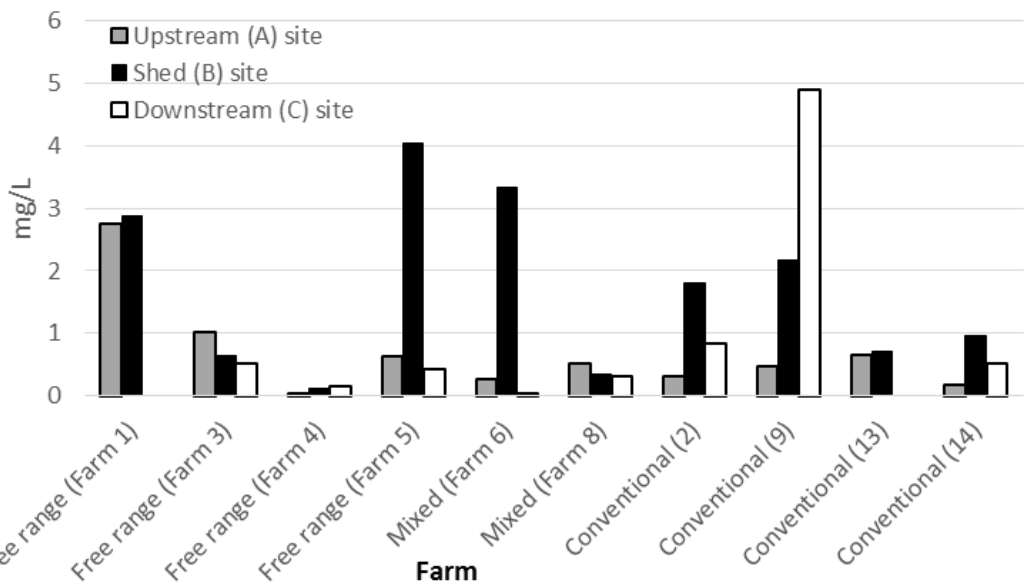


FIGURE 11 – TOTAL PHOSPHORUS BY FARM AND SITE (ONE SAMPLE PER SITE PER FARM)

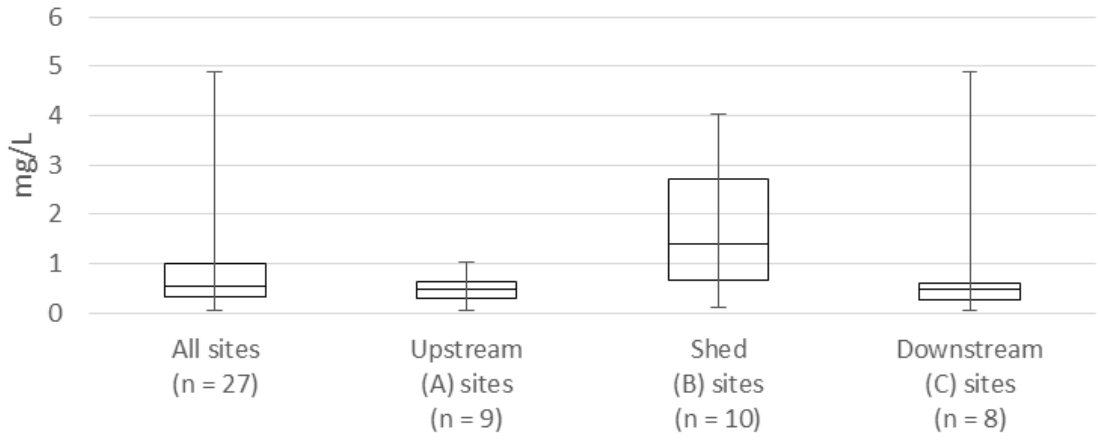


FIGURE 12 – TOTAL PHOSPHORUS VARIABILITY ACROSS SITE TYPES (ALL FARMS)

The downstream total phosphorus value for Farm 9 may have been impacted by the very low rainfall for that site. While the concentration of phosphorus in the sample was high, there was very little movement of runoff due to low rainfall volume.

Total phosphorus levels at shed (B) sites were significantly larger than those at upstream (A) and downstream (C) sites, and had higher variability. Compared with this high variability in total phosphorus levels at shed sites, downstream sites generally showed low total phosphorus levels that were similar to upstream sites. However, one downstream site had increased levels of total phosphorus compared with its shed site and all other downstream sites, indicating that additional phosphorus was being collected by the stormwater after the sheds (i.e. not from the poultry areas).

Similar to total nitrogen analyses, shed (B) sites had higher levels of total phosphorus than control sites for all production systems, with higher variability on free range and mixed production farms. However, contrary to the total nitrogen analyses, the downstream total phosphorus levels for conventional farms were higher and more variable than those of free range and mixed farms. This was due to the single outlier sample mentioned above, where the majority of the phosphorus was picked up by the stormwater after the shed (B) sites (i.e. not from the poultry areas). By excluding this value (Farm 9), the remaining conventional farms show total phosphorus levels similar to the other production systems (mean of 0.40 mg/L; standard deviation of 0.27 mg/L), and implies that stormwater total phosphorus levels from poultry production itself are generally returned to levels similar to upstream control levels by current management systems.

In summary, total phosphorus values in stormwater from poultry farms is higher at shed sites than at upstream control sites, but is generally returned to similar levels of quality to the surrounding landscape by the time it leaves the farm. One farm showed significant mobilisation of additional phosphorus in stormwater from non-poultry areas downstream of the poultry sheds. Further research is required to understand the implications of the downstream addition of total phosphorus levels and whether or not this is a common issue for poultry farms.

4.3.2 SEDIMENTS

A single measure of sediment was included in this study: total suspended solids. Results from analysing total suspended solids levels in the sampled stormwater are detailed in this section.

Total suspended solids

Table 7, Figure 13 and Figure 14 illustrate the distribution of total suspended solids values across stormwater samples. The median and 80th percentile total suspended solids levels across all farms at upstream (A) control sites are 49.0 and 84.0 mg/L; at shed (B) sites are 46.5 and 97.2 mg/L; and at downstream (C) sites are 67.0 and 90.0 mg/L. These values are used for guideline comparison in Section 5.5.

TABLE 7 –TOTAL SUSPENDED SOLIDS DATA BY PRODUCTION SYSTEM AND SITE TYPE

Production system	Control Site Total Suspended Solids (mg/L)		Poultry Sites Total Suspended Solids (mg/L)		Downstream Sites Total Suspended Solids (mg/L)	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Conventional	29.8	25.7	63.0	31.4	34.7	15.0
Free range	97.0	40.8	45.5	34.2	79.5	17.7
Mixed	30.0	26.9	53.5	68.6	93.0	15.6
All farms	52.2	43.3	54.1	36.2	64.1	31.0

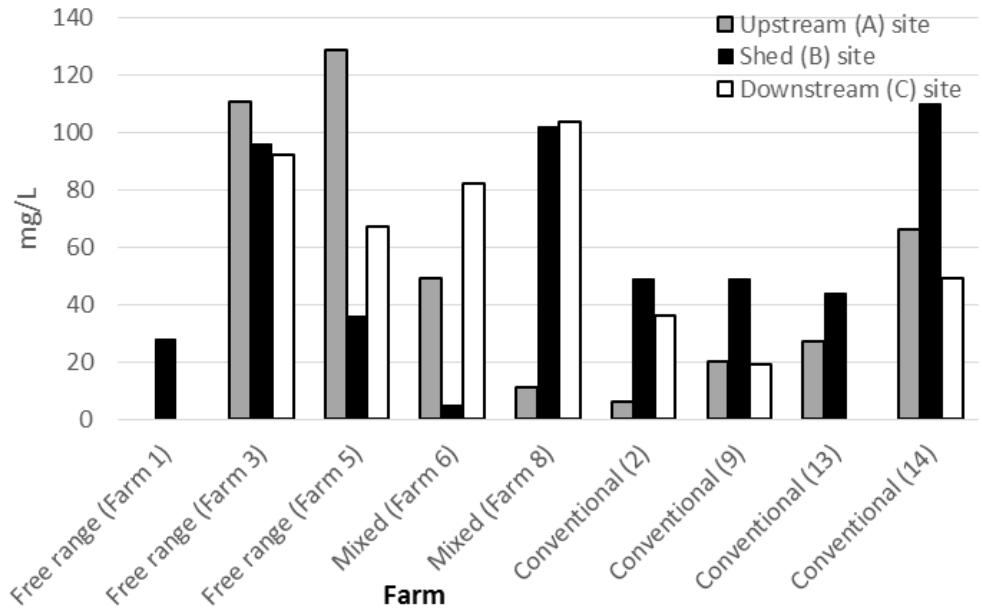


FIGURE 13 – TOTAL SUSPENDED SOLIDS BY FARM AND SITE (ONE SAMPLE PER SITE PER FARM)

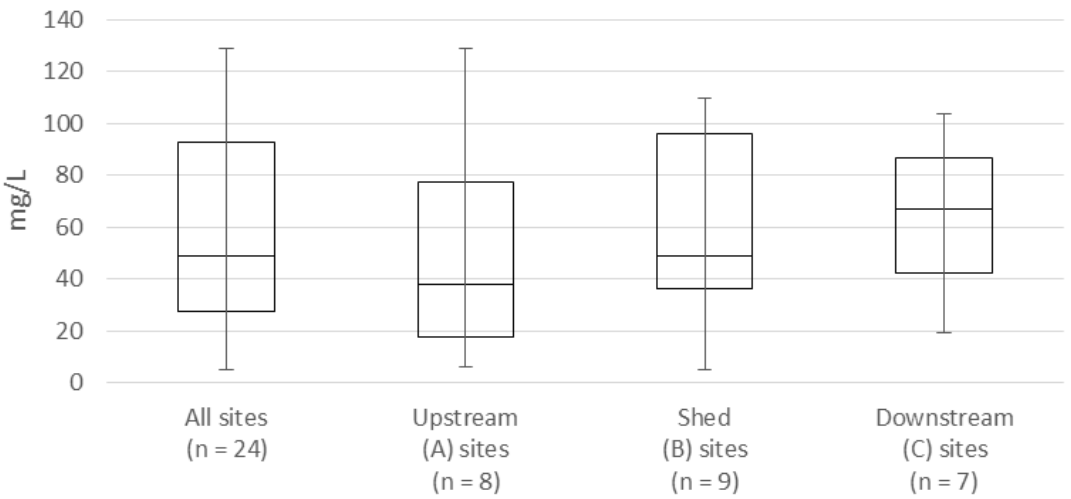


FIGURE 14 – TOTAL SUSPENDED SOLIDS VARIABILITY ACROSS SITE TYPES (ALL FARMS)

Total suspended solids levels across all sites were variable, making statistical comparison difficult. Upstream control (A) sites at the sampled free range sites had higher and more variable suspended solids levels than conventional or mixed production farms, indicating that the landscapes above these farms contributed more suspended solids to stormwater before it reached the poultry areas, which is likely to also contribute to downstream suspended solids levels.

Shed (B) sites had higher total suspended solids levels than control sites for both conventional and mixed production farms, but not for free range farms. This may be due to the isolation of the poultry areas from the direct flow path measured at the upstream sites. Mixed production shed site suspended solids levels were more variable than levels at either conventional or free range shed sites.

Total suspended solids at downstream sites were higher for free range and mixed production farms, but with less variability across all production systems than either control or shed sites.

One farm in particular (Farm 6 as illustrated in Figure 11) shows significantly higher levels of total suspended solids downstream than at the poultry sheds, indicating the additional solids are mobilised by the stormwater from non-poultry areas.

In summary, total suspended solids levels were higher at shed sites for conventional and mixed production farms, and at downstream sites for free range and mixed production farms. Upstream quality was higher for free range farms and the position of sample site along the stormwater flow path, along with the small sample size, may have influenced the representativeness of these values. One farm also showed significant further mobilisation of solids in stormwater from non-poultry areas downstream of the sheds. The effectiveness of management of total suspended solids levels on the sampled poultry farms was inconsistent, and further research is required to better understand the representativeness of these results.

4.3.3 PATHOGENS

Escherichia coli (E. coli) were adopted as representative of potential bacteria present on poultry farms. Results from analysing E. coli levels in the sampled stormwater are detailed in this section.

E. coli

Table 8, Figure 15 and Figure 16 illustrate the distribution of E. coli values across stormwater samples. The median and 80th percentile E. coli levels across all farms at upstream (A) control sites are 2000 and 15,300 CFU/100 mL; at shed (B) sites are 11,350 and 92,800 CFU/100 mL; and at downstream (C) sites are 10,650 and 21,600 CFU/100 mL. These values are used for guideline comparison in Section 5.5

TABLE 8 – E. COLI DATA BY PRODUCTION SYSTEM AND SITE TYPE

Production system	Control Site E. Coli (CFU/100 mL)		Poultry Sites E. Coli (CFU/100 mL)		Downstream Sites E. Coli (CFU/100 mL)	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Conventional	8845	10828	27500	48406	8957	13899
Free range	10833	16601	61755	65529	14367	11533
Mixed	4900	6505	19150	23829	11000	14142
All farms	8631	11112	39532	51494	11496	11319

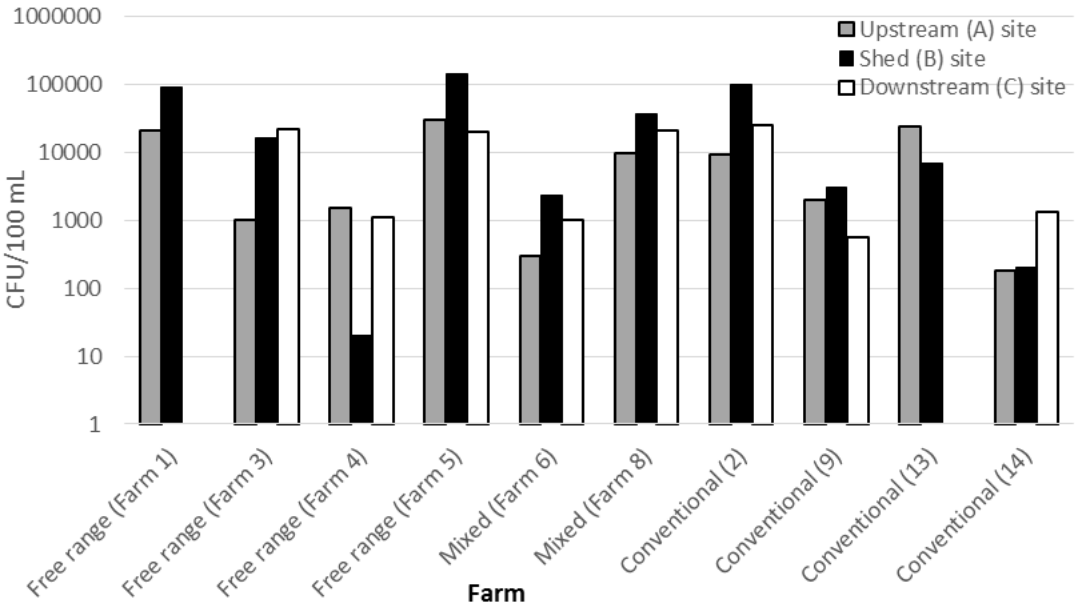


FIGURE 15 – E. COLI BY FARM AND SITE (ONE SAMPLE PER SITE PER FARM)

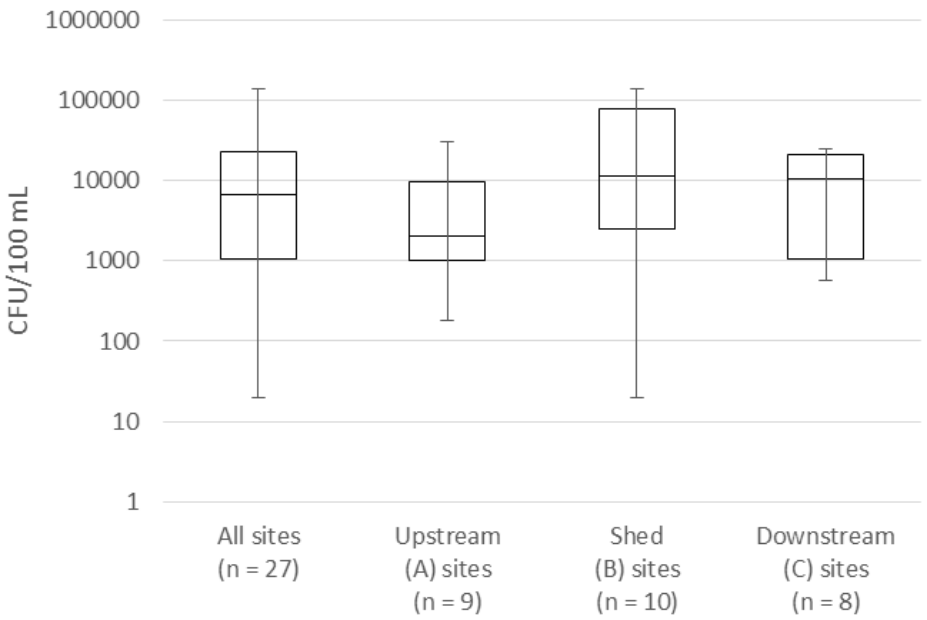


FIGURE 16 – E. COLI VARIABILITY ACROSS SITE TYPES (ALL FARMS)

E. coli levels across all site types was variable, which made statistical analysis difficult. Shed sites were found to have higher levels and more variability in E. coli values than upstream and downstream sites, which were somewhat similar in level and variability.

Comparisons across production systems identified that mixed production farms had somewhat lower levels (and variability) of E. coli at upstream and shed sites, but similar levels to conventional and free range farms at downstream sites. Free range farms had the highest level and variability of E. coli at shed sites, but similar levels to conventional and free range farms at downstream sites. Shed sites had the highest levels of E. coli compared with upstream and downstream levels for all production systems, with free range farms showing higher levels and variability compared with conventional and mixed production farms.

While upstream and downstream E. coli levels and variability generally appear similar for all production systems (with slightly lower upstream values for mixed production farms), the internal variability in site values makes these comparisons tentative.

Two farms in particular (Farms 3 and 14 as illustrated in Figure 15) show higher E. coli levels downstream of their management systems than at the poultry sheds, indicating that additional E. coli is collected from the landscape after the stormwater passes the sheds.

In summary, E. coli values in stormwater from tested poultry farms was higher at shed sites (particularly for free range farms), but was generally returned to similar levels of quality to the surrounding landscape by the time it left the farm. Mixed production farms had slightly lower upstream E. coli levels and variability compared with the other farms, however, and two sampled farms showed increasing E. coli levels downstream of the poultry sheds (i.e. contributed by non-poultry areas). Further research is necessary to identify if these values and their high variability are representative of the industry and of the broader potential pathogens of most concern on poultry farms.

4.4 PARAMETER CORRELATIONS

For urban stormwater, total suspended solids and total phosphorus levels in stormwater are correlated due to the predominantly particulate nature of phosphorus; phosphorus particles which adhere to the solid sediment particles suspended in the stormwater (Water by Design 2010). Total nitrogen in urban stormwater, however, includes more dissolved forms (Water by Design 2007).

The results of correlation analyses of this project's poultry stormwater pollutant data is provided in Table 9, and shows different relationships for these parameters. For control (A) sites and downstream (C) sites, there are no statistically significant relationships between any of the three tested pollutants. Shed (B) sites, however, show strong relationships between nitrogen and phosphorus levels, but less relationship between these and suspended solids, suggesting more soluble forms of phosphorus and nitrogen in poultry stormwater than particulate forms. The relationship between suspended solids and phosphorus was negative for these sites (meaning higher suspended solids levels related to lower phosphorus levels), which is counter to that accepted for urban areas as mentioned above. E. coli levels at shed (B) sites are most correlated with nitrogen levels, and to a lesser extent with phosphorus and suspended solids levels. Control (A) and downstream (C) sites E. coli levels are not significantly correlated with any other parameters.

As these relationships are calculated from a small set of grab samples, further research is warranted to identify if these findings are representative of poultry farms in general and across runoff events and pollutant loads, as these different relationships have implications for assuming that reductions in suspended solids will result in reductions in nutrients, particularly Phosphorus.

TABLE 9 – POULTRY STORMWATER POLLUTANT CORRELATIONS

Sites	No. of samples	Correlation Coefficients					
		TSS-TN	TSS-TP	TSS-E.coli	TN-TP	TN-E.coli	TP-E.coli
All sites	26	-0.21	-0.35*	-0.06	0.64***	0.76***	0.46**
Control (A) sites	9	-0.004	0.42	0.23	0.35	-0.19	0.35
Shed (B) sites	10	-0.41	-0.55*	-0.19	0.77***	0.76**	0.60*
Downstream (C) sites	7	-0.16	-0.71	0.37	0.20	0.40	-0.40

TSS = Total suspended solids; TN = Total nitrogen; TP = Total phosphorus; * $p<0.1$; *** $p<0.001$

4.5 COMPARISON AGAINST OTHER LAND USES

Typical pollutant values for other land uses are usually reported using event mean concentration (emc) values, which are calculated from at least 12 samples with flow data over the length of a rainfall event (Geosyntec Consultants & Wright Water Engineers 2009). It is not appropriate to calculate event mean concentrations from grab samples (Geosyntec Consultants & Wright Water Engineers 2009) or to directly compare other statistics calculated from this project's data to event mean concentration values. To provide context for the poultry industry, however, event mean concentrations was calculated from the poultry stormwater data provided in Brown and Gallagher (2015) report and is compared to typical values across other industries. It should be recognised, however, that the data from Brown and Gallagher's research were calculated from just two farms (both free range production in Queensland) and further research will be required to confirm the representative nature of these farms for the different production systems and landscapes of the poultry industry more generally.

