Detainment Bund^{PS120} ©

A Guideline for on-farm, pasture based, storm water run-off treatment

Photos by C. Mogg

Produced by ***The Phosphorus Mitigation Project Inc.***

John H Paterson, Dylan T. Clarke, Brian Levine

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This guideline includes non-specific advice on:

- phosphorus and sediment loss from pasture
- caveats and criteria for Detainment Bunds^{PS120} (DBs) applications
- site selection process using GIS with LiDAR data
- risk assessment
- Detainment Bund^{PS120} planning and design
- Detainment Bund^{PS120} construction procedures
- operation tips for best performance of pasture based Detainment Bunds^{PS120}

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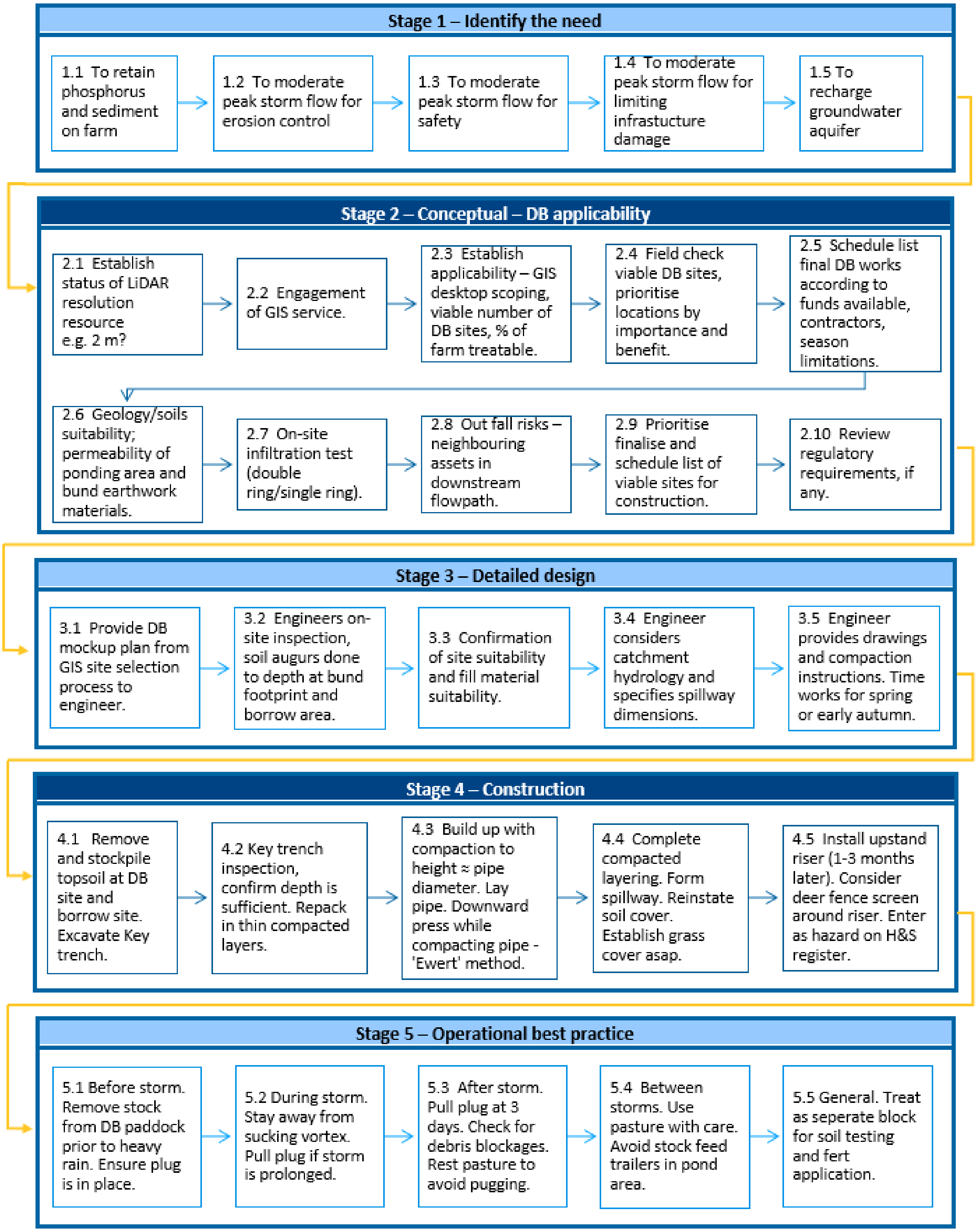
200518 V13

The suffix, ^{PS120}, on the name Detainment Bund, refers to mitigation of phosphorus loss (^{P}), sediment loss (^{S}) and a ponding structure with a minimum storage capacity rated precisely to the area of catchment it services i.e. $\geq$120 m^3 of ponding volume per hectare of catchment.