Table 10 provides comparison event mean concentration data calculated from the free range poultry data reported by Brown and Gallagher (2015) and from other land uses. While Brown and Gallagher reported that their studied sites contributed less pollutants than commercial golf courses, a comparison against these other land uses places the data as being closest to that of intensive agriculture. No pathogen data was available for comparison.

TABLE 10 – LAND USE CONTAMINANT CONCENTRATIONS COMPARISON

Land Use (South East Queensland)	Middle (and range) Event Mean Concentration			
	Total Suspended Solids (mg/L)	Total Phosphorus (mg/L)	Total Nitrogen (mg/L)	Faecal Coliforms (CFU/100 ml)
Free range poultry[1]	550	2.4	6.8	-
Green space[2]	20 (8-90)	0.06 (0.02-0.12)	1.5 (0.8-3.9)	-
Grazing[2]	260 (110-600)	0.3 (0.13-0.77)	2.1 (1.2-6.0)	-
Broadacre Agriculture[2]	300 (80-700)	0.32 (0.11-0.80)	1.9 (0.9-5.2)	-
Intensive Agriculture[2]	550 (300-800)	0.45 (0.16-1.18)	5.2 (2.1-12.4)	-
Rural residential, Urban & Suburban[2]	130 (40-380)	0.28 (0.12-0.72)	1.6 (0.9-4.6)	-
Residential construction[3]	4897	0.9	5.4	-

[1] Calculated from data provided in the report by Brown and Gallagher (2015)
[2] Estimated concentrations "based on limited data" ((Chiew & Scanlon 2001), p. i)
[3] Water and Environment City Design, 2001, *Stormwater Quality Monitoring Program 2000/2001*, Report for Brisbane City Council (2000), Table 4.5.

While event mean concentrations are often used to discuss pollutants in stormwater, national (ANZECC 2000) and local (Water by Design 2007) guidelines outline load-based approaches as more appropriate for consideration of downstream impacts. High concentrations of pollutants in small amounts of water may not be as detrimental to receiving waters as some more diluted samples when the total load is taken into consideration. Thus the interpretation of the concentrations above warrants further consideration and research.

5 STORMWATER QUALITY – GUIDELINES

As discussed in Section 2.3, many different guideline documents exist that can be considered when assessing and designing stormwater management on poultry farms, but not all provide clear and specific guidance that can be easily and consistently interpreted for poultry developments, or provide evidence-based recommendations that foster confidence in their achievement of the objectives of relevant legislation.

Table 11 provides a summary of each of the guidelines, highlighting which contain quantitative guidelines for comparison of stormwater quality, and which provide management recommendations for consideration. While not all are relevant to poultry farm stormwater in the study area, they may provide useful comparative information to contextualise the poultry industry against other sectors (e.g. urban areas).

TABLE 11 – QUANTITATIVE GUIDELINES AND MANAGEMENT RECOMMENDATIONS

Jurisdiction	Regulatory and Guidance Documents	Quantitative Stormwater Guidelines	Management Recommendations	Relevant to Study Area
New South Wales	Guidelines for Managing Risks in Recreational Waters (2008)(NHMRC 2008)	Yes	No	No
	Best Practice Management for Meat Chicken Production in NSW Manual 1 – Site Selection & Development (2012)(NSW DPI 2012)	No (qualitative only—see management recommendations)	Yes (Buffers, siting, vegetative filters, & isolation from contamination)	No
	Environmental Management on the Urban Fringe (2004)(OEH 2004)	No (qualitative only—see management recommendations)	Yes (Buffers, siting, & vegetative filters)	No
Northern Territory	-	No	No	No
Queensland	Queensland Water Quality Guidelines (2009)(DEHP 2009)	Yes	No	Yes
	Stormwater guideline: Environmentally relevant activities (2014)(DEHP. 2014)	Yes	Yes (Vegetative cover & Sediment basins, with possible others)	Yes
	Queensland Guidelines: Meat Chicken Farms (2012)(DAFF 2012)	No (qualitative only—Refers toANZECC (2000))	Yes (Buffers, siting, & vegetative filters)	Yes
	Urban stormwater—Queensland best practice environmental management guidelines(2009): Technical Note: Derivation of Design Objectives (EDAW 2009)	Yes	No	Yes[1]

Jurisdiction	Regulatory and Guidance Documents	Quantitative Stormwater Guidelines	Management Recommendations	Relevant to Study Area
South Australia	Guidelines for the Establishment and Operation of Poultry Farms in South Australia (1998)(SAFF 1998)	No (qualitative only—see management recommendations)	Yes (Buffers & siting)	No
Tasmania	-	No	No	No
Victoria	Victorian Code for Broiler Farms (2009)(DPI VIC 2009)	No (qualitative only—see management recommendations)	Yes (Buffers, dams, & isolation from contamination)	No
Western Australia	Water Quality Protection Note: Land use compatibility in Public Drinking Water Source Areas (2004)(Department of Water 2016)	No (qualitative only)	No (Compatibility only)	No
	Environmental Code of Practice for Poultry Farms in Western Australia (2004)(Department of Environment 2004)	No (qualitative only—see management recommendations)	Yes (Buffers, siting, & isolation from contamination)	No
National	Australian and New Zealand guidelines for fresh and marine water quality - 2000 (ANZECC 2000)	Yes	No	Yes
	Australian Drinking Water Guidelines (2011) - Updated March 2015 (NHMRC & NRMMC 2011)	Yes	No	Yes[2]
	Water Quality Guidelines for the Great Barrier Reef Marine Park (2010)(Great Barrier Reef Marine Park Authority 2010)	Yes	No	No

[1] These guidelines are not necessarily applicable to every poultry farm within the study area, as many will be in areas not considered urban.
[2] These guidelines may only be relevant to some farms—those where downstream neighbours source drinking water directly from the stream network. Even in these cases, however, the guideline values are for the water at point of drinking rather than the raw water source.

From this analysis, two lists of documents were compiled for detailed comparison for the study area: those providing quantitative guidelines (covered in this chapter) and those providing management recommendations (see Section 7).

The guidelines reviewed in this section are those providing quantitative guideline values for water quality against which the study's measured stormwater quality can be assessed. They include:

- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000)(ANZECC 2000)
- Australian Drinking Water Guidelines (2011) (NHMRC & NRMMC 2011) - Updated March 2015
- Queensland Water Quality Guidelines (2009) (DEHP 2009)
- Stormwater Guideline: Environmentally Relevant Activities (2014) (DEHP. 2014)

It has been highlighted that the most effective approach to guidelines for protecting receiving water environments is through the use of load-based targets (ANZECC 2000, Water by Design 2014), however many guideline documents use concentration based guidelines, which do not account for the effects of dilution on cumulative pollutant levels.

It should be noted that the *Urban stormwater—Queensland best practice environmental management guidelines 2009, Technical Note: Derivation of Design Objectives* (EDAW 2009) also provides qualitative overall targets, but as these are provided as percentage reduction targets and are not able to be compared so have been excluded from this analysis.

While not directly relevant to poultry farms, two additional local guideline documents have also been considered:

- *Seqwater Development Guidelines: Development Guidelines for Water Quality Management in Drinking Water Catchments* (Seqwater 2012)—included due to its relevance to the study area
- *Water Sensitive Urban Design Technical Design Guidelines for South East Queensland* (Moreton Bay Waterways and Catchments Partnership 2006)—included due to its strong links between water quality and management option design.

5.1 Australian and New Zealand Guidelines for Fresh and Marine Water Quality

The *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (2000) (ANZECC 2000) provide information on the nutrient, pathogen and contaminant levels permitted in stormwater discharging into waterway. These guidelines are referenced in the Queensland Water Quality Guidelines, which are used for compliance assessment. Thus, these guidelines are used for compliance in some situations.

As discussed in more detail in Section 5.3, compliance assessments under the *Queensland Water Quality Guidelines* refer to these Australian guidelines in areas where local water quality guidelines have not been developed, as an alternative to collecting local water quality data and developing local guidelines.

The Australian guidelines provide specific targets for a range of physical and chemical stressors and contaminants that may negatively impact on receiving waterways. For example, the guidelines provide specific values for total phosphorus, total nitrogen, chlorophyll, filterable reactive phosphate, oxides of nitrogen, ammonium, dissolved oxygen and pH in a variety of waterway ecosystems including upland rivers, freshwater lakes, wetlands and estuaries etc. at locations including south-east—which includes Queensland—Australia, tropical Australia, south-west Australia, south-central Australia and New Zealand.

5.2 Australian Drinking Water Guidelines

The *Australian Drinking Water Guidelines Paper 6 National Water Quality Management Strategy* (NHMRC & NRMMC 2011) provides guidance on the prevention of contamination, treatment, and target values for healthy drinking water (with consideration of aesthetic quality). Quantitative guidelines are provided for both microorganisms and physico-chemical parameters. The guideline focuses on quality at point of use, but stipulates that it applies to any “water intended primarily for human consumption” (NHMRC and NRMMC (2011), p. 3. It defines itself as non-mandatory standards that should be applied with consideration of

economic, political, and cultural issues. The guidelines promote prevention of contamination of raw water supplies as a core principle, which is why it includes catchment managers as one of its named intended user groups.

Parameters with quantitative guideline values provided include:

- Microorganisms – 8 microbial indicators, 3 bacteria, 4 protozoa, 4 cyanobacteria and their toxins, and 5 viruses
- Physico-chemical – approximately 150 metals, pesticides, insecticides, nutrients, and other compounds.

5.3 QUEENSLAND WATER QUALITY GUIDELINES

The *Queensland Water Quality Guidelines* (2009) (DEHP 2009) are one of two guidelines in Queensland that are used in compliance assessment. In areas of overlap, these guidelines take precedence over the second compliance related guidelines—the *Water Quality Guidelines for the Great Barrier Reef Marine Park* (2010) (Great Barrier Reef Marine Park Authority 2010) — except for pesticides, which are not included in the *Queensland Water Quality Guidelines*.

The *Queensland Water Quality Guidelines (*DEHP *2009*) fall under the Environmental Protection (Water) Policy (2009) and were written to assist in setting water quality objects for Queensland. This set of guidelines has been written to fulfil the objectives of the *Australian and New Zealand guidelines for fresh and marine water quality* (ANZECC 2000) by providing statewide pollution reduction targets for total suspended solids (80% reduction), total phosphorus load (60% reduction), total nitrogen load (45% reduction), and gross pollutant load (90% reduction); and methods for the application of locally specific guidelines. Specific local guideline values are provided for many coastal subregions and for urban stormwater quality. For areas where no local guidelines have been developed, readers are directed to either adopt the values specified in the *Australian and New Zealand guidelines for fresh and marine water quality* or to collect local water quality data and develop local guidelines.

Local guidelines have been developed and included in the Queensland guidelines for most coastal areas of Queensland. Local guidelines have also been drafted for areas within the Murray Darling Basin (MDB) by the regional natural resource management organisations and catchment communities, but the draft MDB values have yet to be ratified by the Queensland government and are not currently referenced or otherwise included in the *Queensland Water Quality Guidelines* (DEHP 2009), which leaves these areas as potentially falling under either the draft local guidelines or the Australian guidelines.

Guideline values provided in the *Queensland Water Quality Guidelines* (DEHP 2009) are specified by local catchment area, water type (eg. open coastal, upper estuarine, lowland stream, wetland), and system protection level (ie. systems with high ecological value, slight to moderately disturbed systems, and highly disturbed systems). Parameters with specified values include physico-chemical, biological and riparian function indicators, including:

- *physico-chemical parameters*: ammonium nitrogen, oxidised nitrogen, organic nitrogen, total nitrogen, filterable reactive phosphorus, total phosphorus, Chlorophyll-a, dissolved oxygen, turbidity, Secchi depth, suspended solids, pH, conductivity and temperature

- *biological parameters*: fish diversity (percentage of native species expected, observed/expected, percent alien), invertebrates (number of taxa, PET richness, SIGNAL score), ecological processes (gross primary production, respiration R24,

stable isotope delta ^{13}C, Chlorophyll-a), and nutrient cycling (algal bioassay, stable isotope delta ^{15}N), and seagrass depth where relevant

- *riparian function parameters*: bank vegetation and canopy shade, instream large woody debris, weeds, bed vegetation, stock access.

5.4 STORMWATER GUIDELINE: ENVIRONMENTALLY RELEVANT ACTIVITIES

This guideline aims to protect receiving environments from the impacts of poor stormwater quality and altered stormwater flow. It is not specific to any individual ERA, but provides two levels of guidelines depending on the erosion potential of the site: high and low erosion hazard. Sites with high erosion hazard are required to develop site-specific release limit guidelines for a minimum of four parameters (total suspended solids, pH, electrical conductivity, dissolved oxygen) but up to 23 water quality parameters depending on the ERA (not specified) and generally relating to soil mineral qualities. Sites with low erosion hazard sites are provided with guidelines of the minimum reductions in mean annual loads from unmitigated development for each of the State's different regions for four parameters: total suspended solids, total phosphorus, total nitrogen, and gross pollutants. No guidelines are provided for pathogens or specific hazardous chemicals.

5.5 QUANTITATIVE GUIDELINE COMPARISON

Table 12 provides a comparison of the quantitative guideline values provided in the reviewed documents. It is important to note that the interpretation of guidelines depends on the location, nature and quality of the receiving waters in each instance. For the purposes of comparison, some assumptions have been made to allow the selection of guidelines most relevant to poultry farms in the study area. These assumptions vary across guideline documents and are detailed in the table footnotes.

As mentioned in Section 5, the most effective approach to management of water quality impacts on receiving water environments is through load-based targets. While this is recognised, the majority of targets available in guidelines for comparison purposes were concentrations (as were the grab sample results) so concentrations have been used here for comparative purposes. Further research should be undertaken to understand the load-based pollutant contributions of poultry stormwater.

Comparison of the sampled stormwater quality identifies that both upstream and downstream water quality typically exceeds guideline values, except for some irrigation water uses. This indicates that the general landscape within which poultry farms are situated does not meet guideline requirements and should, theoretically, require treatment before running on to poultry farms if these farms are to also meet the guidelines.

5.6 IMPLICATIONS FOR NEW POULTRY DEVELOPMENTS

Data available to date on poultry stormwater quality indicates that it may be of similar quality to that of other agriculture such as cropping and grazing, and thus is unlikely to meet water quality guidelines without tailored treatment approaches. The neighbouring (upstream) rural landscapes from the study sites appear to also not meet guideline quality, and this should be considered when comparing overall stormwater quality against guideline values. Load

based guidelines specific to the contribution of the farm itself are likely to be the most appropriate approach for helping these developments support local water quality objectives.

TABLE 12 – COMPARISON OF QUANTITATIVE GUIDELINES

Para-meter	Project sampled median (80th percentile) values			Guideline										
				Australian and New Zealand Guidelines for Fresh and Marine Waters			Australian Drinking Water Guidelines	Queensland Water Quality Guidelines (QWG)		Stormwater guideline: Environmentally relevant activities		Seqwater Develop-ment Guidelines	Water Sensitive Urban Design[8]	Poultry drinking water[6]
	Control (A) sites	Shed (B) sites	Down-stream (C) sites	Aquatic eco-systems [1, 2]	Irrigation[2]	Stock drinking water	Drinking water	Upland streams [3]	Drinking water supply storages[4]	High erosion sites	Low erosion sites[7]	Intensive animal husbandry	Urban runoff[7]	Poultry drinking water
Total Nitrogen (mg/L)	2.10 (2.70)	5.25 (6.74)	3.15 (3.82)	0.25–0.50	25–125 ([5])	-	-	0.25	-	Refer to QWG	45%	-	45%	-
Total Phosphorus (mg/L)	0.47 (0.65)	1.40 (2.97)	0.48 (0.72)	0.01–0.05	0.8–12 ([5])	-	-	0.03	-	Refer to QWG	60%	-	60%	-
Suspen-ded solids (mg/L)	49.0 (84.0)	46.5 (97.2)	67.0 (90.0)	-	-	-	-	6	25	50	80%	30 no sample over 45	80%	-
E. Coli/ Faecal coliforms (CFU/100 mL)	2000 (15,300)	11,350 (92,800)	10,650 (21,600)	-	1000–10,000	100	No guideline; Prevent from reaching water sources	-	60	-	-	200 no sample over 1000		0

[1] Based on slightly-moderately disturbed receiving waters
[2] Where ranges are listed, guideline values depend on the nature of the receiving environment (i.e. value and quality of natural environment; crop type, crop tolerance, and soil characteristics for irrigation)
[3] South east region
[4] These guidelines are pre-treatment values for level 1 quality (i.e. limit beyond which treatment plant process changes would be required but customer quality still assured)
[5] Value applicable for up to 20 years (short term) irrigation
[6] This guideline (DAFF 2009a) has been included as some poultry farms are known to reuse stormwater for watering poultry. This guideline only specifies pathogen levels.
[7] Only reduction targets are provided, based on mean annual loads from unmitigated developments
[8] Water Sensitive Urban Design: Technical Design Guidelines for South East Queensland (Moreton Bay Waterways and Catchments Partnership 2006)

6 STORMWATER MANAGEMENT – OPTIONS

A range of stormwater treatment approaches used by poultry and other industries are reviewed in this report. The mix of options that have been adopted by the sampled broiler farms are listed in Table 13. While many of the treatment options reviewed in this report are not represented on the sampled farms, each approach is considered here for potential use by the poultry industry. A key aim of this section, is to provide a snapshot of the approaches available to the industry, and to establish the effectiveness of these for use in the treatment of poultry stormwater.

TABLE 13 – APPLICATION OF MANAGEMENT OPTIONS ACROSS SAMPLED FIELD SITES

Treatment train (in order)	Farm production type			
	Conventional	**Free range**	**Mixed**	**All**
Vegetated filter strips	-	3	-	3
Vegetated filter strips + Retention ponds	1	1	2	4
Vegetated filter strips + Detention basins	1	-	-	1
Retention pond	1	-	-	1
First flush ponds + Vegetated filter strips	1	-	-	1

While many guideline documents provide management option recommendations (see Table 11), the guidelines do not generally discuss removal efficiencies of the recommended treatment systems. Urban guidelines in Queensland require modelling using MUSIC software to determine suitability for each situation. Without removal efficiency information and reliable stormwater quality values for comparison, it is unclear how well the recommended treatment systems are likely to achieve the guideline quality targets in each situation. This can place regulators and developers in a state of uncertainty, and can result in additional costs for developers, or even refusal of developments. Therefore, knowledge of the removal performance of different stormwater treatment systems should be a prime consideration when determining the best option for poultry operations.

Important factors that influence the choice of stormwater treatment system include performance for the range of expected stormwater pollutants, available space, operation and maintenance requirements, and cost. The processes that occur using these systems are complex and involve hydraulic, physical and biochemical mechanisms. Physical processes include particulate removal through infiltration, deposition and filtration. Biochemical processes include nitrogen removal through denitrification, bio-storage (plant and animal uptake), and variations in soil storage (Deletic & Fletcher 2006).

Another important consideration for selection of stormwater management options in Australia is the large proportion of soils that are dispersive (i.e. their structure will collapse and disperse when wet). Approximately one third of Australian soils are dispersive (Northcote & Skene, 1972, as cited in Rengasamy and Olsson (1991)) and thus easily erodible when exposed.

Options for stormwater management reviewed in this section are categorised into two types:

- Low structure options — limited infrastructure and limited excavation required
- Higher structure options — higher levels of infrastructure and excavation required

6.1 LOW STRUCTURE OPTIONS

Low structure options for poultry stormwater management are those that involve manipulation of surface features of the land without significant earthworks or infrastructure. They typically involve the installation of tailored vegetation cover, and include vegetative filter strips and swales.

6.1.1 VEGETATIVE FILTER STRIPS

Vegetative filter strips were used by nine of the ten sampled poultry farms—usually in conjunction with other treatment measures—as shown in Table 13. Vegetative filter strips are grassed or otherwise vegetated strips of ground that are placed at intervals down a slope for stormwater to flow across. They are installed along the contour (perpendicular to the slope) and are designed for sheet (spread) flows, not concentrated runoff (IECA 2010a). They are best suited to sandy soils, but can also achieve some benefit on clay soils (IECA 2010a). Figure 17 shows a partially filled vegetative filter strip and its component parts. These filter strips treat stormwater by slowing it down to soak in, settle out sediment, and allow for adsorption (where the particles stick to the surface of the soil to form a film or sludge). The slowing of the flow occurs because of the resistance of the vegetation, and results in reduced capacity to transport sediment. Sediment first deposits in the backwater, where the water backs up to form a deeper, slow flowing area just before the slowing vegetation, and then the water progresses through the strip at the slower speed. Eventually, the backwater area fills with sediment, which then accumulates across the whole filter strip as it reaches its storage capacity. The storage capacity must be renewed by the continued growth of vegetation above the stored sediment.

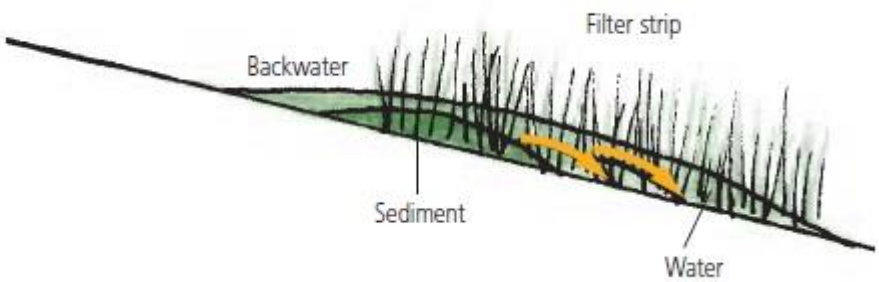


FIGURE 17 – PARTIALLY FILLED VEGETATIVE FILTER STRIP

(Source: Karssies and Prosser 1999)

Filter strips are commonly used in agricultural systems and act as a buffer zone between the pollutant sources and watercourses, protecting the waterways from any sediment, nutrients and bacteria in stormwater runoff. They are simple, low maintenance, and low cost stormwater treatment systems (Deletic & Fletcher 2006).

6.1.2 SWALES

Swales were not used on any of the sampled poultry farms. Swales are broad shallow, vegetated and typically flat-bottomed channels, their key difference from filter strips, that receive flow laterally through vegetated side slopes. They filter stormwater before discharging into nearby watercourses or downstream drainage systems. They remove pollutants in a similar way to vegetative filter strips, by reducing stormwater flow velocities and allowing filtering and sedimentation processes to occur within the swale. Like filter

strips, they require little maintenance and are a cost-effective stormwater treatment system (Deletic & Fletcher 2006, Lucke et al. 2014). Similar to filter strips, slope steepness, runoff velocity and pollutant concentration are extremely important factors to consider when designing vegetated swales.

Where low structure options are insufficient to manage stormwater pollutants, higher structure options are considered.

6.2 HIGHER STRUCTURE OPTIONS

Higher structure options for poultry stormwater management are those that require tailored infrastructure and/or excavation to direct flow and hold stormwater. In urban developments, the most effective hard engineering stormwater management options for addressing suspended solids levels are:

- Bio-retention basins
- High efficiency sediment basins
- Wetlands
- Managed sediment basins/retention ponds

Other higher structure stormwater management options used on poultry farms include unmanaged (i.e. no chemical flocculants added) retention ponds, detention basins, and first flush ponds. No information was available for first flush ponds, but it is assumed that similar constraints apply to these fast, unmanaged ponds as is the case for the other two basins, which the International Erosion Control Association (2010) (IECA 2010c) describe as not effective at settling out soils from areas with more than 10% dispersive soils (i.e. a large proportion of Australian soils as discussed in Section 6.2.8).

6.2.1 BIO-RETENTION SWALES

Water by Design (2014) describe bio-retention systems as shallow depressions that treat stormwater by filtering it through dense vegetation over a filtering base of sand and loam. These systems can be installed in a wide range of sizes and configurations to suit many situations. They are regularly used in urban areas, and include: basins, swales, biopods and street trees. This report reviews bio-retention basins and swales for their potential use by poultry farms.

Bio-retention swales are similar to grassed swales, but include a central channel with a filter material base that extends the pollutant filtering and biological uptake potential by supporting slower flow in the filter material and a small amount of ponding above it (Water by Design 2014). The swale component transports the stormwater to the bio-retention system along the centre of the channel. They are typically vegetated with densely packed sedges and rushes, and can include trees (Water by Design 2014). Figure 18 illustrates the typical components of a bio-retention swale as used in urban streetscapes.

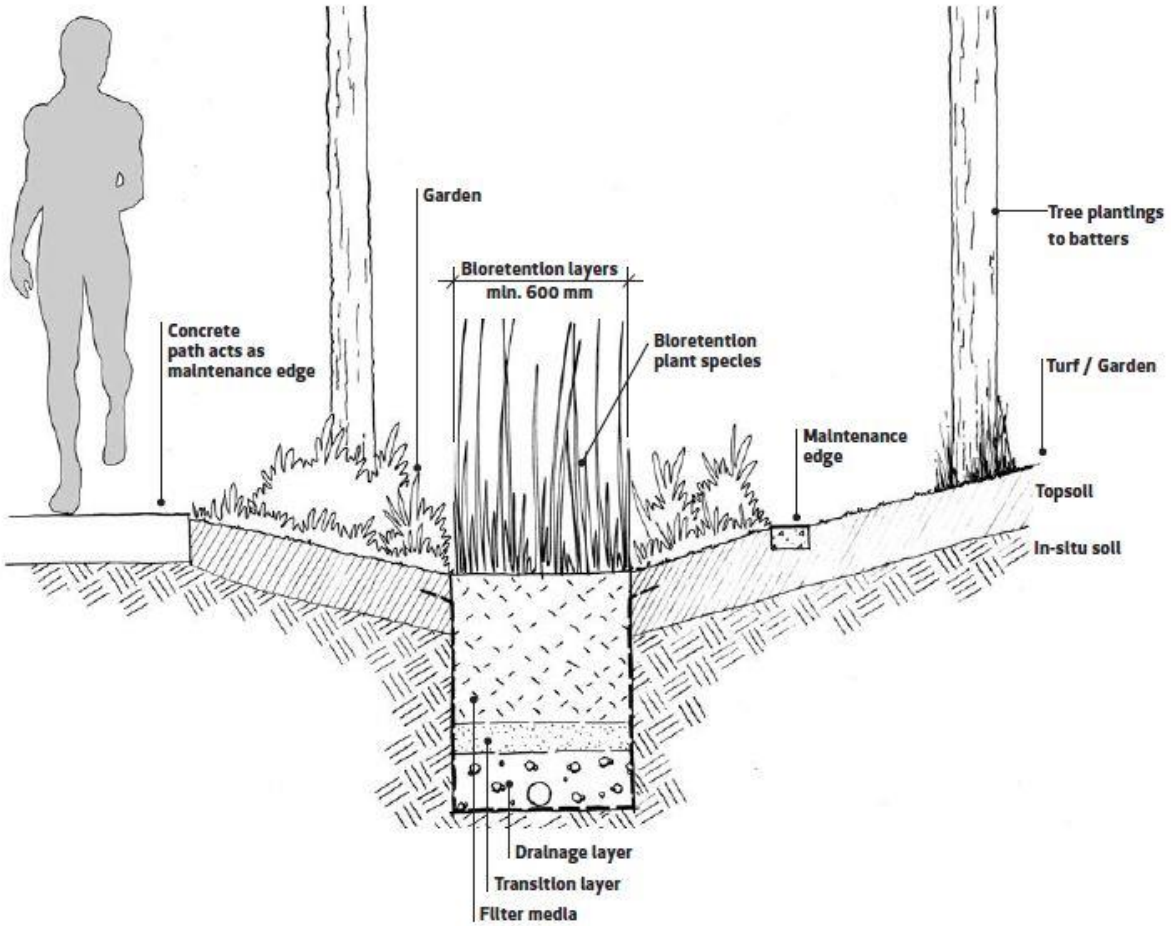


FIGURE 18 – URBAN EXAMPLE OF BIO-RETENTION SWALE

(Source:Water by Design (2014), p. 24)

6.2.2 BIO-RETENTION BASINS

As outlined above, bio-retention basins are one of a suite of bio-retention system configurations. Like the other bio-retention systems, these basins are densely vegetated shallow depressions with a base of biologically active filter material (e.g. soil, sand and gravel). They are designed to allow captured stormwater to drain through the filter materials and vegetation, and thus improve water quality by removing pollutants through of filtration and biological uptake (Water by Design 2014). Figure 19 provides an example of a bio-retention basin as applied in areas with steep slope.

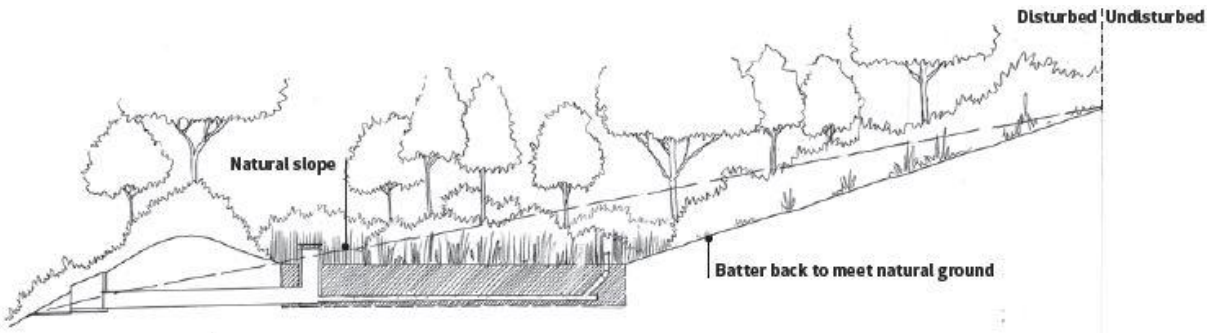


FIGURE 19 – EXAMPLE OF BIO-RETENTION BASIN IN AN AREA WITH STEEP SLOPE

(Source:Water by Design (2014), p. 58)

6.2.3 HIGH EFFICIENCY SEDIMENT BASINS

High efficiency sediment basins are specifically designed to maximise the efficiency of sediment settling processes and are less than half the size of conventional sediment basins (Robson 2013). They include an initial sediment bay for collecting coarse sediment material that settles quickly, and automated chemical treatment with flocculants to settle remaining material (DEHP. 2014). They also typically include a weir structure between sections to assist with the sedimentation of coarse material, have systems that automate the release of the treated water, and retain about 30% of their total volume of water for reuse (Turbid 2016). These basins are particularly effective in areas with dispersive soils, which are otherwise managed by managed retention (wet) basins. They require much less land than these retention basins, 25% of the area required for basins sized against Queensland guidelines, and 50% of the area required for basins sized against NSW guidelines (Robson 2013). They also require no manual treatment or dewatering, which improves performance (Robson 2013). Figure 20 illustrates a typical high efficiency sediment basin layout.

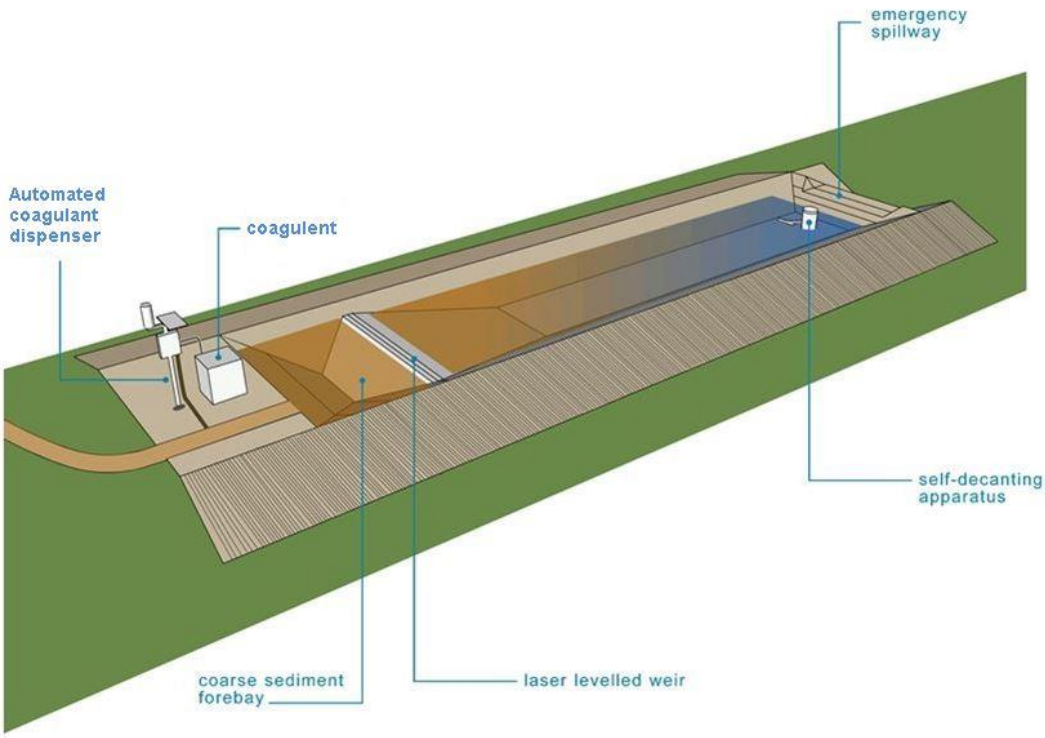


FIGURE 20 – HIGH EFFICIENCY SEDIMENT BASIN

(Image provided courtesy of Turbid)

6.2.4 CONSTRUCTED WETLANDS

Constructed wetlands are shallow, vegetated ponds that use similar processes to bio-retention basins to improve stormwater quality: filtration and biological uptake. They also use advanced sedimentation processes (Moreton Bay Waterways and Catchments Partnership 2006). Figure 21 illustrates the typical components of a constructed wetland.

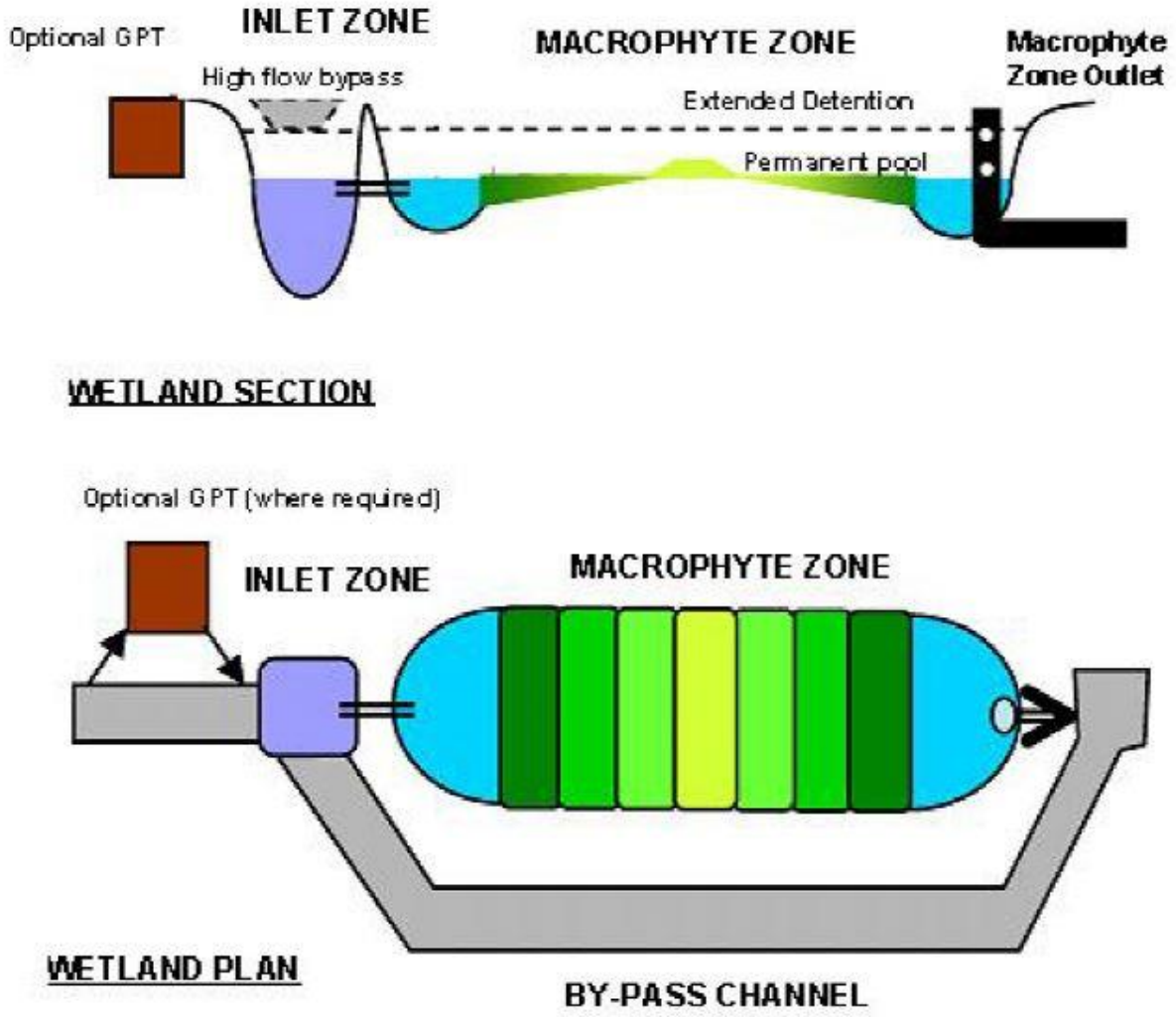


FIGURE 21 – CONSTRUCTED WETLAND TYPICAL LAYOUT

(Note: GPT = Gross pollutant trap; Source:Moreton Bay Waterways and Catchments Partnership (2006), p. 6-2)

6.2.5 RETENTION (WET) PONDS — MANAGED AND UNMANAGED

Retention ponds were used by five of the ten sampled poultry farms, usually in conjunction with vegetative filter strips. Retention ponds contain some water at all times. They retain incoming stormwater; and frequently have vegetated edges. They have been commonly used for stormwater management (Mangangka et al. 2015). The quality of the stored water is improved through the processes of sedimentation, decomposition, solar disinfection, and soil filtration. For areas with less than 10% dispersive soils, no additives are used to facilitate the sedimentation processes (i.e. an unmanaged pond). If more than 10% of soils are dispersive, chemical flocculation is required (i.e. a managed pond) to support settling (IECA 2010c). Retention ponds constantly keep standing water, which allows longer periods for the sediment to settle. The construction costs of retention ponds are relatively high compared with filter strips and swales. Operational and maintenance costs will be ongoing, and also relatively high. These basins generally require large areas due to the high storage requirements. Figure 22 illustrates the main components of retention (wet) ponds.

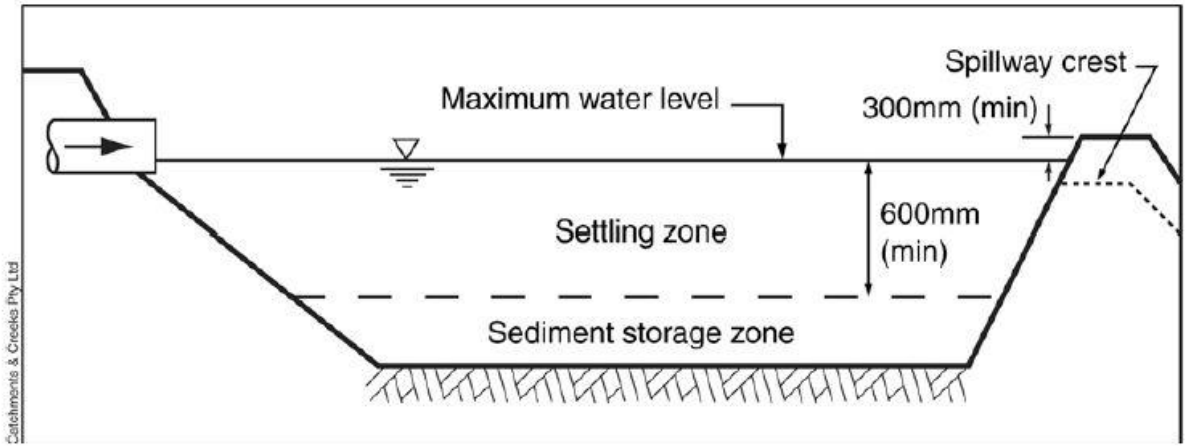


FIGURE 22 – TYPICAL COMPONENTS OF RETENTION (WET) PONDS

(Source: Catchments & Creeks Pty Ltd; in IECA (2010b), p. 5)

6.2.6 DETENTION (DRY) BASINS

Detention basins were used by one of the ten sampled poultry farms, in conjunction with vegetative filter strips. Detention basins usually have a grassed surface, are dry most of the time and able to temporarily store stormwater during wet conditions. They have also been commonly used for stormwater treatment (Mangangka et al. 2015) and use filtration as the primary mechanism for pollutant removal. No additives are used to facilitate the sedimentation processes. These systems filter polluted stormwater through a bottom draining outlet. Costs associate with the construction, operation and maintenance of detention basins is similar to that of retention ponds. These basins, however, generally require less area than retention ponds due to their lower storage volume requirements. These basins are not suitable for areas with more than 10% dispersive soils (IECA 2010c). Figure 23 illustrates the typical components of an unmanaged detention (dry) basin.

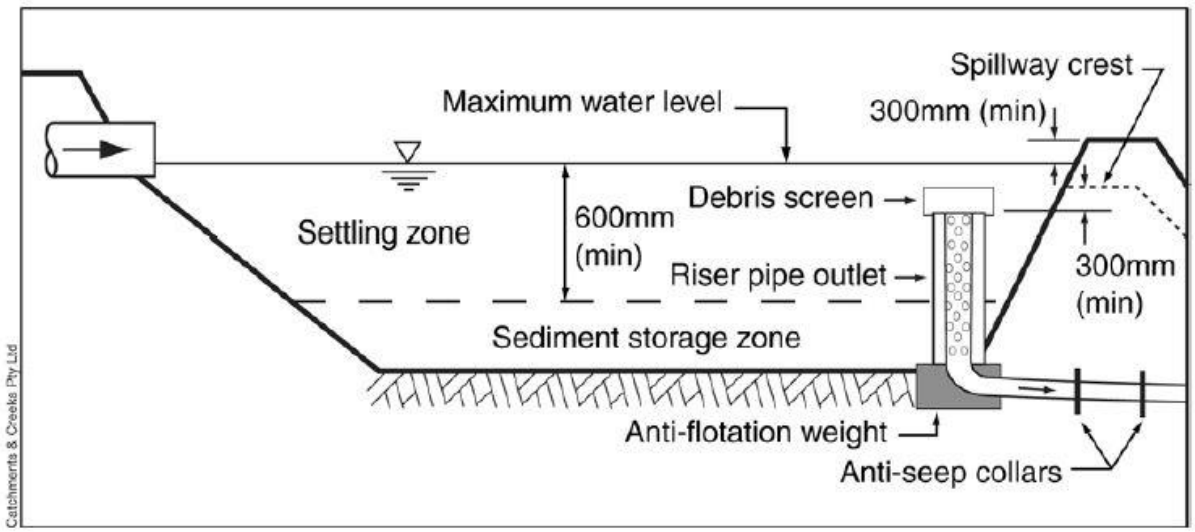


FIGURE 23 – UNMANAGED DETENTION (DRY) BASIN

(Source: Catchments & Creeks Pty Ltd; in IECA (2010b), p. 4)

6.2.7 FIRST FLUSH PONDS

First flush ponds were used by one of the ten sampled poultry farms, in conjunction with vegetative filter strips. These ponds are designed to collect the first flush of stormwater runoff from target areas, and allow any later runoff to pass by. Typically, they are designed to capture the first 20 mm of rainfall from an area (OEH 2015), and are also used to moderate runoff volumes where impervious areas have changed flow volumes to the receiving waters (e.g. Moreton Bay Waterways and Catchments Partnership (2006). Costs associated with construction, operation and maintenance of first flush ponds are similar to those for detention basins and retention ponds, but these ponds require less area due to their lower storage volume requirements. No images were available for illustrating first flush ponds.