Detainment Bund^{PS120} construction flowchart



Stage 1 – Identify the need

- 1.1 To retain phosphorus and sediment on farm
- 1.2 To moderate peak storm flow for erosion control
- 1.3 To moderate peak storm flow for safety
- 1.4 To moderate peak storm flow for limiting infrastructure damage
- 1.5 To recharge groundwater aquifer

Stage 2 – Conceptual – DB applicability

- 2.1 Establish status of LiDAR resolution resource e.g. 2 m?
- 2.2 Engagement of GIS service.
- 2.3 Establish applicability – GIS desktop scoping, viable number of DB sites, % of farm treatable.
- 2.4 Field check viable DB sites, prioritise locations by importance and benefit.
- 2.5 Schedule list final DB works according to funds available, contractors, season limitations.
- 2.6 Geology/soils suitability; permeability of ponding area and bund earthwork materials.
- 2.7 On-site infiltration test (double ring/single ring).
- 2.8 Out fall risks – neighbouring assets in downstream flowpath.
- 2.9 Prioritise finalise and schedule list of viable sites for construction.
- 2.10 Review regulatory requirements, if any.

Stage 3 – Detailed design

- 3.1 Provide DB mockup plan from GIS site selection process to engineer.
- 3.2 Engineers on-site inspection, soil augurs done to depth at bund footprint and borrow area.
- 3.3 Confirmation of site suitability and fill material suitability.
- 3.4 Engineer considers catchment hydrology and specifies spillway dimensions.
- 3.5 Engineer provides drawings and compaction instructions. Time works for spring or early autumn.

Stage 4 – Construction

- 4.1 Remove and stockpile topsoil at DB site and borrow site. Excavate Key trench.
- 4.2 Key trench inspection, confirm depth is sufficient. Repack in thin compacted layers.
- 4.3 Build up with compaction to height ≈ pipe diameter. Lay pipe. Downward press while compacting pipe - 'Ewert' method.
- 4.4 Complete compacted layering. Form spillway. Reinstate soil cover. Establish grass cover asap.
- 4.5 Install upstand riser (1-3 months later). Consider deer fence screen around riser. Enter as hazard on H&S register.

Stage 5 – Operational best practice

- 5.1 Before storm. Remove stock from DB paddock prior to heavy rain. Ensure plug is in place.
- 5.2 During storm. Stay away from sucking vortex. Pull plug if storm is prolonged.
- 5.3 After storm. Pull plug at 3 days. Check for debris blockages. Rest pasture to avoid pugging.
- 5.4 Between storms. Use pasture with care. Avoid stock feed trailers in pond area.
- 5.5 General. Treat as seperate block for soil testing and fert application.

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Preface

A message to farmers addressing water quality

Storm water run-off from farmland can be a significant pathway for contaminants (pathogens, nutrients and sediment) to enter fresh water. Once delivered by storm flows, these contaminants can reduce water quality and affect the values of the receiving water bodies. Storm water run-off from farmland can also exacerbate erosion and downstream flooding, resulting in a range of economic, environmental, cultural and safety impacts on farmland itself, or downstream receiving environments.

There are a broad range of possible actions to mitigate these impacts on water quality, with this guideline offering advice on only one mitigation tool. There is a vast range of mitigation tools that include **preventative actions** that reduce the generation and release of contaminants in the first place, and **interceptive actions** that arrest contaminants already on the move, stopping them before they leave the farm and enter waterways.

Preventative actions include change of land use (e.g. retirement of pastoral land into afforestation, wetlands) and continuously improving farm management practices such as best fertiliser and stock management practices and closing down critical source areas for contaminant loss. These preventative actions are vitally important for the environmentally sustainable farmer, and arguably are more effective than later interceptive actions (dealing with the horse that has bolted). This guideline document does not provide detail on the important preventative actions but we do include a summary, (see 'good management practices for minimising phosphorus loss' in Appendix 12).

Interceptive actions are the next best thing to preventative actions and can complement those actions, examples include riparian fences and vegetation buffers, deferred grazing pasture swaths, well-managed wetlands (constructed or natural) and run-off retention infrastructure, such as Detainment Bunds^{PS120} (DBs). Choices about the most appropriate mitigation actions must be informed by established cause-effect relationships (i.e. is there a sensitive receiving environment, what are the critical contaminants, where are they coming from, how are they entering fresh water and what impact are they having?) and the cost-effectiveness of mitigation measures, among other considerations. DBs are only viable (and effective) in locations of certain geophysical characteristics.