6.2.8 SITE INFLUENCES ON HIGHER STRUCTURE OPTION SELECTION

Site influences on management option selection are highlighted in *Water Sensitive Urban Design Technical Design Guidelines for South East Queensland* (Moreton Bay Waterways and Catchments Partnership 2006) as shown in Table 14. These limitations will require consideration when selecting management options within a risk based approach.

TABLE 14 – SITE CONSTRAINTS FOR RELEVANT STORMWATER MANAGEMENT MEASURES

Management option	Steep site	Shallow bedrock	Acid sulfate soils	Low permeability soil (e.g. clay)	High permeability soil (e.g. sand)	High water table	High sediment input	Land availability
Vegetative buffers	C	D	D	✓	✓	D	D	C
Bio-retention swales	C	D	D	✓	✓	D	D	C
Sedimentation [managed retention] basin	C	✓	✓	✓	✓	C	C	C
Bio-retention basins	C	D	D	✓	✓	C	C	C
Constructed wetlands	C	D	C	✓	D	D	D	C

C – Constraint may preclude use
D – Constraint may be overcome through appropriate design
✓ – Generally not a constraint
(Source:Moreton Bay Waterways and Catchments Partnership (2006), Table 1.4, p. 1-9)

The *Water Sensitive Urban Design Technical Design Guidelines* (2006) (Moreton Bay Waterways and Catchments Partnership 2006) does not specify site constraints for detention basins or unmanaged retention basins, vegetative filter strips, or first flush ponds. For the purposes of this project, it was assumed that high efficiency sedimentation basins, detention basins, and first flush ponds would have similar site limitations to those of retention basins, but with moderately less (for high efficiency sedimentation basins and first flush ponds) to slightly less (for detention basins) land required due to their relative differences in storage volume.

6.3 SYSTEM PERFORMANCE

The pollutant removal performance of different stormwater treatment systems is critical information for determining appropriate measures for management of stormwater quality. With each of the different management options affecting stormwater quality through a

different mix of mechanisms (e.g. sedimentation and biochemical processes), different parameters will be more effectively addressed by some options than others.

While the options reviewed in this report cover a breadth of techniques used by poultry and other industries, innovative options should be encouraged. Such options may arise as researchers adapt approaches used in other effluent management sectors - for example, the potential offered by planting crops in free range runs (e.g. fruit trees) or the use of paddock rotation to spell free range areas.

6.3.1 SAMPLE SITES' SYSTEM PERFORMANCE

Due to the lack of sufficient samples across the various management option mixes (see Table 13), it was not possible to statistically assess the performance of each treatment mix from field data. The high variability in values at downstream (C) sites, however, indicates mixed levels of effectiveness in treatment for the different types of production systems. Table 15 provides a summary of the pollutant removal effectiveness of selected treatment options combinations based on the data from sampled farms. Data from both shed and downstream sites were not available for all farms, so the number of samples included in each treatment mix is specified in brackets after each treatment mix column heading.

TABLE 15 – IN-SITU TREATMENT PERFORMANCE (SHED SITE MINUS DOWNSTREAM SITE QUALITY)

Treatment train combination (in process order)		Parameter reduction			
		Total nitrogen (mg/L)	Total phosphorus (mg/L)	Total suspended solids (mg/L)	E. coli (CFU/100 mL)
First flush ponds + Vegetative filter strips (n = 1)	Min	2.7 (45%)	0.96 (53%)	13 (27%)	75000 (75%)
	Max	2.7 (45%)	0.96 (53%)	13 (27%)	75000 (75%)
	Ave	2.7 (45%)	0.96 (53%)	13 (27%)	75000 (75%)
Vegetative filter strips (n = 1 to 2)	Min	-0.6 (-46%)	-0.03 (-25%)	4 (4%)	-6000 (-5400%)
	Max	1.8 (64%)	0.12 (19%)	4 (4%)	-1080 (-38%)
	Ave	0.6 (9%)	0.05 (-3%)	4 (4%)	-3540 (-2719%)
Vegetative filter strips + Detention basins (n = 1)	Min	1.5 (33%)	0.44 (46%)	61 (55%)	-1100 (-550%)
	Max	1.5 (33%)	0.44 (46%)	61 (55%)	-1100 (-550%)
	Ave	1.5 (33%)	0.44 (46%)	61 (55%)	-1100 (-550%)
Vegetative filter strips + Retention ponds (n = 4)	Min	-1.8 (-69%)	-2.73 (-126%)	-77 (-1540%)	1300 (42%)
	Max	9.0 (81%)	3.60 (99%)	30 (61%)	120000 (86%)
	Ave	3.4 (31%)	1.05 (18%)	-20 (-392%)	34708 (66%)

Note: Cell values are the amount of each parameter reduced by the treatment train, and were calculated based on the difference between shed (B) site and downstream (C) site values. Negative values indicate that the stormwater quality was worse after treatment than at the shed site.

As discussed in Section 4.3, most of the sampled farms' treatment measures maintained their stormwater at quality levels similar to that of the surrounding landscape. The instances where this was not found were:

- Phosphorus levels higher downstream than at shed sites for one farm, possibly due to low flow volume.
- Suspended solids levels higher downstream than at shed sites for one farm and not well treated at three others, possibly due to ineffective systems or erosion at intervening sites.

- E. coli levels higher downstream than at shed sites for one farm and not well treated at two others, possibly due to low flow and/or ineffective treatment systems.

6.3.2 PERFORMANCE MEASUREMENTS IN PAST RESEARCH

The *Water Sensitive Urban Design Guidelines Technical Design Guidelines for South East Queensland* (Moreton Bay Waterways and Catchments Partnership 2006) provide a summary table outlining the effectiveness of a range of management options for treatment of stormwater (see Table 16), although it does not address the effectiveness for individual pollutants.

TABLE 16 – EFFECTIVENESS OF OPTIONS FOR STORMWATER QUALITY MANAGEMENT

Management Option*	Water quality treatment effectiveness	Peak flow attenuation of frequent events	Reduction in runoff volume of frequent events
Swales and buffer strips	Medium	Low	Low
Bio-retention swales	High	Medium	Low
Sedimentation basins	Medium	Medium	Low
Bio-retention basins	High	Medium	Low
Constructed wetlands	High	High	Low
Infiltration measures	High	High	High
Sand filters	Medium	Low	Low

* Excludes aquifer storage and recovery as it is a regional scale option, rather than relevant at smaller scales. It should also be noted that this guideline lists sedimentation basins as only suitable at precinct and regional scales. (Source: Adapted from Moreton Bay Waterways and Catchments Partnership (2006), p. 1-9)

A range of individual research articles were identified that provide treatment effectiveness data for selected stormwater management options. The findings reported across all the reviewed articles are summarised in Table 17 and provided in more detail in Appendix C – Detailed Research-Based Stormwater Treatment Option Performance (Table 27 to Table 29). Care should be taken when interpreting these values, as for simplicity the unweighted mean is calculated by the number of reference articles, not the number of studies within them. The ranges may also appear worse (or better) due to seeming outliers, such as one article listing highly variable negative nitrogen treatment performances for bio-retention basins, but all five other articles reporting only positive treatment performances (refer to Appendix B).

TABLE 17 – TREATMENT PERFORMANCE OVERVIEW FROM RESEARCH ARTICLES

Management Option	Percent pollutant reduction identified from previous research[A] Unweighted mean (range)			
	Total nitrogen (% reduction)	Total phosphorus (% reduction)	Total suspended solids (% reduction)	Bacteria (% reduction)
Vegetative filter strips	26% (-19 to 71)	25% (-79 to 88)	69% (5 to 98)	37% (-85 to 83)
Grassed swales	25% (-62 to 99)	31% (-100 to 99)	67% (1 to 99)	-19% (-100 to -13)
Wetland[B]	24% (-49 to 76)	48% (-55 to 100)	72% (-100 to 100)	78% (55 to 97)[C]
Detention (dry) basins[B]	24% (-19 to 43)	20% (-12 to 87)	49% (-1 to 90)	88% (78 to 97)
Bio-retention basins	37% (-79 to 88)	64% (-18 to 90)	78% (28 to 100)	1 log reduction [D] (90%)

[A] Summary of values detailed in Table 27 to Table 29 in Appendix C.
[B] This data is sourced from one meta-analysis report (Center for Watershed Protection 2007), so is not repeated in Appendix C.
[C] This data comes from only 3 studies and should be treated as indicative only.

[D] This data is sourced from Payne et al. (2015).

Many of the reviewed studies focus on phosphorus and nitrogen removal due to the impact of these parameters on waterways, with only two reports discussing bacterial removal performance (Center for Watershed Protection 2007, Leisenring et al. 2014). Their summary data listed in this report relate to faecal coliforms.

Table 17 shows negative effectiveness values for some pollutants for each management option (Center for Watershed Protection 2007, Hatt et al. 2009, Leisenring et al. 2014, Mangangka et al. 2015, Stagge et al. 2012, Yu et al. 2013). In the case of nutrient levels, Mangangka et al. (2015) interpret these negative values as implying the occurrence of nutrient leaching. This occurs when runoff retained in the stormwater treatment system following an earlier rainfall event is released. This runoff can contain elevated concentrations of pollutants due to evapotranspiration. In these cases, replacing the vegetation (filter material) in these systems in a timely manner becomes critical to maintaining their effectiveness.

For the reviewed stormwater treatment systems, total suspended solids removal efficiency ranged from 67% (swales) to 78% (bio-retention basins). Magette et al. (1989) found that the total suspended solids removal performance of biological filtration systems such as vegetative filter strips and grass swales (rather than bio-retention systems) can be extremely variable, depending on factors such as soil characteristics, size of the system, surface runoff, rainfall intensity and slope (Fulazzaky et al. 2013). Total suspended solids removal efficiency is also significantly affected by particle size, with smaller particles not being easily trapped (Bäckström 2002, Deletic 2005). If relatively clean water enters these systems, the performance potential will be limited (Center for Watershed Protection 2007). Conversely, if the total suspended solids storage capacity of the system is limited by mass, then an increase in total suspended solids concentration will lead to a decrease in system performance (Lambrechts et al. 2014). Therefore, it is imperative that the system is sized correctly for the total suspended solids load in order to operate efficiently.

Mangangka et al. (2015) found that longer dry periods combined with a lower filter media moisture content can increase the removal performance of detention basins. In addition, planting of vegetation with a high water absorbing capacity will increase the treatment efficiency. In addition, the performance can be improved by using plants which are most suited to the system in terms of species and growth stage, as different plants and growth stages display varying potentials for total suspended solids removal (Lambrechts et al. 2014).

No specific data was available on the effectiveness of first flush basins, but based on the effectiveness of the other water holding approaches without chemical amendment (i.e. retention and detention basins), and research on the pollutant distribution in first flush water compared with later stormwater, it is believed that these ponds may offer effective management of stormwater pollutants in some situations, but are unlikely to be effective in areas with more than 10% dispersive soils, or where turbidity is a key pollutant of concern. The first flush of stormwater flow has been shown to contain a significantly larger volume of pollutants than later flow, across a range of storm intensities on impervious surfaces (Tiefenthaler & Schiff 2003), but some rainfall events may not have sufficient initial intensity to mobilise the pollutants, leading to delayed flushing or slow release of pollutants. Another consideration when translating this research to the poultry industry, is that Tiefenthaler & Schiff (2003) study was undertaken on an impervious (carpark) surface, which will have faster flushing than may be the case in free range areas and areas around conventional sheds. Depending on the size of the farm, the first flush may also take longer to make its way across the farm and collect pollutants.

Vegetation as a key filter media for many systems, has a limited total suspended solids storage capacity. Making it very important to ensure that there is renewed germination and growth on (and through) the trapped sediment, on an ongoing basis.

Removal of nutrients, such as total phosphorus and total nitrogen, is dependent on hydraulic, physical and biochemical mechanisms. Biochemical mechanisms tend to remove the dissolved components, and an adequate hydraulic retention time is required for these reactions to occur. Vegetative filter strips and swales may not provide a sufficient hydraulic retention time for these reactions (Winston et al. 2012). This could potentially explain their relatively lower nitrogen (25-26.3%) and phosphorus (25.1 to 31%) removal efficiencies, compared with total nitrogen (29-38.7%) and total phosphorus (51.5-54%) removal in detention and bio-retention basins.

Removal of phosphorus is also largely dependent on the total suspended solids removal, as particulate bound forms of phosphorus typically constitute a high percentage of Total Phosphorus in stormwater. Therefore, if the removal of total suspended solids is high, there should be a relatively large proportion of phosphorus removal. Overall, the removal of total phosphorus was better than that of total nitrogen for the systems, except for the vegetative filter strips.

While parameter-specific performance data was not available for high efficiency sediment basins, information comparing overall treatment performance, size and cost were presented by Robson (2013) as shown in Table 18.

TABLE 18 – COMPARISON OF BASIN PERFORMANCE, SIZE AND COST

Comparison characteristic	Queensland guideline requirement[1]	New South Wales guideline requirement[2]	High efficiency basin
Treatment performance (suspended sediment)	Varies on turnaround timeframe: < 65% for >10 days ~ 66% for 10 days ~ 90% for 5 days	~ 65%	≥ 90%
Size[3]	100%	50%	25%
Cost[3]	100% for construction 100% for annual operation	62% for construction 67% for annual operation	39% for construction 33% for annual operation

[1] Based on a 1 in 10 year Average Recurrence Interval, 24 hour storm as per Queensland guideline requirements
[2] Based on 95th percentile in 5 days as per New South Wales guideline requirements
[3] Relative to Queensland guideline requirements
(Source: Robson (2013), p. 10)

Analyses undertaken by Water by Design (2014) of urban stormwater management options provides useful comparison data for the various management options. Figure 24 shows the cost-abatement results (cost per kilogram of pollutant removed) for each of the reviewed management options. The most cost-effective treatments that address all three pollutants (TSS, TP and TN) are swales and bio-retention systems (depending on size and land costs), with wetlands showing more variability for management across parameters compared with the other systems.

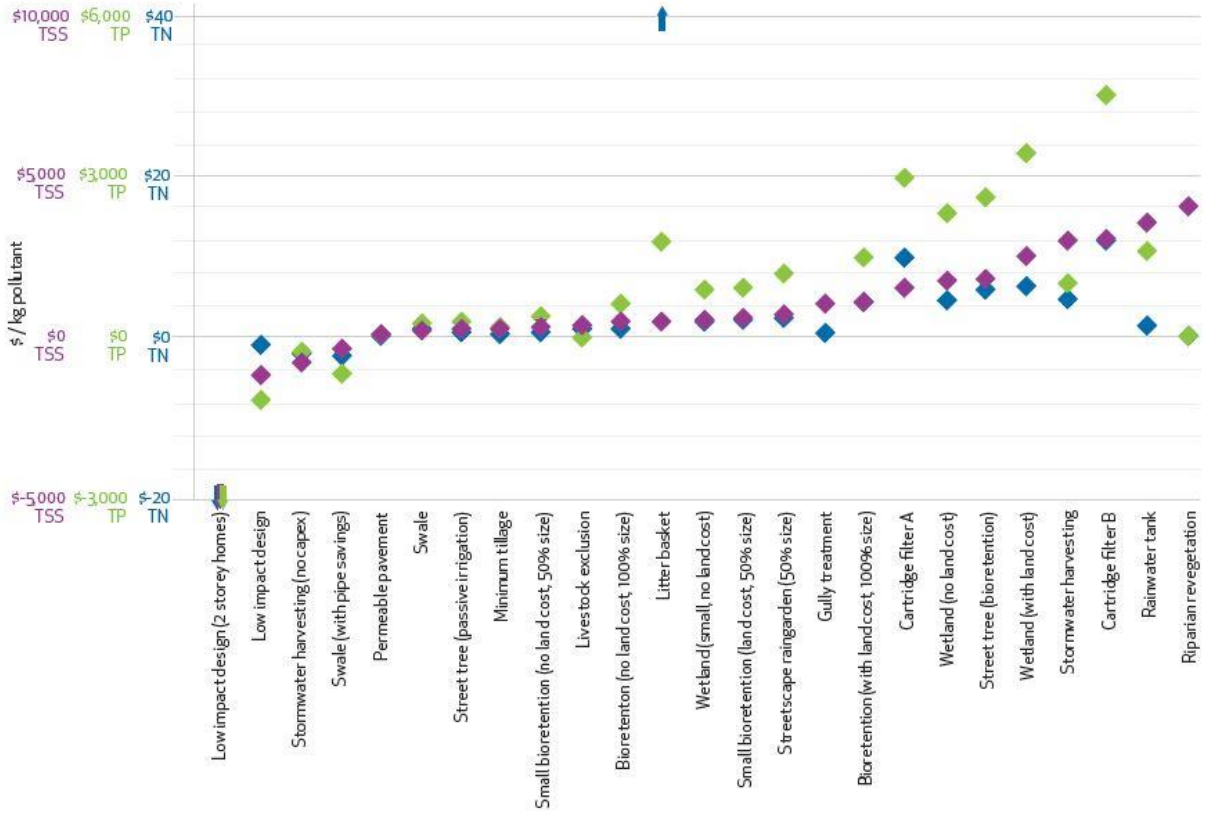


FIGURE 24 –COST-ABATEMENT VALUES FOR STORMWATER MANAGEMENT OPTIONS

(Source:Water by Design (2014), Appendix 5)

6.3.3 IMPLICATIONS FOR NEW POULTRY DEVELOPMENTS

It is clear that there may not be one best treatment solution to cover all pollutants in all situations, however, some solutions provide more consistent outcomes, which may be an attractive alternative. Confirmation of the representative levels of pollutants from poultry farms will be critical in determining which solutions are more likely to support water quality objectives.

If further sampling identifies that **suspended solids** (especially from dispersive soils) is a key pollutant from poultry farms, the most cost-effective options appear to be high efficiency sedimentation basins (particularly for farms with dispersive soils) and bio-retention systems, vegetative filter strips and grassed swales (depending on site soil characteristics). For **phosphorus**, effectiveness is highly variable across management options, but bio-retention basins appear to be the most cost-effective. No parameter-specific data is available for high efficiency sedimentation basins, but these may also provide cost-effective management of phosphorus. For **nitrogen**, none of the systems appear to provide consistently high treatment effectiveness, although bio-retention basins appear to offer slightly higher capability. Similar to phosphorus, the lack of parameter-specific data for high efficiency sedimentation basins should not be assumed to preclude their effectiveness and more research should be undertaken to confirm this. Should **pathogen levels** from free range areas or shed ventilation systems be identified as a pollutant of key concern, the available data indicates that bioretention systems and wetlands may be effective. There is inconsistent data for detention (dry) basins from sample sites and research data, and no data available for pathogen treatment effectiveness high efficiency sedimentation basins.

7 STORMWATER MANAGEMENT – GUIDELINES

There are a wide variety of approaches available to poultry farmers to manage stormwater from their sites, ranging from expensive constructed wetlands to simple vegetated buffers. With the variability in regulatory requirements and guideline recommendations for stormwater management across jurisdictions, it is not always clear which treatment systems should be used to meet the relevant water quality objectives. This section provides a summary and comparison of the management option recommendations provided in the reviewed guideline documents, including:

- National Environmental Management System for the Meat Chicken Industry, Version 2: Part A – Manual of Good Practice for the Meat Chicken Industry
- Best Practice Management for Meat Chicken Production in NSW: Manual 1 – Site Selection & Development
- Guidelines for the Establishment and Operation of Poultry Farms in South Australia
- Operator's Environment Guide for Environmentally Relevant Activity
- Queensland Guidelines for Meat Chicken Farms
- Stormwater Guideline: Environmentally Relevant Activities

While not directly relevant to poultry farms, two additional local guideline documents have been included for their potential for providing transferrable management options:

- *Seqwater Development Guidelines: Development Guidelines for Water Quality Management in Drinking Water Catchments* (Seqwater 2012)—included due to its relevance to the study area
- *Water Sensitive Urban Design Technical Design Guidelines for South East Queensland* (Moreton Bay Waterways and Catchments Partnership 2006) included due to its strong links between water quality and management option design.

7.1 MANUAL OF GOOD PRACTICE FOR THE MEAT CHICKEN INDUSTRY

The *Manual of Good Practice for the Meat Chicken Industry* (McGahan et al. 2015) is not intended to replace environmental codes of practice and guidelines that exist in each state and territory, but to provide the industry, governments and the community with general information on good environmental practices for the meat chicken industry. The Manual makes the following specific management recommendations to minimise potential contamination of surface waters:

- Not situating sheds, spent litter stockpiles, dead bird disposal sites on flood prone areas.
- Bunding around spent litter stockpiles, compost and carcass compost sites. Effluent collection ponds may also need to be constructed if there is significant water storage in these bunded areas.
- Bunding around dead bird disposal pits and trenches.
- Careful storage and application of chemicals to avoid spills and contamination of runoff water.

When spreading spent litter onto crop and pasture land, nutrient export can be minimised by:

- Avoiding land immediately adjacent to streams and watercourses. Most separation/buffer guidelines will specify minimum separation distances, but 50m is recommended as a minimum. The planting of appropriate vegetative buffer strips (grass and trees) can also be useful in intercepting nutrients.
- Avoiding over-application. Matching nutrient application rates to crop uptake, safe storage and allowable losses.
- Avoiding land subject to frequent flooding.

- Avoiding steep slopes with inadequate groundcover. Slopes greater than 10% should be avoided.
- Avoid rocky, slaking or highly erodible land.
- Avoiding highly impermeable soils.

7.2 BEST PRACTICE MANAGEMENT FOR MEAT CHICKEN PRODUCTION IN NSW

The *Best Practice Management for Meat Chicken Production in NSW: Manual 1 – Site Selection & Development* (NSW DPI 2012) proposes management techniques similar to those discussed in the equivalent Queensland guidelines including:

- siting poultry farm facilities away from flood zones, watercourses and major urban water supplies, and on gently sloping land
- installing impermeable shed floors
- isolation of contaminated water from stormwater by using bunds and drains
- using vegetation as a natural buffer/filter.

7.3 GUIDELINES FOR THE ESTABLISHMENT AND OPERATION OF POULTRY FARMS IN SA

The *Guidelines for the Establishment and Operation of Poultry Farms in South Australia* (SAFF 1998) provide planning principles for poultry developments, information on the planning approval process, and management recommendations for all aspects of poultry farming from disease management, to bird welfare, to environmental protection. Recommendations specific to stormwater management include:

- diversion of stormwater around litter stockpiles to prevent nutrients entering surface/groundwater.
- covering litter or storing it in a roofed building with an impermeable floor
- maintaining buffers between watercourses and any spread waste (eg. manure)
- stockpiling waste as far as is practicable from open water sources, and preventing contaminated runoff from reaching nearby waterways
- using diversion drains and/or bunds to prevent stormwater being contaminated by composting areas.

7.4 POLLUTION SOLUTIONS: POULTRY FARMS

The *Pollution Solutions: Poultry Farms – Operator's Environment Guide for Environmentally Relevant Activity* was developed by the Brisbane City Council (2000) in conjunction with the poultry farming industry with the aim of providing information that enables farms to achieve compliance with the *Environmental Protection Act (1994)*. This guideline makes recommendations for managing water quality on poultry farms through:

- separation distances from sheds to dry gullies and channels; and to watercourses, wells and bores
- impermeable, raised and bunded shed floors to isolate them from stormwater
- buffering, and collection and treatment of stormwater, where litter/manure has been reused on-site
- isolation of cleaning water from stormwater for appropriate reuse or disposal
- undercover solid waste storage areas that are cleaned with vacuum cleaners, rather than sweeping or washing down with water, to reduce impacts for groundwater.

7.5 QUEENSLAND GUIDELINES FOR MEAT CHICKEN FARMS

The *Queensland Guidelines for Meat Chicken Farms* (DAFF 2012) provides advice on the planning, design, development and operation of meat chicken farms in Queensland. It is designed to be used as an advice document by both local government and proponents of chicken farms during the approval and development process. It does not address free range poultry farms "as these require a specific site-by-site approach" (DAFF (2012), p. 7), but for conventional broiler farms it provides information on a number of performance criteria and acceptable solutions (i.e. management techniques) to ensure surface and groundwater are not adversely affected by a poultry farm development.

The recommended performance criteria include:

- stormwater peak discharge/runoff volumes are not increased
- existing contours and drainage lines are maintained (as far as is practicable)
- maintenance of environmental value of receiving waters (surface and ground water)
- prevention of stormwater entering sheds/waste storage areas.

Recommended solutions for achievement of the criteria include:

- site selection measures (eg. maintaining buffer distances and avoiding flood zones)
- maintenance of natural drainage lines
- isolation of washdown water for storage in effluent pond and sustainable land application
- installation of elevated shed floors to exclude stormwater
- onsite waste storage and management areas isolated from stormwater by diversion banks and from infiltration by impermeable floors.

7.6 SEQWATER DEVELOPMENT GUIDELINES

The *SEQ Development Guidelines: Development Guidelines for Water Quality Management in Drinking Water Catchments* (Seqwater 2012) are designed for use by developers and government assessors to assist in ensuring water quality outcomes for any land use within the Queensland Bulk Water Supply Authority's catchments. In regards to animal husbandry (including poultry sheds) the guidelines specify:

- sheds, loading areas, stockpiles etc. must be free draining, above high groundwater level, and outside of groundwater recharge areas
- maintain separation distances from watercourses and water supplies (including bores and dams)
- storage and potentially polluted areas are to be bunded or have raised floors, and be isolated from runoff and diverted to appropriate treatment areas.

A series of principles are provided for the selection, design and installation of stormwater management measures:

- minimise site disturbance
- maintain vegetation cover to maximise infiltration
- minimise the area of impervious surfaces and compacted soils
- isolate contaminated stormwater from clean runoff
- slow clean runoff flow to maximise infiltration
- protect natural stormwater flow paths;
- prevent effluent overflow
- capture and treat runoff and sediment from impervious surfaces at the point of source to prevent nutrients other contaminants from entering the environment
- use filter strips in erosion areas and stormwater discharge points

- avoid clearing and earthworks in riparian lands and other sensitive areas
- revegetate disturbed areas
- reuse stormwater onsite.

7.7 STORMWATER GUIDELINE: ENVIRONMENTALLY RELEVANT ACTIVITIES

The *Stormwater Guideline: Environmentally Relevant Activities* (DEHP. 2014) provides a hierarchy of desired management approaches/outcomes starting with a preference for preservation of the natural waterway systems, followed by controlling quality and quantity at the potential contaminant source, then by the use of structural interventions such as retention basins, and finally with the least desired option of management at the receiving waters. Specific management options listed for high erosion hazard sites address disturbed and undisturbed areas, and concentrated flow paths. The main option discussed throughout, however, is the use of managed sediment basins, which best matches the descriptions included here for high efficiency sedimentation basins (i.e. allowing release of water to waterways after settling out of sufficient sediment). A note is made, however, that options for low erosion areas include swales, gross pollutant traps, bio-retention systems, sediment basins, water harvesting and treatment wetlands.

7.8 WATER SENSITIVE URBAN DESIGN TECHNICAL DESIGN GUIDELINES FOR SEQ

The *Water Sensitive Urban Design Technical Design Guidelines for South East Queensland* (Moreton Bay Waterways and Catchments Partnership 2006) provides detailed design information for swales and buffer strips, sedimentation basins, constructed wetlands, infiltration measures, sand filters, and aquifer storage and recovery. It does not provide stormwater management option selection recommendations, however, but is intended for use after the conceptual layouts of developments are completed. For use in rural situations such as poultry developments, the cost-prohibitive and unnecessarily complex option of aquifer storage and recover has been excluded. Two other measures have also been excluded from this review: infiltration measures, which are flow control devices rather than for pollutant removal; and sand filters, which are for filtering fine particulates rather than a broader range of pollutants.

7.9 MANAGEMENT GUIDELINE COMPARISON

A comparison of the management options recommended in the above guidelines relevant to the study area highlights some consistent options that could be considered as ‘standard’ and others that vary across sites (refer to Table 19).

TABLE 19 – MANAGEMENT GUIDELINE RECOMMENDATIONS RELEVANT TO THE STUDY AREA

Guideline Title	Pollution Solutions: Poultry Farms	Queensland Guidelines for Meat Chicken Farms	Stormwater Guideline: Environmentally Relevant Activities	Seqwater Development Guidelines
GENERAL				
Planning	Not specified	Sited in 'Rural' zone of relevant planning scheme Site-specific environmental management plan	Site specific stormwater control plan Addresses prevention, reduction and treatment of contaminants	Site based stormwater management plan All treatment measures will be self-regulatory and low maintenance Use non-structural & non-mechanical management measures where possible
SITING				
Flood zone exclusion	Not specified	1 in 100 year ARI	Not specified	1 in 50 year ARI Sheds at least 2 metres above the seasonal high groundwater level and outside groundwater recharge areas
Buffers/Setbacks	300 m from settlements of more than 10 houses 100 m from well trafficked public roads 20 m from other boundaries of the land and dry gullies and channels 100 m from watercourses, wells and bores 150 m from neighbouring houses 500 m from poultry sites on adjoining land	1000 m from other meat chicken or other poultry farms 5000 m from meat chicken breeder farm 50 m from intermittent watercourse 100 m from permanent watercourse 250 m from well, bore or dam used for water supply 800 m from upper flood margin of urban water supply storage 250 m from wetland or tidal waters 100 m from surface waters not otherwise listed 100 m from property boundary	Not specified	30 m nearest point where effluent might surface 50 m Intermittent watercourse 100 m permanent watercourse 250 m water supply bore/dam 800 m upper flood margin of urban water supply storage
Natural grade	Not specified	Average gradient less than 10%	Not specified	5%

Guideline Title	Pollution Solutions: Poultry Farms	Queensland Guidelines for Meat Chicken Farms	Stormwater Guideline: Environmentally Relevant Activities	Seqwater Development Guidelines
Other	Suitable elevation to provide better drainage Level site, to reduce site preparation costs Large enough to accommodate any future planned expansion	Generally requires minimum of 100 ha to allow for appropriate buffers (see above)	Not specified	Avoid ground water recharge or discharge areas Only on stable land
WASTE/STORM WATER				
Floors	Impervious to water: • compacted clay is the minimum requirement • concrete is best practice Floor levels raised above the surrounding land or suitably bunded	Isolate sheds and waste storage areas from contact with stormwater by elevating shed floors, and installing diversion banks and impermeable bases for waste storage areas Elevate shed bases above natural ground level	Not specified	Impervious floors and bunds to contain spills and wash water
Washing	Use wet/dry vacuum cleaners for general cleaning of floors instead of sweeping and hosing with water	Not specified	Not specified	Minimal water use Dry methods or high pressure water use
Collection	Divert rainwater, irrigation sprinklers and surface water from the sheds	No increase in peak stormwater discharge and volume Natural drainage lines & hydrological regimes maintained as far as practicable Collect & store washdown water in effluent pond Sustainably apply collected effluent to utilisation areas	Stormwater flows concentrated to drainage lines, drains, channels etc. designed for 1 in 10 year ARI storm to avoid erosion, contamination and damage Divert around site where necessary	Suspended solids are isolated Discharge to pits/basins and sumps without overflow Animal areas located on compacted, well drained surfaces for capture of contaminated runoff

Guideline Title	Pollution Solutions: Poultry Farms	Queensland Guidelines for Meat Chicken Farms	Stormwater Guideline: Environmentally Relevant Activities	Seqwater Development Guidelines
Treatment & disposal	Never discharge wastewater to the stormwater system, land or water Washdown and equipment cleaning water sent to the sewerage system under a Trade Waste Permit, or collected for recycling or disposal by a licensed waste removalist	Nutrient, pathogen and contaminant loads do not exceed ANZEC 2000 guidelines and relevant regional plan on stormwater release to environment	Sediment (managed retention) basins for 24-hour storm with 1 in 10 year ARI to settle out sediment Sufficient storage for 50% of upper settling volume Able to store runoff from new event 120 hours after treatment and release of previous event Basin sediment removed and disposed of appropriately Release water quality modelled consistent with MUSIC modelling guideline	Treatment reflects waste water constituents, volumes and concentrations Sufficient storage for first-flush holding in major storms, and for maintenance without release Periodic desludging of storages to maximise settlement
Monitoring & reporting	Not specified	Not specified	Measure and record quality of all release from sediment (managed retention) basins Report releases causing serious and material harm as per Environmental Protection Act	Not specified
SOLID WASTE				
Storage	Surface runoff from land application or composting areas must be collected and treated Store solid wastes undercover so contaminants cannot be washed to stormwater by rain	Spent litter stockpiles covered to avoid nutrient leaching from rainfall Spent litter storage areas: • Impermeable bases to avoid leaching to groundwater • Bunded to prevent stormwater contact • Runoff on area collected • Depth to water table more than 2 meters	Not specified	Use sealed receptacles Minimise stockpiling

Guideline Title	Pollution Solutions: Poultry Farms	Queensland Guidelines for Meat Chicken Farms	Stormwater Guideline: Environmentally Relevant Activities	Seqwater Development Guidelines
Reuse	Spent litter can be reused by: • direct land application (land application is discouraged and must be assessed by a suitably qualified consultant) • off-site removal to commercial processors such as composting/ pelleting operations, the nursery industry and market gardens • composting Litter and manure must not be spread within 20 m of waterways, wetlands, open drains, boundaries or residences.	Litter land application to match plant removal and soil storage capacity, while crop is actively growing or incorporated into bare soil as soon as possible after spreading Application areas should be: • More than 50m from watercourse • More than 250m from tidal waters or wetland • Not frequently flooded • Less than 10% slope • Not rocky or erodible • Not highly impermeable	Not specified	Minimise use as soil conditioner Any composting is aerobic and in accordance with government requirements
Disposal	Dead poultry and associated wastes should not be buried on site without approval from Council Incinerating waste on site is prohibited	Carcass composting areas: • Impermeable bases to avoid leaching to groundwater • Bunded to prevent stormwater contact • Runoff on area collected • Depth to water table more than 2 meters	Not specified	No onsite incineration or burial Removed for disposal by licensed contractor Water table deeper than 5 metres at any carcass disposal facility and diversion drains redirect surface water away
Monitoring & reporting	Monitor manure levels in free range farms and ensure that manure concentrations do not become excessive	Not specified	Not specified	Not specified

7.10 COMPARISON OF QUANTITATIVE GUIDELINES AND SAMPLED STORMWATER QUALITY

The quality of water leaving the sampled poultry farms after treatment is generally similar to that of cropping and grazing land, except for E. coli, for which there was no comparison data. The comparison with MUSIC modelled examples identified that the source quality used in the models are generally similar to the quality of stormwater leaving the sampled poultry farms, however the water quality objectives in the areas covered by the examples (all within the study area) identify that significant reductions in pollutants is expected from poultry farms as regulated developments.

The broad range of stormwater management measures discussed in the guidelines (see Table 19) cover many aspects of site design and management with a focus on avoidance and minimisation of stormwater contamination. They do not generally specify physical stormwater management measures for achieving the desired outcomes past bunding and separation of farm areas from stormwater. This leaves room for interpretation and flexibility in meeting the required outcomes. To achieve the intent of the reviewed guidelines, it will be necessary to incorporate a deeper understanding of the performance potential and risks associated with the various management options, as all are not appropriate for all pollutants, as discussed in Chapter 6.

7.11 IMPLICATIONS FOR NEW POULTRY DEVELOPMENTS

Current guidance on stormwater management does not provide sufficiently targeted advice relevant to treatment performance for the specific risks posed by poultry farms, which can result in uncertainty of appropriateness of options selected and the costs involved.

The application of a risk based approach to stormwater management is likely to improve the effectiveness and efficiency of the development approval process by reducing unnecessary time and expense, and increasing certainty of the targeted nature and consistency of approaches used.

8 STORMWATER RISK ASSESSMENT FRAMEWORK

Risks are usually assessed based on combining the likelihood of occurrence of the risk incident, and the expected consequence of such an incident. Mitigation measures then aim to reduce risk ratings from unacceptable to acceptable levels by reducing the likelihood or consequence (or both) of the risk.

Risk-based frameworks for development assessment are not new to Australia. One example is the Queensland government's approach to development assessment in coastal hazard areas (DEHP 2013). The six-step risk framework used in assessing development risks in coastal hazard areas is:

> "1. Identify if the development site is affected by coastal hazards
> 2. If the site is affected by coastal hazards then determine the nature and extent of the hazard
> 3. Determine the impact of the inundation on the proposed development
> 4. Identify potential mitigation measures
> 5. Asses the viability of mitigation measures both onsite and offsite, taking into account environmental, social and financial factors
> 6. Select preferred mitigation measures." (p. 3)

The risk assessment framework proposed in this report for assessing and managing stormwater risks from poultry farms follows a similar approach to the above, as described below.

8.1 RISK IDENTIFICATION

The key components of stormwater risk from poultry farms are the presence of hazardous contaminants and the likelihood that they might reach a sensitive receiving environment. If no hazardous contaminants were present, there would be no risk irrespective of how sensitive or exposed receiving environments were. Similarly, if there were no exposed, sensitive receiving environments, the level of contaminant would not be of concern. It is the combination of these two components that creates risk.

In the case of broiler farms, site and farm operation characteristics influence both the presence and transport of potential contaminants. The primary potential stormwater contaminant sources and transport mechanisms are listed in Figure 25.

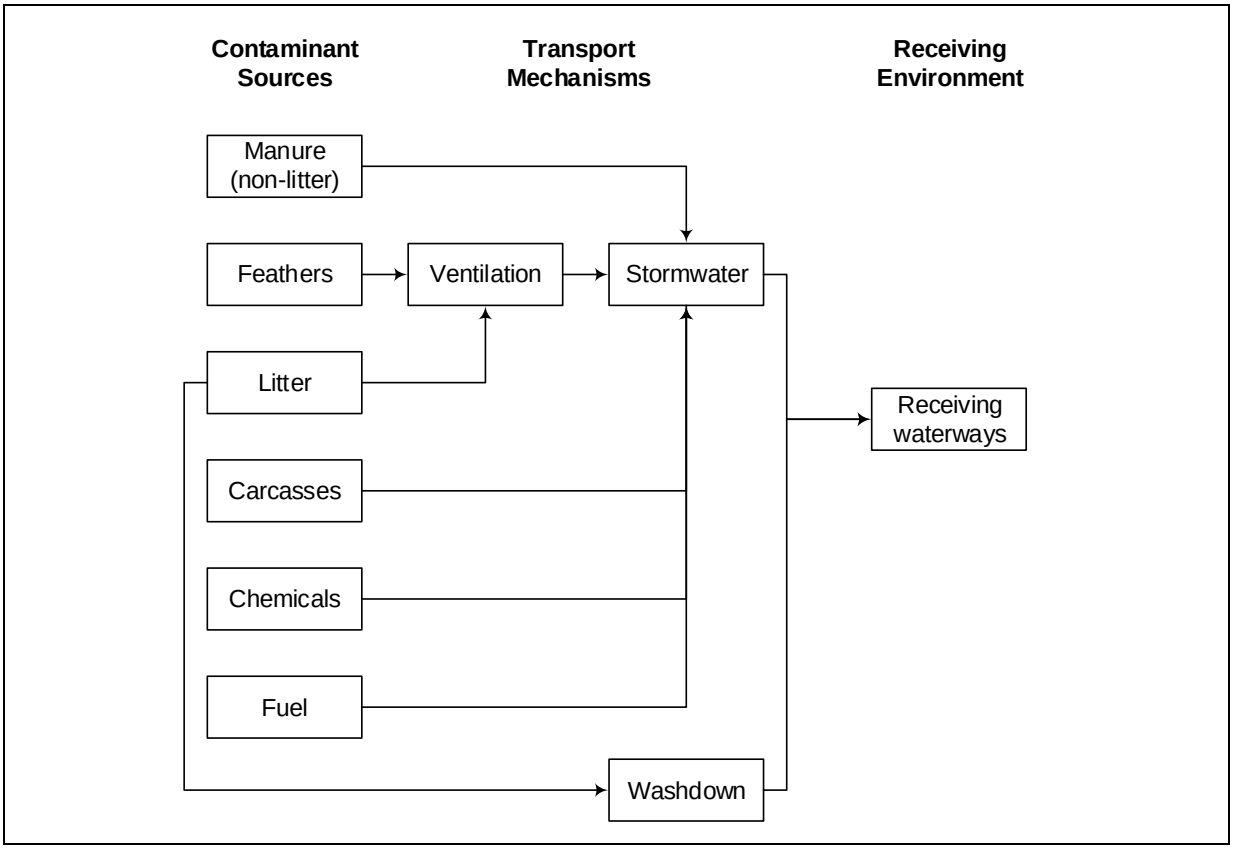


FIGURE 25 – STORMWATER CONTAMINANT SOURCES AND TRANSPORT MECHANISMS

Certain farm operation characteristics are consistently applied across farms, allowing their associated risks to be treated as 'standard', requiring consistent management rather than site-specific levels of mitigation. A list of these standard risks and their usual mitigation approaches is provided in Table 20. By excluding these standard risks, a streamlined, case-specific, two dimensional framework has been developed as the basis of the risk assessment hierarchy including:

- farm factors (site and operations) – category and level (see Table 21)
- nature of receiving environment – sensitivity and exposure (see Table 22)

TABLE 20 – STANDARD BROILER OPERATION RISKS AND MITIGATION MEASURES

Hazard name	Risk Description	Standard Mitigation
Washdown water	Contamination of stormwater by shed and equipment washdown water, negatively affecting downstream water values	• Raised, bunded shed floor isolating shed water from stormwater • Low volume, high pressure washdown system to reduce the amount of residual waste water from cleaning • Ventilation system used to evaporate any washdown water remaining in shed after cleaning
Airborne particles	Contamination of stormwater by airborne particles from shed ventilation system	• Use of tube ventilation rather than open, fan-assisted sheds for improved air movement and temperature control, and reduced pathogen transport
Chemicals and fuel	Contamination of stormwater by chemicals or fuel, negatively affecting downstream water values	• Bunded storage area that excludes contact with stormwater • Emergency response plan in place for spills
Solid waste storage	Contamination of stormwater by carcasses and spent litter, which negatively affects downstream water values	• Carcasses collected and frozen for regular removal by licenced contractor to approved disposal facility, or composted in impermeable, bunded areas isolated from ground and surface waters • Spent litter stored on impervious floors, covered to prevent rainfall leaching, and bunded to prevent stormwater contact

TABLE 21 – VARIABLE RISK FACTORS FROM SITE CHARACTERISTICS AND FARM-SPECIFIC OPERATIONS

Hazard name	Description
Farm Operations	
Contaminants from runs	Potential nutrient and pathogen load from manure and feather material on runs
	Influences selection of management option for best treatment outcome
Other farm practices	Potential nutrient and pathogen load from litter applied to crops on farm
Site Characteristics	
Rainfall	Influences the design of management options (in combination with landform)
Landform (slope and soil type)	Influence runoff speed and potential for picking up contaminants from the soil in the surrounding landscape.
	Influences choice of management options as may limit selection of some options

TABLE 22 – RECEIVING ENVIRONMENT CHARACTERISTICS

Receiving environment	Description
Aquatic ecosystem	Based on ANZECC guidelines categorisation, refer to local water quality guidelines
Irrigation source	Based on crop type as per ANZECC guidelines
Human drinking water source	Refer to Australian Drinking Water Guidelines
Stock drinking water	Based on stock type, refer to ANZECC guidelines
Poultry drinking water	Refer to relevant guidelines

8.2 RISK AND MITIGATION OPTION ASSESSMENT

After identifying risk factors, the assessment process combines these in a way that allows estimation of the overall risk posed by their interaction.