It is anticipated that the information presented in this guideline will help you as a farmer make informed decisions about appropriate Detainment Bund^{PS120} installation, and provide you with an additional novel tool in your extensive mitigation toolbox already in action on your farm. We hope you find this DB guideline interesting and useful for continuously improving the environmental sustainability of your farm.

The Authors; John Paterson, Brian Levine, and Dylan Clarke

Foreword

This provisional guideline has been prepared to help pastoral farmers undertake the process of appropriately locating and integrating Detainment Bunds^{PS120} (DBs) into existing good management practices as an additional mitigation tool. The purpose of DBs is to temporarily intercept, hold and treat run-off generated during high intensity storm events in the context of pastoral farms in New Zealand.

Because DBs are generally located on valuable pasture locations, the willingness of farmers to adopt DBs is paramount. To ensure this good will, and to prevent the pasture quality from being compromised, the maximum pasture inundation time is limited to three days and solely controlled at the farmer's discretion for releasing any residual pond water. The desired outcomes are improved water quality, improved farm environmental sustainability and multiple other downstream benefits for the wider community. The process illustrated in these DB guidelines includes engagement of expertise for selection of appropriate sites, assessment of risks, DB design and supervision of the construction.

These guidelines reflects many years of experience with DBs and the findings of two applied science research projects. It contains the collective best judgement and knowledge of the authors together with the experiences of the many farmers engaged, who have had hands on experience operating nearly 30 DBs over the last 10 years. Publication of this guideline has been enabled by the Phosphorus Mitigation Project Inc. (PMP) led by a governance group of farmers, and implemented by the researchers, the selected science advisory team and the project's sponsors (see Appendix 16 for full acknowledgements). If your farm has suitable topography and suitable soils for DBs, I strongly recommend you carefully read this guideline and consider DB installations.

Lachlan Mckenzie, Dairy farmer, Chairman of the Phosphorus Mitigation Project Inc. governance group.

Disclaimer

All reasonable effort has been made to offer complete, current, accurate and practical information throughout this guideline. This set of guidelines is based on research and field testing carried out in Bay of Plenty and the performance results achieved there may not be applicable in all types of terrain and soils. Further research is pending for DBs on other soil types and additional mitigation benefits e.g. E.coli.

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Detainment Bund^{PS120} © (2019) definition and caveats

Definition

There are many types of structures that can be built across a farm valley to impound water for various purposes and a plethora of names to describe them. Some of the names of these types of structures include; storm water retention dam, detention dam, decanting dams, water supply reservoir, duck pond, sediment trap, sediment retention weirs, sediment retention pond, holding pond, settling pond, silt trap, irrigation reservoir, diversion dam, stock water dam, etc. Many of these names have strong connotations to specific purposes and regulatory requirements. We stress that **Detainment Bunds^{PS120} are not dams.** DBs are pasture areas that occasionally hold water whereas dams are usually holding water.

The name **Detainment Bund^{PS120}** (DB) is a descriptive brand name deliberately coined in 2019 by the Phosphorus Mitigation Project Inc. to provide unequivocal association of DBs to the caveats that apply with the use of this name. This is to avoid confusion with any other type of water interception or water storage structure. It also provides greater assurance of performance and mitigation accountability return to farmers/land owners for their investment in the treatment of their storm water run-off when targeting contaminant reductions to achieve water quality outcomes.

The suffix, **^{PS120}**, refers to mitigation of phosphorus loss (^{P}), sediment loss (^{S}) and a ponding structure with a minimum storage capacity rated to the catchment area it services i.e. ≥120 m³ of ponding volume per hectare of catchment.

Caveats

Caveats intrinsic with the name **Detainment Bund^{PS120}** include:

- primary purpose is to mitigate contaminant loads in storm water run-off,
- targeted contaminants are phosphorus and sediment,
- located on storm water flow paths on farm pasture,
- temporary ponding (less than three days per run-off event),
- application to small catchments <42 hectares,
- attainment of a minimum threshold storage:catchment ratio of ≥120 m³ per hectare,
- volume of storm water held is <5,000 m³, and
- no significant compromise to farm productivity in the DB footprint and ponding area.

Figure 1 A Detainment Bund^{PS120} starting to fill during a run-off event. Lake Rotorua catchment.