As discussed above, at the coarsest level of risk assessment, stormwater risks are defined by the potential of a farm to produce contaminants in a location where they may come into contact with and be transported by stormwater, and the nature of the receiving environment. Once the level of risk is identified, potential mitigation measures can be assessed for appropriateness to the specific development instance. The nine risk assessment steps proposed for poultry stormwater can be grouped into three stages, as follows.

Stage 1: identify the development characteristics:

1. Identify the production system and operating protocols (including avoidance and minimisation strategies for stormwater contamination
2. Determine the expected stormwater quality
3. Identify landscape characteristics that may influence management option selection

Stage 2: assesses the risks:

4. Identify the nature of the receiving waters
5. Determine the poultry stormwater pollutants of relevance to the receiving waters
6. Determine the level of treatment required to protect the receiving waters from these pollutants

Stage 3: assesses the mitigation options:

7. Identify potential mitigation measures based on effectiveness for the specific pollutants
8. Asses the viability of mitigation measures, taking into account environmental, social and financial factors
9. Select preferred mitigation measures.

8.3 SUGGESTED IMPLEMENTATION

To simplify the assessment process, a guided self-assessment process could be applied to support identification of development risks and options for appropriate risk management. A proposed version of this process is provided in Section 12 (Appendix B – Risk-based Stormwater Assessment Process) that is suggested for testing.

During the early stages of development planning, proponents would be able to use this process and associated checklists to assist them identify stormwater management options appropriate to the level of risk their development would pose. By following each step of the process and considering each issue point, appropriate decisions may be proposed in development applications with structured explanation and representation that supports clear communication and improved understanding between developers and assessors. Detailing the decision process in terms of the checklist's steps, will provide a consistent explanation of reasoning behind stormwater management decisions that may increase the efficiency of the assessment process.

9 CONCLUSIONS AND RECOMMENDATIONS

This project reviewed the stormwater quality across 11 poultry farms in south east Queensland to identify the risks posed by different pollutants. It assessed the levels of total nitrogen, total phosphorus, total suspended solids, and E. coli in the stormwater, and compared these with relevant guidelines and to other land uses. The limited monitoring program indicates poultry stormwater is generally similar to that typical of cropping and grazing land, except for bacteria levels (E. coli), for which there was no comparison data.

Stormwater from the landscapes within which the sampled poultry farms were situated was found to not meet guideline requirements for aquatic ecosystems, placing additional pressure on these farms to meet these guidelines requirements. Some treatment methods were also found to be ineffective at treating certain pollutants (both in-situ on existing farms and in research literature). The most successful treatment options were those that filtered stormwater through vegetation and soil media (bioretention) and treatment systems that held stormwater back to allow pollutants to settle out (i.e. High Efficiency Sedimentation Basins, first flush basins, detention and retention basins, and constructed wetlands). Vegetative filter strips and swales were found to be considerably less effective than the alternatives for most parameters.

The overall risk posed by stormwater from poultry farms is highly dependent on the level of successful adoption of on-farm stormwater contamination avoidance and minimisation measures, as detailed in the numerous national and state guides. Where good on-farm environmental practices are employed, the quality of poultry stormwater can be expected to be comparable to other types of less intensive agriculture (e.g. cropping and grazing). This indicates that many poultry farms should not need significant stormwater treatment prior to release, however, it will be important to identify those developments that may pose risk to their receiving waters. Appropriate options for managing these risks are likely to vary, as not all development sites will be suitable any specific management measures (whether due to biosecurity, financial, space, landscape, or other issues). Innovation should continue to be encouraged and new management options researched.

To support the appropriate selection of tailored methods to treat specific risks associated with poultry farms in different contexts, a risk-based framework was developed. This framework is suitable for use by developers during the early stages of planning, and provides a structure that can be used for documenting the decision process to improve communication of potential risk and mitigation measure selection with assessors. Assessors can also use the framework when reviewing applications, to ensure each step has been adequately addressed for appropriate outcomes in each development instance.

Recommendations stemming from the findings of this project address identified areas of uncertainty (knowledge gaps) and potential areas for procedural improvement of the development approval process (process improvements).

9.1 KNOWLEDGE GAPS

Recommendation 1 Undertake further stormwater monitoring, including event auto-sampling, at a range of poultry sites with different production systems for confirmation of stormwater quality for use in industry stormwater management and modelling (including pathogens, total nitrogen, total phosphorus, and total suspended solids).

Recommendation 2 Undertake auto-sampling of event stormwater quality entering and exiting on-farm stormwater treatments to continuously build the evidence base for treatment performance. This should be done across a broad geography and for a sufficient sample size for each treatment option. In particular, a current paucity of field performance data for High Efficiency Sedimentation basins and first flush basins needs to be addressed.

Recommendation 3 Determine persistence of bacteria in free range runs to determine if outdoor temperatures and natural drying of manure sufficiently reduces pathogen risks.

9.2 PROCESS IMPROVEMENTS

Recommendation 4 Coordinate and streamline poultry stormwater management regulation processes within and across States to improve clarity and certainty for developers, regulators, and the community.

10 REFERENCES

ABS 2013, *Australian Farming in Brief*, ABS Catalogue No. 7106.0, Australian Bureau of Statistics, Canberra, Australia, < http://www.ausstats.abs.gov.au/ausstats/subscriber.nsf/0/013A316AFB16FE6ACA257BCD00166531/$File/finalfarming%20in%20brief%202013.pdf >.

Ackerman, D & Stein, ED 2008, 'Estimating the Variability and Confidence of Land Use and Imperviousness Relationships at a Regional Scale', *Journal of the American Water Resources Association*, vol. 44, no. 4, pp. 996-1008.

ACMF 2013a, *Growing Meat Chickens*, Australian Chicken Meat Federation viewed 24 May 2016, < http://www.chicken.org.au/page.php?id=6#BroilerFarm >.

ACMF 2013b, *Industry Facts and Figures*, Australian Chicken Meat Federation, viewed 19 January 2016, < http://www.chicken.org.au/page.php?id=4 >.

ACMF 2013c, *Location of Farms and Processing Plants*, Australian Chicken Meat Federation, viewed 13 June 2014, < http://www.chicken.org.au/page.php?id=3 >.

ACMF nd-a, *Biosecurity Fact Sheet: Good chicken farming practices make good sense.*, Australian Chicken Meat Federation Inc, viewed, < http://www.chicken.org.au/files/chicken_meat_fact_sheet_01_02_06R.pdf >.

ACMF nd-b, *Significant, Growing and Rewarding*, Australian Chicken Meat Federation Inc, viewed, < http://www.chicken.org.au/files/_system/Document/New%20Growers/MS%2001-244%20ACMF%20EASTER%20A4%20FLYER%20V2%202014.pdf >.

Agriculture Victoria 2008, *Biosecurity Guidelines for Poultry Producers*, Note Number: AG1155, viewed 27 May 2016, < http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/animal-diseases/poultry/biosecurity-guidelines-for-poultry-producers >.

ANZECC 2000, *Australian and New Zealand guidelines for fresh and marine water quality*, National Water Quality Management Strategy - Paper No. 4, vol. 1, Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand., Canberra.

Bäckström, M 2002, 'Sediment transport in grassed swales during simulated runoff events', *Water Science and Technology*, vol. 45, no. 7, pp. 41-49.

Barrett, ME, Keblin, MV, Walsh, PM, Malina Jr, JF & Charbeneau, RJ 1998, *Evaluation of the performance of permanent runoff controls: summary and conclusions*.

Blackall, PJ, Chinivasagam, HN & Ristovski, Z 2010, *Evaluating risks posed by pathogen and dust emissions from meat chicken sheds*, RIRDC Project No. PRJ-000591, RIRDC Publication No. 10/101, September 2010, Rural Industries Research and Development Corporation, Canberra.

Brisbane City Council 2000, *Pollution Solutions: Poultry Farms - Operator's Environmental Guide for Environmentally Relevant Activity 4*, July 2000, viewed 25 May 2016, < http://www.gladstone.qld.gov.au/c/document_library/get_file?uuid=8f89ff57-9909-42fa-bdb1-f323ac4ef5c6&groupId=1570002 >.

Brown, G & Gallagher, E 2015, *Free range chicken farms – odour emissions and nutrient management*, RIRDC Publication No. 15/017, Project No. PRJ-005044, 4 March 2015, Rural Industries Research and Development Corporation, Canberra.

Center for Watershed Protection 2007, *National Pollutant Removal Performance Database*, 3 Edn, September 2007, viewed 24 May 2016, < http://www.stormwaterok.net/CWP%20Documents/CWP-07%20Natl%20Pollutant%20Removal%20Perform%20Database.pdf >.

Chiew, FHS & Scanlon, PJ 2001, *Estimation of Pollutant Concentrations for EMSS Modelling of the South-East Queensland Region*, August 2001, South East Queensland Regional Water Quality Management Strategy, viewed 25 May 2016, < http://healthywaterways.org/u/lib/mob/20141010162643_1eccfb190cf2e9572/2011_pollutantconcentrations-emss-modelling.pdf >.

CRC for Catchment Hydrology 2005, *Music Version 3.0.1 User Manual*, 25 May 2016, viewed 25 May 2016, < http://toolkit.ewater.org.au/Search/Details.aspx?type=doc&id=2000173 >.

DAFF 2009a, *National Farm Biosecurity Manual: Poultry Production*, May 2009, Department of Agriculture, Fisheries and Forestry, Orange, NSW, < http://www.daff.gov.au/__data/assets/pdf_file/0009/1147554/poultry-biosecurity-manual.pdf >.

DAFF 2009b, *National Water Biosecurity Manual: Poultry Production*, August, 2009, Department of Agriculture, Fisheries and Forestry, Moonee Ponds, VIC, < http://farmbiosecurity.com.au/wp-content/uploads/2012/11/National-Water-Biosecurity-Manual-Poultry-Production.pdf >.

DAFF 2012, *Queensland Guidelines* Meat Chicken Farms, Department of Agriculture, Fisheries and Forestry, Australian Government, State of Queensland, < https://www.daf.qld.gov.au/__data/assets/pdf_file/0006/60567/chicken-meat-guidelines.pdf >.

DEHP 2009, *Queensland Water Quality Guidelines*, Department of Environment and Heritage Protection, State of Queensland, < https://www.ehp.qld.gov.au/water/pdf/water-quality-guidelines.pdf >.

DEHP 2013, *Guideline: A risk assessment approach to development assessment in coastal hazard areas*, Department of Environment and Heritage Protection, Brisbane, Australia, viewed 13 June 2016, < https://www.ehp.qld.gov.au/coastal/development/pdf/guideline-risk-assessment-approach.pdf >.

DEHP 2015, *Eligibility criteria and standard conditions for poultry farming (ERA 4)*, 2 Edn, 30 September 2015, Department of Environment and Heritage Protection Government, Brisbane, Australia, viewed 25 May 2016, < http://www.ehp.qld.gov.au/assets/documents/regulation/pr-es-poultry-farming.pdf >.

DEHP. 2014, *Stormwater Guideline: Environmentally Relevant Activities*, Department of Environment and Heritage Protection Government, Brisbane, Australia, viewed 25 May 2016, < https://www.ehp.qld.gov.au/assets/documents/regulation/pr-gl-stormwater-guideline-era.pdf >.

Deletic, A 2005, 'Sediment transport in urban runoff over grassed areas', *Journal of Hydrology*, vol. 301, no. 1-4, pp. 108-122.

Deletic, A & Fletcher, TD 2006, 'Performance of grass filters used for stormwater treatment—a field and modelling study', *Journal of Hydrology*, vol. 317, no. 3, pp. 261-275.

Department of Environment 2004, *Environmental Code of Practice for Poultry Farms in Western Australia*, May 2004, Government of Western Australia, Western Australia, viewed 25 May 2016, < https://www.water.wa.gov.au/__data/assets/pdf_file/0010/5140/47509.pdf >.

Department of Water 2009, *Water quality protection note 36*, Protecting public drinking water source areas February 2009, Government of Western Australia, viewed 24 May 2016, < https://www.water.wa.gov.au/__data/assets/pdf_file/0011/1631/84602.pdf >.

Department of Water 2016, *Water quality protection note no. 25*, Land use compatibility tables for public drinking water source areas, April 2016, Government of Western Australia, viewed 24 May 2016, < https://www.water.wa.gov.au/__data/assets/pdf_file/0014/1733/12441.pdf >.

DILGP 2016a, *State Planning Policy—state interest guideline: Agriculture*, Department of Infrastructure, Local Government and Planning, Queensland.

DILGP 2016b, *State Planning Policy—state interest guideline: Water quality*, Department of Infrastructure, Local Government and Planning, Queensland.

DPI VIC 2009, *Victorian Code for Broiler Farms*, Department of Primary Industries, Victoria, viewed 26 May 2016, < http://agriculture.vic.gov.au/__data/assets/pdf_file/0008/272258/DPI_Broiler_Part1.pdf >.

EDAW 2009, *Urban stormwater - Queensland best practice environmental guidelines 2009 Technical Note: Derivation of design objectives*, Prepared for Environmental Protection Agency, January 2009, EDAW Australia Pty Ltd, viewed 17 January 2012, < http://www.derm.qld.gov.au/register/p03047aa.pdf >.

Environment Protection (Scheduled Premises and Exemptions) Regulations 2007 - S.R. No. 77/2007 2007, State Government of Victoria.

Environment Protection Act 1970, State Government of Victoria.

Environment Protection Act 1993, Government of South Australia.

Environment Protection and Biodiversity Conservation Act 1999, Australian Government.

Environmental (Water Quality) Protection Policy 2003, Government of South Australia.

Environmental Guidance for Planning and Development 2008, *Guidance Statement 33 - Environmental Guidance for Planning and Development*, Environmental Protection Authority, Western Australia viewed 26 May 2008, < http://www.epa.wa.gov.au/Policies_guidelines/EAGs/guidance/Pages/2717_GuidanceStatement33-EnvironmentalGuidancefor.aspx >.

Environmental Management and Pollution Control Act 1994, Department of Primary Industries, Parks, Water and Environment, Tasmania, viewed, < http://epa.tas.gov.au/policy/empca >.

Environmental Planning and Assessment Act 1979, New South Wales Government.

Environmental Protection (Water) Policy 2009, Queensland Government.

Environmental Protection Act 1986, Government of Western Australia.

Environmental Protection Act 1994, Queensland Government.

Environmental Protection Regulation 1998, Queensland Government.

FSA Consulting 2005, *Best practice technical guide for the meat chicken industry in Queensland*, Draft Edn, 21 October 2005, viewed 24 May 2016, < http://www.goodpracticespoultry.org/index.php/documents/chicken-farm/doc_download/12-best-practice-technical-guide-for-the-meat-chicken-industry-in-queensland >.

Fulazzaky, MA, Khamidun, MH & Yusof, B 2013, 'Sediment traps from synthetic construction site stormwater runoff by grassed filter strip', *Journal of Hydrology*, vol. 502, pp. 53-61.

Geosyntec Consultants & Wright Water Engineers 2009, *Urban Stormwater BMP Performance Monitoring*, June 2009, viewed 24 May 2016, < http://www.bmpdatabase.org/Docs/2009%20Stormwater%20BMP%20Monitoring%20Manual%20(Interim%20Ch%201-6,%20App).pdf >.

Great Barrier Reef Marine Park Authority 2010, *Water Quality Guidelines for the Great Barrier Reef Marine Park*, Great Barrier Reef Marine Park Authority, Townsville, Queensland, < http://www.gbrmpa.gov.au/__data/assets/pdf_file/0017/4526/GBRMPA_WQualityGuidelinesGBRMP_RevEdition_2010.pdf >.

Hatt, BE, Fletcher, TD & Deletic, A 2009, 'Hydrologic and pollutant removal performance of stormwater biofiltration systems at the field scale', *Journal of Hydrology*, vol. 365, no. 3-4, pp. 310–321.

IECA 2010a, *Grass Filter Strips: Sediment Control Technique*, 2 Edn, April, 2010, IECA (Australasian), Picton, NSW, viewed 25 May 2016, < http://www.austieca.com.au/documents/item/261 >.

IECA 2010b, *Sediment Basins SB-01*, February 2010, IECA (Australasian), viewed 30 May 2016, < http://www.catchmentsandcreeks.com.au/docs/SD-SB-1.pdf >.

IECA 2010c, *Sediment Basins: Sediment Control Technique*, 1 Edn, April, 2010, IECA (Australasian), Picton, NSW, viewed 25 May 2016, < http://www.austieca.com.au/documents/item/272 >.

Karssies, LE & Prosser, IP 1999, *Guidelines for Riparian Filter Strips fpr Queensland Irrigators*, Technical Report 32/99, September 1999, CSIRO Land and Water, Canberra.

Lambrechts, T, De Braekeleer, C, Fautsch, V, Iserentant, A, Rentmeesters, G, Lutts, S et al. 2014, 'Can vegetative filter strips efficiently trap trace elements during water erosion events? A flume experiment with contaminated sediments', *Ecological Engineering*, vol. 68, pp. 60-64.

Land Use Planning and Approvals Act 1993, Tasmanian Government.

Lee, A & Macarthur, E 2014, *Poultry health - keeping diseases out*, Primefact 141, NSW Department of Primary Industries, viewed 27 May 2016, < http://www.chicken.org.au/files/chicken_meat_fact_sheet_01_02_06R.pdf >.

Leisenring, M, Clary, J & Hobson, P 2014, *International Stormwater Best Management Practices (BMP) Database Pollutant Category Statistical Summary Report*, Solids, Bacteria, Nutrients, and Metals, December 2014, Geosyntec Consultants, Wright Water Engineers,, viewed 24 May 2016, < http://www.bmpdatabase.org/Docs/2014%20Water%20Quality%20Analysis%20Addendum/BMP%20Database%20Categorical_StatisticalSummaryReport_December2014.pdf >.

Lloyd, SD, Fletcher, TD, Wong, THF & Wootton, RM 2001, 'Assessment of Pollutant Removal in a Newly Constructed Bio-retention System', Paper submitted to the *Second South Pacific Stormwater Conference*, Auckland, New Zealand, 27 – 29 June 2001.

Lucke, T, Mohamed, MAK & Tindale, N 2014, 'Pollutant Removal and Hydraulic Reduction Performance of Field Grassed Swales during Runoff Simulation Experiments', *Water*, vol. 6, no. 7, pp. 1887-1904.

Magette, WL, Brinsfield, RB, Palmer, RE & Wood, JD 1989, 'Nutrient and sediment removal by vegetated filter strips', *Transactions of the American Society of Agricultural Engineers*, vol. 32, no. 2, pp. 663-667.

Mangangka, IR, Liu, A, Egodawatta, P & Goonetilleke, A 2015, 'Performance characterisation of a stormwater treatment bioretention basin', *Journal of Environmental Management*, vol. 150, pp. 173-178.

McGahan, EJ, Tucker, RW, Zadow, EN, Wiedemann, SG & Poad, GD 2015, *National Environmental Management System for the Meat Chicken Industry Version 2. Part A – Manual of Good Environmental Practice Publication No 14/100*, Project No. PRJ-005765, December 2011, Rural Industries Research and Development Corporation, Barton ACT.

Moreton Bay Waterways and Catchments Partnership 2006, *Water Sensitive Urban Design Technical Design Guidelines for South East Queensland*, Healthy Waterways, Brisbane.

National Water Quality Management Strategy 2014, *Environmental Protection Regulation 2008*, Queensland Government.

NHMRC 2008, *Guidelines for Managing Risks in Recreational Waters*, National Water Quality Management Strategy, February 2008, National Health and Medical Research Council, viewed 27 May 2016, < https://www.nhmrc.gov.au/_files_nhmrc/publications/attachments/eh38.pdf >.

NHMRC & NRMMC 2011, *Australian Drinking Water Guidelines 6*, National Water Quality Management Strategy, Version 3.2 Updated February 2016 National Health and Medical Research Council and the Natural Resource Management Ministerial Council, Canberra, ACT, < https://www.nhmrc.gov.au/guidelines-publications/eh52 >.

NSW DPI 2012, *Best Practice Management for Meat Chicken Production in NSW*, Manual 1 - Site Selection & Development, September 2012, NSW Department of Primary Industries, Orange, NSW, Orange, NSW, viewed 13 January 2015, < www.dpi.nsw.gov.au >.

OEH 2004, *Environmental Management on the Urban Fringe*, November 2004, Office of Environment and Heritage, NSW, New South Wales, viewed, < http://www.environment.nsw.gov.au/publications/stormwater/040107-environmental-assessment.htm >.

OEH 2015, *Stormwater first flush pollution*, January 2015, Office of Environment and Heritage, New South Wales Government, Sydney, NSW, viewed 30 May 2016, < http://www.environment.nsw.gov.au/water/stormwatermao.htm >.

Passeport, E, Hunt, WF, Line, DE, Smith, RA & Brown, RA 2009, 'Field Study of the Ability of Two Grassed Bioretention Cells to Reduce Storm-Water Runoff Pollution', *Journal of Irrigation and Drainage Engineering*, vol. 135, no. 4, pp. 505-510.

Payne, EGI, Hatt, BE, Deletic, A, Dobbie, MF, McCarthy, DT & Chandrasena, GI 2015, *Adoption Guidelines for Stormwater Biofiltration Systems*, Cooperative Research Centre for Water Sensitive Cities, Melbourne, Australia.

Planning and Development Act 2005, Government of Western Australia.

Poultry Meat Industry Act 1986, New South Wales Government.

Protection of Environment Operations Act 1997, New South Wales Government.

R Core Team 2015, *R: A language and environment for statistical computing version 3.2.3*, R Foundation for Statistical Computing, Vienna, Austria, viewed 14 June 2016, < https://www.R-project.org/ >.

Rengasamy, P & Olsson, K 1991, 'Sodicity and soil structure', *Soil Research*, vol. 29, no. 6, pp. 935-952.

Robson, K 2013, 'High Efficiency Sediment HES Basins', in *Construction and Demolition Landfill Meeting*, Waste Management Association of Australia, viewed 26 May 2016, < http://www.wmaa.asn.au/event-documents/2013cdlf/papers/0808/robson,k.pdf >.

SAFF 1998, *Guidelines for the Establishment and Operation of Poultry Farms in South Australia*, South Australian Farmers Federation, South Australia.

Scott, P, Turner, A, Bibby, S & Chamings, A 2009, *Structure and Dynamics of Australia's Commercial Poultry and Ratite Industries*, December 2009 Department of Agriculture, Fisheries and Forestry, Scolexia Animal and Avian Health Consultancy, Symonston, Canberra, viewed 26 May 2016, < http://www.agriculture.gov.au/SiteCollectionDocuments/animal-plant/animal-health/livestock-movement/structure-poultry-ratite-ind.doc >.

Seqwater 2012, *Seqwater development guidelines for water quality management in drinking water catchments*, July 2012, Seqwater, Brisbane.

Sobsey, MD, Khatib, LA, Hill, VR, Alocilja, E & Pillai, S 2006, 'Pathogens in animal wastes and the impacts of waste management practices on their survival, transport and fate', in *Animal Agriculture and the Environment: National Center for Manure and Animal Waste Management White Papers*, JM Rice, et al. (eds.), St. Joseph, MI, USA, ASABE, pp. 609-666.

Stagge, JH, Davis, AP, Jamil, E & Kim, H 2012, 'Performance of grass swales for improving water quality from highway runoff', *Water Research*, vol. 46, no. 20, pp. 6731–6742.

State Environment Protection Policy (Waters of Victoria) 1988, *No. S13, Gazette 26/2/1988*, State Government of Victoria.

State Policies and Projects Act 1993, Tasmanian Government.

State Policy on Water Quality Management 1997, Tasmanian Government.

Sustainable Planning Act 2009, Office of the Queensland Parliamentary Counsel.

Tiefenthaler, LL & Schiff, KC 2003, 'Effects of rainfall intensity and duration on first flush of stormwater pollutants', in *Southern California Coastal Water Research Project Annual Report 2001-2002*, SB Weisberg and D Elmore (eds.), Westminster, California, pp. 209-215.

Turbid 2016, *High Efficiency Basin Design*, viewed 6 May 2016, < http://www.turbid.com.au/products-services/high-efficiency-basin-design.html >.

Water Act 2000, Office of the Queensland Parliamentary Counsel.

Water by Design 2007, *Water sensitive urban design*, 2 Edn, Developing design objectives for urban development in South East Queensland, 8 November 2007, South East Queensland Healthy Waterways Partnership and Ecological Engineering, Brisbane, viewed 26 May 2016, < http://healthywaterways.org/u/lib/mob/20141014141023_77f2b3fe883ad9676/2007_wsuddesignobjectives.pdf >.

Water by Design 2010, *MUSIC Modelling Guidelines*, 1 Edn, ISBN 978-0-9806278-4-8, SEQ Healthy Waterways Partnership Brisbane, Queensland, viewed 26 May 2016, < http://waterbydesign.com.au/wp-content/uploads/2010/08/MUSIC-Modelling-Guidelines-V1.0-short-version2.pdf >.

Water by Design 2014, *Off-site Stormwater Quality Solutions: Discussion Paper*, 1 Edn, Healthy Waterways Ltd., Brisbane, viewed 26 May 2016, < http://healthywaterways.org/u/lib/mob/20141110112122_17739fe2372e18aa6/20140901-off-site-solutions-discussion-paper-final-website.pdf >.

Water Management Act 1999, Tasmanian Government.

Water Management Act 2000, New South Wales Government.

Waterways Conservation Act 1976, Government of Western Australia.

Waterways Conservation Regulations 1981, Government of Western Australia.

Western Australian Planning Commission 2003, *Statement of Planning Policy No. 2.7: Public Drinking Water Source Policy*.

Western Australian Planning Commission 2006, 'Statement of Planning Policy No. 2.9: Water Resources ', accessed 26 May 2016 < http://www.planning.wa.gov.au/dop_pub_pdf/spp_2_9.pdf >.

Winston, R, Hunt, W, Kennedy, S, Wright, J & Lauffer, M 2012, 'Field Evaluation of Storm-Water Control Measures for Highway Runoff Treatment', *Journal of Environmental Engineering*, vol. 138, no. 1, pp. 101-111.

Yi, Q, Lu, W, Yu, J & Kim, Y 2010, 'Characteristics of nutrient retention in a stormwater wetland during dry and wet days', *Water Science and Technology*, vol. 61, no. 6, pp. 1535-1545.

Yu, J, Yu, H & Xu, L 2013, 'Performance evaluation of various stormwater best management practices', *Environmental Science and Pollution Research*, vol. 20, no. 9, pp. 6160-6171.

11 APPENDIX A – STORMWATER QUALITY ANALYSIS RESULTS

11.1 TOTAL NITROGEN

11.1.1 SAMPLE SITE DIFFERENCES – ALL SAMPLES

A Bartlett's test identified that the variances in total nitrogen values were unequal across site types, so t-tests were used to assess the differences in stormwater total nitrogen levels across sites (irrespective of production system).

Welch two sample t-tests assuming unequal variance, found that the variabilities between total nitrogen values at shed (B) sites compared with both upstream (A) and downstream (C) sites, were significantly larger than the variability within each type of site ($t_{A\&Bsites}$ = -3.069, df = 9.96, p = 0.012, CI_{95} [-5.84, -0.96]; $t_{B\&Csites}$ = -2.391, df = 12.33, p = 0.034, CI_{95} [-5.37, -0.26]; $t_{C\&Asites}$ = -1.054, df = 10.62, p = 0.315, CI_{95} [-1.77, 0.63]).

11.1.1 SAMPLE SITE DIFFERENCES – BY PRODUCTION SYSTEM

A Bartlett's test identified that the variances in total nitrogen values for the different production systems were equal across upstream (A) control sites and downstream (C) sites, but not for shed (B) sites (K^2 = 6.89, df = 2, p = 0.031), so t-tests assuming unequal variances were used for shed sites, and ANOVA tests for the other sites.

An ANOVA test of upstream (A) control site total nitrogen levels across production systems identified that the variability between production systems was not larger than the variability within production systems, $F(2, 6) = 0.575$, $p = 0.591$. A similar test for downstream (C) sites also found that the variability between production systems was not larger than the variability within production systems, $F(2, 5) = 0.271$, $p = 0.773$.

Welch two sample t-tests assuming unequal variance, found that the variabilities between total nitrogen values at shed (B) sites across the different production systems was also not larger than the variability at shed sites within these systems, $t_{Conv\text{-}Free}$ = -0.255, df = 3.139, p = 0.814, CI_{95} [-9.22, 7.82]; $t_{Conv\text{-}Mix}$ = 2.407, df = 1.50, p = 0.178, CI_{95} [-3.41, 7.96]; $t_{Free\text{-}Mix}$ = 1.047, df = 3.52, p = 0.362, CI_{95} [-5.36, 11.31].

11.1.2 SAMPLE SITE DIFFERENCES – WITHIN PRODUCTION SYSTEM

A Bartlett's test identified that the variances in total nitrogen values were equal across site types within each production system, so ANOVA tests were used to assess the differences between site types for each production system.

For *conventional broiler farms*, the variability in total nitrogen between sites was larger than the variability within sites, $F(2,8) = 26.41$, $p = 0.0003$. While upstream (A) and downstream (C) sites' total nitrogen values were not found to be significantly different on conventional farms, shed (B) site values were significantly different than both upstream (A) and downstream (C) sites ($p = 0.003$ and $p = 0.003$, respectively).

For *free range broiler farms*, the variability in total nitrogen between sites was not found to be larger than the variability within sites, $F(2, 7) = 1.712$, $p = 0.248$. A review of the standard deviation of total nitrogen values at free range sites (refer to Table 5) shows that shed (B) site variability is relatively large (SD = 5.42 mg/L) in comparison with upstream control (A) sites (SD = 0.87 mg/L) and downstream (C) sites (SD = 1.59 mg/L).

For *mixed production broiler* farms, the variability in total nitrogen between sites was not found to be larger than the variability within sites, $F(2, 3) = 0.216$, $p = 0.817$. A review of the

standard deviation of total nitrogen values at mixed production sites (refer to Table 5) shows that downstream (C) site variability is relatively large (*SD* = 2.55 mg/L) in comparison with upstream (A) control sites (*SD* = 0.85 mg/L), and somewhat larger than that of shed (B) sites (*SD* = 1.20 mg/L).

11.2 TOTAL PHOSPHORUS

11.2.1 SAMPLE SITE DIFFERENCES – ALL SAMPLES

A Bartlett's test identified that the variances in total phosphorus values were unequal across site types (K^2 = 15.701, *df* = 2, *p* = 0.0004), so t-tests were used to assess the differences in stormwater total phosphorus levels across sites (irrespective of production system).

Welch two sample t-tests assuming unequal variance, found that the variabilities between total phosphorus values at shed (B) sites compared with upstream (A) sites, were significantly larger than the variability within each site type, but both other site combinations showed higher variability within site types rather than between site types ($t_{A\&Bsites}$ = -2.803, *df* = 9.95, *p* = 0.019, CI_{95} [-2.22, -0.25]; $t_{B\&Csites}$ = -1.032, *df* = 13.82, *p* = 0.32, CI_{95} [-2.26, -0.80]; $t_{C\&Asites}$ = -0.875, *df* = 17.43, *p* = 0.409, CI_{95} [-1.85, 0.84]). The relatively large variabilities in total phosphorus values at downstream (C) sites (*SD* = 1.61 mg/L) and shed (B) sites (*SD* = 1.36 mg/L), however, may mask any differences between these sites.

11.2.2 SAMPLE SITE DIFFERENCES – BY PRODUCTION SYSTEM

Bartlett's tests identified that the variances in total phosphorus values for the different production systems were equal across upstream (A) control sites and shed (B) sites, but not for downstream (C) sites ($K^2_{control}$ = 1.95, *df* = 2, *p* = 0.378; K^2_{shed} = 2.33, *df* = 2, *p* = 0.313; $K^2_{downstream}$ = 8.17, *df* = 2, *p* = 0.017), so t-tests assuming unequal variances were used for shed sites, and ANOVA tests for the other sites.

An ANOVA test of upstream (A) control site total phosphorus levels across production systems identified that the variability between production systems was not larger than the variability within production systems, *F*(2, 6) = 0.245, *p* = 0.790. A similar test for shed (B) sites also found that the variability between production systems was not larger than the variability within production systems, *F*(2, 7) = 0.123, *p* = 0.886.

Welch two sample t-tests assuming unequal variance, found that the variabilities between total phosphorus values at shed (B) sites across the different production systems were also not larger than the variability at within these systems, $t_{Conv\text{-}Free}$ = -1.221, *df* = 2.03, *p* = 0.345, CI_{95} [-4.27, 7.71]; $t_{Conv\text{-}Mix}$ = 1.351, *df* = 2.04, *p* = 0.307, CI_{95} [-4.06, 7.87]; $t_{Free\text{-}Mix}$ = 1.044, *df* = 2.22, *p* = 0.397, CI_{95} [-0.51, 0.89].

11.2.3 SAMPLE SITE DIFFERENCES – WITHIN PRODUCTION SYSTEM

A Bartlett's test identified that the variances in total phosphorus values were equal across site types within each production system, so ANOVA tests were used to assess the differences between site types for each production system.

Bartlett's tests identified that the variances in total phosphorus values were unequal across conventional and free range sites, but not for mixed production farm sites ($K^2_{conventional}$ = 10.53, *df* = 2, *p* = 0.005; $K^2_{free\ range}$ = 7.28, *df* = 2, *p* = 0.026; K^2_{mixed} = 4.47, *df* = 2, *p* = 0.107), so t-tests assuming unequal variances were used for conventional and free range farm sites, and an ANOVA test for the mixed production farm sites.

For *conventional broiler farms*, Welch two sample t-tests found the variability in total phosphorus between sites was not larger than the variability within sites (all $p > 0.05$). A review of the standard deviation of total phosphorus values at conventional sites (refer to Table 6) shows that the downstream sites have much higher variability in their total phosphorus levels, which may be masking any differences between the sites. A visual comparison of the mean values indicates that the total phosphorus levels appear to be worse at downstream sites than at the sheds.

For *free range broiler farms*, Welch two sample t-tests found the variability in total phosphorus between sites was not larger than the variability within sites (all $p > 0.05$). A review of the standard deviation of total phosphorus values at free range sites (refer to Table 6) shows that the shed sites have slightly higher variability in their total phosphorus levels, which may be masking any differences between the sites. A visual comparison of the mean values indicates that the total phosphorus levels appear to be slightly higher at the poultry sheds, but not significantly worse at downstream sites than at the control sites.

For *mixed production broiler* farms, the variability in total phosphorus between sites was not found to be larger than the variability within sites, $F(2, 3) = 1.078$, $p = 0.444$. A review of the standard deviation of total phosphorus values at mixed production sites (refer to Table 6) shows that the shed sites have slightly higher variability in their total phosphorus levels, which may be masking any differences between the sites. A visual comparison of the mean values indicates that the total phosphorus levels appear to be slightly higher at the poultry sheds, but not significantly worse at downstream sites than at the control sites.

11.3 TOTAL SUSPENDED SOLIDS

11.3.1 SAMPLE SITE DIFFERENCES – ALL SAMPLES

A Bartlett's test identified that the variances in total suspended solids values were equal across site types ($K^2 = 0.743$, $df = 2$, $p = 0.690$), so ANOVA tests were used to assess the differences in stormwater total suspended solids levels across sites (irrespective of production system).

An ANOVA test found that the variabilities between total suspended solids values at across the different site types were not significantly larger than the variability within each type of site, $F(2, 23) = 0.222$, $p = 0.803$. A review of the variability within sites (refer to Table 7) shows comparable standard deviation values (and similar box sizes in Figure 14), suggesting that suspended solid values are likely to be similar across site types rather than have their differences masked.

11.3.2 SAMPLE SITE DIFFERENCES – BY PRODUCTION SYSTEM

Bartlett's tests identified that the variances in total suspended solids values for the different production systems were equal across all site types (all $p > 0.05$), so ANOVA tests were used for all sites.

An ANOVA test of upstream (A) control site total suspended solids levels across production systems identified that the variability between production systems was not significantly larger than the variability within production systems, $F(2, 6) = 4.482$, $p = 0.065$. As the significance value was close to 0.05, a follow-up Tukey multiple comparisons of means test was undertaken, which identified a slight difference between free range and conventional sites ($p = 0.072$), but with no significant differences between either of these and mixed farms (both $p > 0.10$).

A similar test for downstream (C) sites found that the variability between production systems was larger than the variability within production systems, $F(2, 4) = 9.42$, $p = 0.031$. A follow-

up Tukey multiple comparisons of means test found significant differences between mixed and conventional farms' downstream suspended solids (p = 0.034), and slight difference between free range and conventional farms' downstream suspended solids values (p = 0.076).

For shed (B) sites, however, an ANOVA test found that the variability between production systems was not larger than the variability within production systems, $F(2, 7) = 0.192$, $p = 0.829$.

11.3.3 Sample site differences – within production system

Bartlett's tests identified that the variances in total suspended solids values were equal across site types within each production system (all $p > 0.05$), so ANOVA tests were used to assess the differences between site types for each production system.

For conventional broiler farms, the variability in total suspended solids between sites was not larger than the variability within sites, $F(2, 8) = 1.861$, $p = 0.217$. For free range broiler farms, the variability in total suspended solids between sites was not found to be larger than the variability within sites, $F(2, 6) = 2.001$, $p = 0.216$. For mixed production broiler farms, the variability in total suspended solids between sites was not found to be larger than the variability within sites, $F(2,3) = 1.073$, $p = 0.445$.

11.4 E. Coli

11.4.1 Sample site differences – all samples

A Bartlett's test identified that the variances in total nitrogen values were unequal across site types ($K^2 = 22.75$, $df = 2$, $p < 0.0001$), so t-tests were used to assess the differences in stormwater E. coli levels across sites (irrespective of production system).

Welch two sample t-tests assuming unequal variance, found that the variabilities between E. coli values across sites, were not significantly larger than the variability within each type of site ($t_{A\&Bsites} = -1.850$, $df = 9.93$, $p = 0.094$, CI_{95} [-68148, 6347]; $t_{C\&Bsites} = -1.672$, $df = 10.07$, $p = 0.125$, CI_{95} [-65362, 9290]; $t_{A\&Csites} = -0.525$, $df = 14.69$, $p = 0.607$, CI_{95} [-14509, 8779]). A review of the variability within E. coli values at each site type (refer to Table 8) shows significantly higher variability at shed (B) sites than at upstream (A) and downstream (C) sites (SD_B = 51494 CFU/100 ml, compared with SD_A = 11112 CFU/100 ml and SD_C = 11319 CFU/100 ml).

11.4.2 Sample site differences – by production system

Bartlett's tests identified that the variances in E. coli values for the different production systems were equal across sites (all p > 0.05), so ANOVA tests were applied to compare sites.

An ANOVA test of upstream (A) control site E. coli levels across production systems identified that the variability between production systems was not larger than the variability within production systems, $F_A(2, 6) = 0.135$, $p = 0.876$. Similar tests for downstream (C) sites and shed (B) sites also found that the variability between production systems was not larger than the variability within production systems, $F_C(2, 5) = 0.131$, $p = 0.880$; $F_B(2, 7) = 0.579$, $p = 0.585$.

11.4.3 Sample site differences – within production system

Bartlett's tests identified that the variances in E. coli values were equal across site types within each production system ($K^2_{conventional}$ = 5.90, *df* = 2, *p* = 0.052; $K^2_{freerange}$ = 5.79, *df* = 2, *p* = 0.0553; K^2_{mixed} = 0.98, *df* = 2, *p* = 0.614), so ANOVA tests were used to assess the differences between site types for each production system.

For *conventional broiler farms*, the variability in E. coli between sites was not larger than the variability within sites, $F(2,8) = 0.454$, $p = 0.651$. A comparison of the variability in E. coli values across site types for conventional farms (refer to Table 8) shows much larger variability in shed (B) site values compared with upstream (A) and downstream (C) sites, with little apparent difference between upstream (A) and downstream (C) sites (M_A = 8845 CFU/100 ml, SD_A = 10828 CFU/100 ml; M_B = 27500, SD_B = 48406; M_C = 8957, SD_C = 13899).

For *free range broiler farms*, the variability in E. coli levels between sites was not found to be larger than the variability within sites, $F(2, 7) = 1.486$, $p = 0.290$. A comparison of the variability in E. coli values across site types for free range farms (refer to Table 8) shows much larger variability in shed (B) site values compared with upstream (A) and downstream (C) sites, with little apparent difference between upstream (A) and downstream (C) sites (M_A = 10833 CFU/100 ml, SD_A = 16601 CFU/100 ml; M_B = 61755, SD_B = 65529; M_C = 14367, SD_C = 11533).

For *mixed production broiler* farms, the variability in E. coli levels between sites was not found to be larger than the variability within sites, $F(2, 3) = 0.379$, $p = 0.714$. A comparison of the variability in E. coli values across site types for mixed production farms (refer to Table 8) shows larger variability in shed (B) site values and downstream (C) site values compared with upstream (A) sites, however upstream (A) site E. coli levels for these farms were lower than those of conventional and free range farms, indicating higher quality stormwater in the surrounding landscape. The downstream (C) sites' E. coli levels, were similar to those of free range farms, with lower shed site values at mixed compared with free range farms (M_A = 4900 CFU/100 ml, SD_A = 6505 CFU/100 ml; M_B = 19150, SD_B = 23829; M_C = 11000, SD_C = 14142).

12 APPENDIX B – RISK-BASED STORMWATER ASSESSMENT PROCESS

12.1 PURPOSE

This risk based assessment process has been developed to assist poultry developers, development regulators, and their advisors with:

- the assessment of risks to stormwater quality posed by proposed poultry developments
- the selection of appropriate stormwater management approaches to mitigate the identified risks.

It has been compiled in two forms: an overview as graphical decision trees, and a checklist that provides more detail for consideration at each step.

12.2 HOW TO USE

This risk based framework for stormwater management decision making is intended for use by developers during the early stages of planning, for the assessment of risk and identification of stormwater management options appropriate for the location and nature of their proposed development. The framework provides a structure that can be used for documenting the decision process within development approval documentation to improve consistency of communication of potential risk and mitigation measure selection with assessors. Assessors can also use the framework when reviewing applications, to ensure each step has been adequately addressed for appropriate outcomes in each development instance.

12.3 DECISION TREES

The decision process contains nine steps arranged in three stages.

Stage 1: identify the development characteristics

1. Identify the production system
2. Determine the expected stormwater quality
3. Identify landscape characteristics that may influence management option selection

Stage 2: assesses the risks:

4. Identify the nature of the receiving waters
5. Determine the poultry stormwater pollutants of relevance to the receiving waters
6. Determine the level of treatment required to protect the receiving waters from these pollutants

Stage 3: assesses the mitigation options:

7. Identify potential mitigation measures based on effectiveness for the specific pollutants
8. Asses the viability of mitigation measures, taking into account environmental, social and financial factors
9. Select preferred mitigation measures.

Decision trees are provided to illustrate each of these stages. Stage 1 steps are illustrated in Figure 26, Stage 2 steps in Figure 27, and Stage 3 steps in

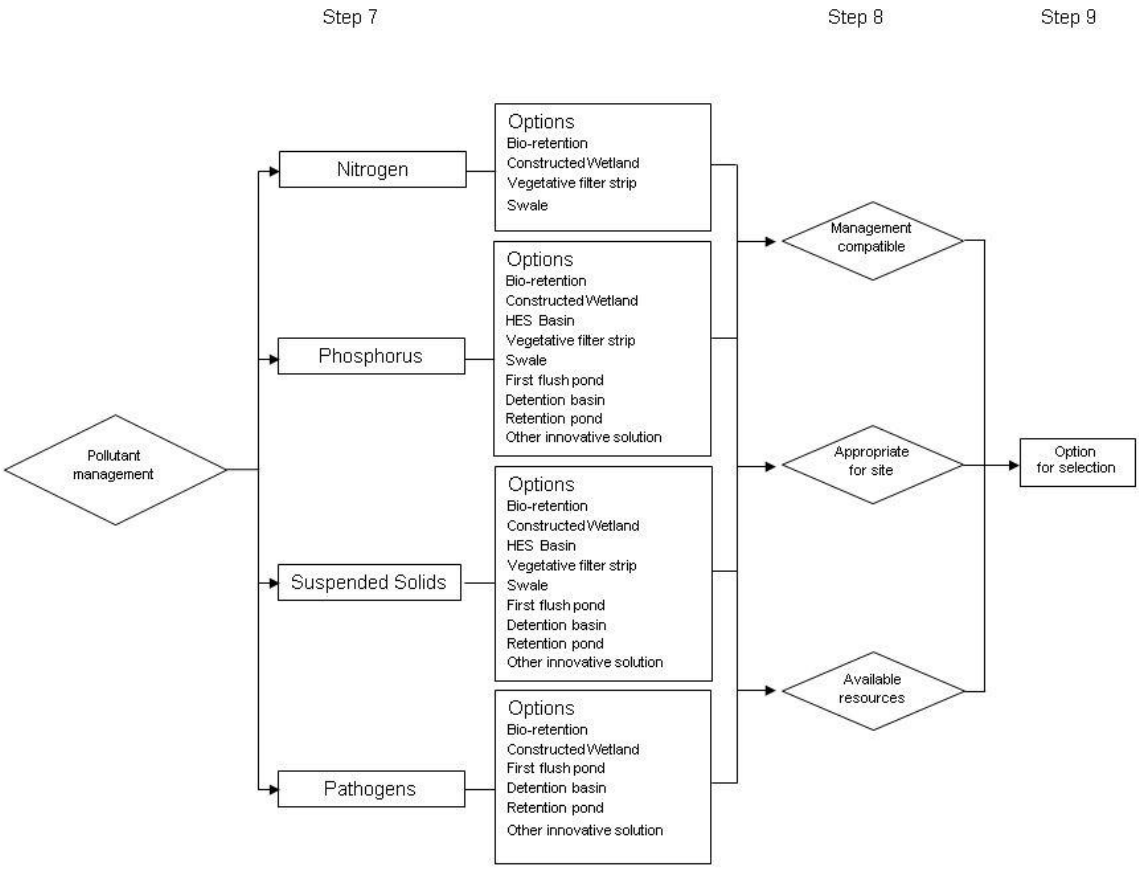


Figure 28.

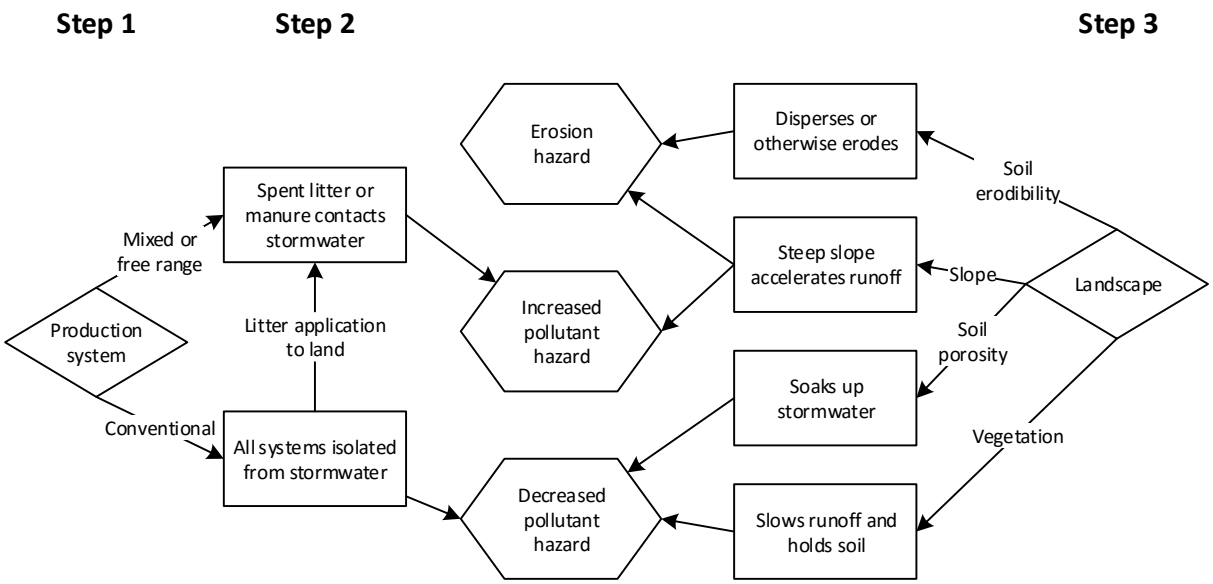


FIGURE 26 – STAGE 1: DEVELOPMENT CHARACTERISTICS (STEPS 1–3)

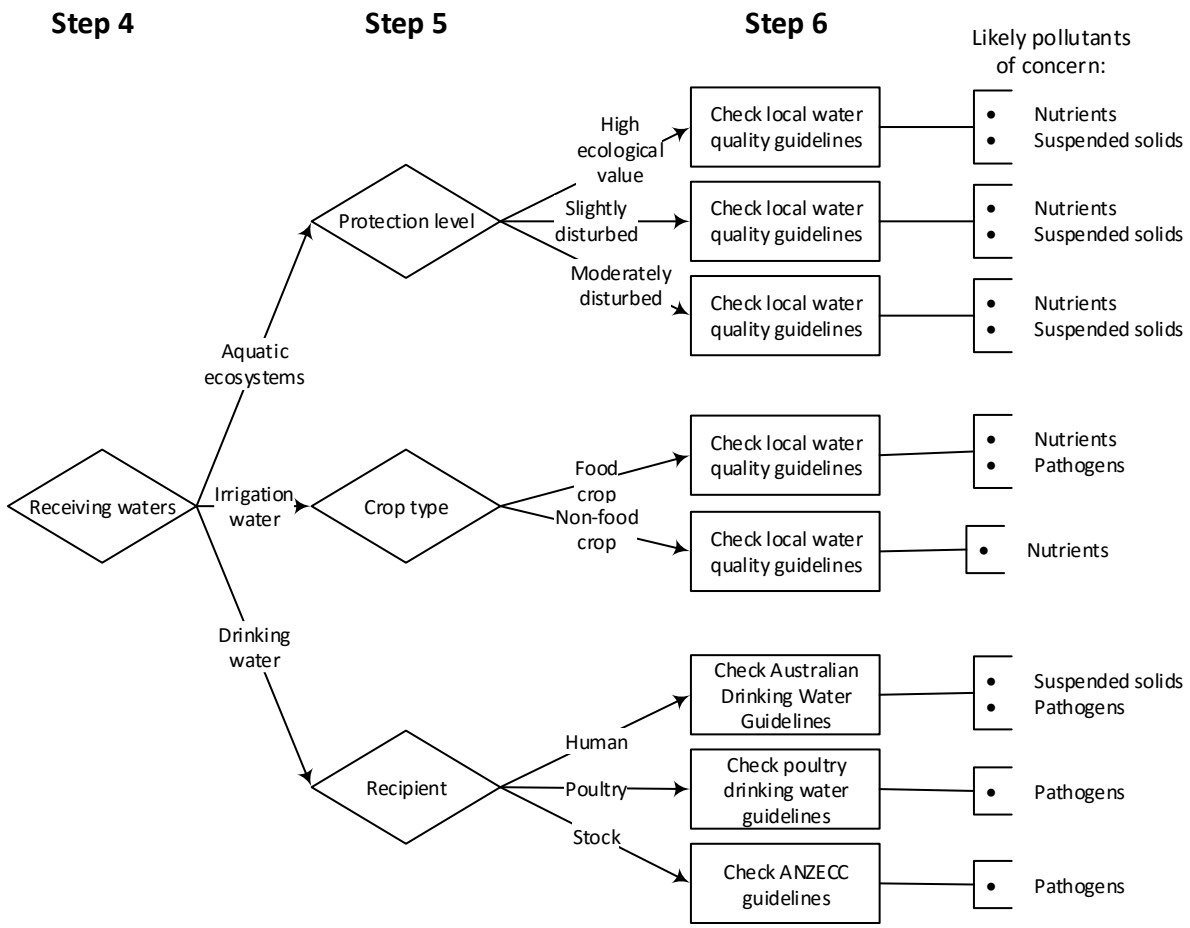


FIGURE 27 – STAGE 2: RISK ASSESSMENT (STEPS 4–6)

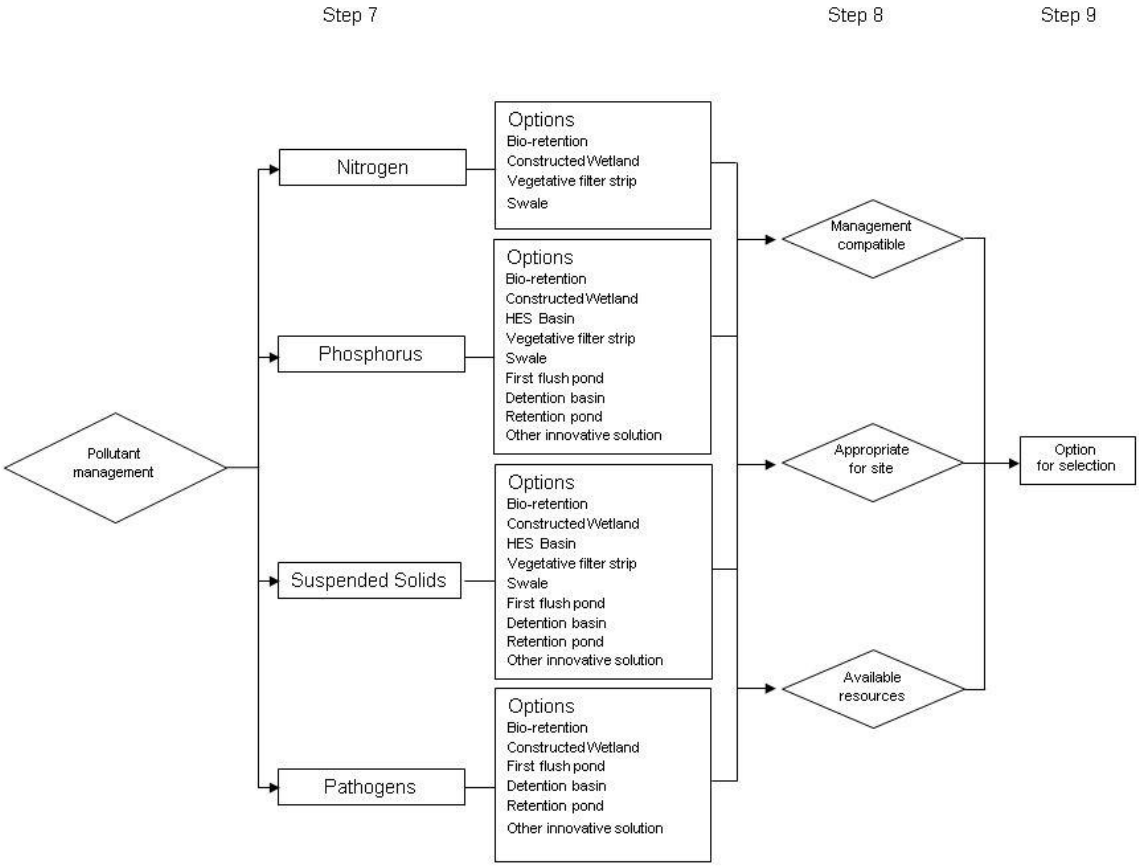


FIGURE 28 – STAGE 3: MITIGATION ASSESSMENT (STEPS 7–9)

(Note that other nutrients may also be relevant for some receiving waters and should be considered on a case by case basis, e.g. calcium and magnesium levels for irrigation water)

12.4 RISK MANAGEMENT CHECKLISTS

A checklist form of the risk assessment process is included to highlight key considerations within each step.

TABLE 23 – STAGE 1 HAZARD ASSESSMENT

Step 1	Step 2	Initial hazard	Step 3	Final hazard[1]
Will the development include free range runs or apply spent litter to land on-farm?	No. If later conversion to free range (or land application of spent litter) is planned, continue as free range to ensure appropriate measures can be implemented when necessary. Conventional farms may contribute suspended solids (and associated nutrients) through soil erosion.	Low (1)	Is the soil highly erodible? If yes, add 1 hazard point: For each 'No' to questions below, add 1 hazard point: Is the site flat? Is soil porous? Is the site well vegetated?	Low (1) to High (5)
	Yes. Free range runs may contribute pathogens, suspended solids and nutrients from runs and soil erosion.	Moderate (3)	For each 'Yes' to questions below, add 1 hazard point: Is soil highly erodible? Is the site steep? For each 'No' to questions below, add 1 hazard point: Is soil porous? Is the site well vegetated?	Moderate (3) to Very high (7)

[1] If the final hazard rating comes from step three (e.g. initial hazard is low, but final hazard is moderate to high), the primary hazard is soil erosion.

TABLE 24 – STAGE 2 VULNERABILITY ASSESSMENT

Step 4		Initial vulnerability	Step 5	Final vulnerability	Step 6	Likely risk pollutants
What is the untreated downstream water used for? (Adopt the relevant response of highest vulnerability)	Aquatic ecosystems Not within 100 m (permanent) Within 50 m (intermittent)	High (3)	High ecological value Slightly disturbed Moderately disturbed	High (3) Moderate (2) Low (1)	Check local water quality guidelines for requirements	Suspended solids and nutrients
	Irrigation Not within 250 m	Low (1)	Food crop Non-food crop	High (3) Low (1)	Check local water quality guidelines for requirements	Suspended solids, nutrients and pathogens
	Drinking Not within 250 m	High (3)	Human Poultry Stock	High (3) High (3) Low (1)	Check relevant guidelines for requirements	Suspended solids and pathogens

Combine hazard and vulnerability to calculate risk as illustrated in Table 25.

TABLE 25 – OVERALL RISK ASSESSMENT

Vulnerability		Hazard						
		Very high		High		Moderate		Low
		7	6	5	4	3	2	1
High	3							
Moderate	2							
Low	1							

Legend:

High risk | Moderate risk | Low risk | (white)

TABLE 26 – STAGE 3 MANAGEMENT OPTION ASSESSMENT

Step 7		Step 8				
			Influence of site constraints			
Risk	**Pollutants of concern**	**Pollutant relevant options[1]**	**Steep site**	**Limited land**	**High sediment input**	**Other constraints**
High or moderate risk (seek expert advice)	Nutrients	Nitrogen only: • Bio-retention • Constructed Wetland • Vegetative filter strip • Swale Nitrogen & phosphorus: • Bio-retention • Constructed Wetland • HES Basin • First flush pond • Detention basin • Retention pond • Other innovative solution	May constrain all options.	May constrain wetlands and detention /retention ponds.	May require pre-treatment (e.g. veg filter strip or swale upstream of higher structure treatment)	Biosecurity risk may limit use of basins/ ponds unless sufficient benefit from water reuse
	Suspended solids	• Bio-retention • Constructed Wetland • HES Basin • Vegetative filter strip • Swale • First flush pond • Detention basin • Retention pond • Other innovative solution	May constrain all options.	May constrain wetlands and detention /retention ponds.	May require pre-treatment (e.g. veg filter strip or swale upstream of higher structure treatment).	Biosecurity risk may limit use of basins/ ponds unless sufficient benefit from water reuse
	Pathogens	• Bio-retention • Constructed Wetland • First flush pond • Detention basin • Retention pond • Other innovative solution	May constrain all options.	May constrain wetlands and detention /retention ponds.	May require pre-treatment (e.g. veg filter strip or swale upstream of higher structure treatment).	Biosecurity risk may limit use of basins/ ponds unless sufficient benefit from water reuse
Low risk	No significant concerns	Maintain good vegetative cover across site	-	-	-	-

[1] The inclusion of an option in this column does not imply it is appropriate or a minimum requirement as a range of approaches should be considered with development-specific characteristics.

13 APPENDIX C – DETAILED RESEARCH-BASED STORMWATER TREATMENT OPTION PERFORMANCE

TABLE 27 – SUMMARY STATISTICS OF VEGETATIVE FILTER STRIPS PERFORMANCE STUDIES (% REMOVAL)

TSS	TP	TN	Bacteria	Reference	Location
86 (8 to 98)	59 (-79 to 88)	32 (17 to 71)	37 (-85 to 83)	Center for Watershed Protection (2007)- based on 166 studies	USA
57 (53 to 61)	-26 (-29 to 24)	15.7 (14.9 to 16.5)	n.d.	Leisenring et al. (2014)- International Stormwater BMP Database - based on 530 studies	International
86 (58 to 87)	39 (34 to 44)	n.d.	n.d.	Barrett et al. (1998)	USA
67.9 (53.1 to 88.2)	n.d.	n.d.	n.d.	Fulazzaky et al. (2013)	Kuala Lumpar, Malaysia
50 (35 to 50)	n.d.	n.d.	n.d.	Lambrechts et al. (2014)	France
66.1 (5.2 to 96.0)	28.5 (-19.4 to 75)	31.2 (-18.5 to 67.6)	n.d.	Yu et al. (2013)	Korea
68.8 (5 to 98)	***25.1 (-79 to 88)***	***26.3 (-19 to 71)***	***37 (-85 to 83)***	***Unweighted mean value (and range) of the listed literature performance data***	

n.d. indicates no data.

TABLE 28 – SUMMARY STATISTICS OF SWALE PERFORMANCE STUDIES (% REMOVAL)

TSS	TP	TN	Bacteria	Reference	Location
81 (18 to 99)	24 (-100 to 72)	56 (8 to 99)	-25 (-100 to -25)	Center for Watershed Protection (2007)- based on 166 studies	USA
22 (21 to 23)	-55 (-59 to -52)	-13 (-13.1 to -12.8)	-12.8 (-13 to -12.6)	Leisenring et al. (2014)- International Stormwater BMP Database - based on 530 studies	International
69	46	56	n.d.	Deletic and Fletcher (2006)	Brisbane, Australia
76	55	50	n.d.	Review of 20 studies by Deletic (2005)	International
74	55	0	n.d.	Lloyd et al. (2001)	Melbourne, Australia
89	n.d.	n.d.	n.d.	Ackerman and Stein (2008)	USA
44.1 to 82.7	-49.2 to 68.7	-25.6 to 85.6	n.d.	Stagge et al. (2012)	USA
47.7 to 94	28.8 to 98.6	13.8 to 23.1	n.d.	Yi et al. (2010)	Taiwan, USA
58.3 (1.3 to 94.2)	35.6 (3.1 to 78.4)	4.5 (-62.1 to 85.9)		Yu et al. (2013)	Korea
67 (1 to 99)	***31 (-100 to 99)***	***25 (-62 to 99)***	***-19 (-100 to -13)***	***Unweighted mean value (and range) of the listed literature performance data***	

n.d. indicates no data.

TABLE 29 – SUMMARY STATISTICS OF BIORETENTION BASIN PERFORMANCE STUDIES (% REMOVAL)

TSS	TP	TN	Bacteria	Reference	Location
95	65	50	90	Payne et al. (2015)	Various, across Australia
76 ± 25	-398 ± 559[A]	-7 ± 72	n.d.	Hatt et al. (2009)	Bioretention Unit 1, Monash University, VIC, Australia
93 ± 4	86 ± 3	37 ± 21	n.d.	Hatt et al. (2009)	Bioretention Unit 2, Monash University, VIC, Australia
n.d.	53	56	n.d.	Passeport et al. (2009)	Bioretention Unit in North, Graham High School, N.C., USA
n.d.	68	47	n.d.	Passeport et al. (2009)	Bioretention Unit in South, Graham High School, N.C., USA
80.8 (67.34 to 94.03)	75.3 (48.9 to 90.18)	47.9 (6.28 to 88.03)	n.d.	Mangangka et al. (2015)	Gold Coast, QLD, Australia
61.8 (27.5 to 85.31)	36.4 (-18.44 to 76.14)	38.7 (1.82 to 84.38)	n.d.	Mangangka et al. (2015)	Gold Coast, QLD, Australia
78% (28 to 100)	***64% (-18 to 90)***	***37% (-79 to 88)***	***n.d.***	***Unweighted mean value (and range) of the listed literature performance data***	

n.d. indicates no data.
[A] this data point was not included within the predicted average mean and range for the listed literature as it was an outlier and skewed the dataset negatively when included.