Introduction - A decade of trials

From 2010 to 2020 around 30 Detainment Bunds^{PS120} (DBs) have been built on farms in the Lake Rotorua district, most in partnership with Bay of Plenty Regional Council (BOPRC). These guidelines summarises the valuable experiences of the many farmers now operating DBs and the knowledge gained during DB construction over this 10 year period. As well as the host farmers, dozens of people and many organisations have contributed to the knowledge summarised in this Guideline.

The numerous individuals we are indebted to are listed by group in Appendix 16. There will certainly be others who we have failed to mention and we sincerely thank them also for their contribution. The key participant groups were; the Pioneer Farmers, the PMP Inc. Governance Group, the Science Advisory Team and the Science Supervisors. There have been two stages of applied science research, Stage 1, 'Proof of DB Concept' conducted from 2010 – 2013 by **Dylan Clarke** (Clarke 2013) and Stage 2, 'Quantification of DB Performance' implemented by **Brian Levine** (Levine 2020). For more detail on the two stages of applied research and the agencies involved refer to Appendix 15.

Constructing a DB is not just about shifting earth. To maximise the benefits for improved water quality outcomes, it is important that good planning prior to construction is undertaken. In our experience, only one proposed DB site for every three sites investigated is actually suitable.

We strongly advocate the use of GIS mapping technology to fast track the process of selecting a potential DB location and estimating the water storage capacity of a site. GIS with LiDAR data enables confirmation of the most suitable DB locations by testing each probable site with a quickly drafted, 'what-if' DB 'mock-up' to confirm catchment size, bund wall dimensions, ponding area, and ponding volume, see Figure 2 below. This enables full assessment of the proposed DB site's volumetric capacity and catchment area, to ensure the minimum ratio of $120m^3$/ha is met.

Figure 2 A typical DB 'mock-up' with ponding volume and catchment size drawn by use of GIS with LiDAR data. Here the storage to catchment area ratio is 178:1.

In a nutshell - What we have learnt about DBs

After 10 years of farmer experience, multiple DB constructions and two applied research projects (Clarke 2013 MSc, Levine 2020 PhD), the key findings are:

DBs are not a silver bullet

(See also Appendix 12)

- **Good management practice (GMP)** is the farmer's most efficient first step for improving water quality.
- **DBs are not an alternative to fundamental GMPs.**
- **DBs can be a valuable addition to a farms environment plan.**

Farmer/DB owner implications

(See Table 3)

- **Farmer commitment** to the DB concept is an essential prerequisite for DB construction.
- **Best sites** for DBs are generally on farms and usually on some of the farm's best pasture land.
- **No significant compromise** of pasture quality occurs in the DB ponding areas.
- **Farm activity and productivity is largely unaffected** on both the bund site and its ponding area.

Siting DBs in pastoral landscapes

(See also page 19 and Appendix 10 and 11)

- **Geographic Information Systems (GIS) with LiDAR** data is required for planning best DB locations.
- **Opportunities for DB installations** vary widely between landscape topography types.
- **Geology and soil types** need to be considered.

Sizing of DBs

(See also page 20)

- **DB storage volume (m^3) to catchment size (ha) ratio** is the preferred metric to guide location and design of DBs.
- **The 120 m^3:1 ha ratio** is the minimum threshold for DB site assessment, however, the bigger this ratio the better because more of the larger storms can be fully detained.

DB construction

(See also page 26)

- **Professional advice** is recommended.
- **Compaction** during construction is critical.
- **Spread fill material in thin layers** <200 mm thick and compact each layer.
- **Use a dedicated roller** (compacting with machine tracks is inadequate).
- **Compacting around the culvert** pipe requires special care to prevent voids and leakage.

DB performance and benefits

(See also pages 12 and 14)

- **A significant proportion of the contaminant load** of storm water run-off is retained on-farm.
- ***47%-68% of phosphorus** in storm water run-off can be retained by DBs.
- ***51%-59% of suspended sediment** can be retained by DBs.
- ***Good soil infiltration rates** in DB ponding area contributing to >50% of the delivered run-off infiltrating the soil is essential for good performance.
- **High pond storage capacity** relative to catchment area (≥120 m^3/ha.) is essential for good performance.
- **DBs reduce both storm peak flows** and damage to farm and roading infrastructure.
- **DBs on farms benefit the wider community in multiple ways** which justifies a public cost share.

*Levine (2020) - see more detail on PhD results on page 14.

What is a Detainment Bund^{PS120}? - Key features

A **Detainment Bund^{PS120} (DB) is** a low earth berm placed across an ephemeral storm water flow path on a farm to temporarily detain storm water run-off for water quality objectives. DBs are usually located on valuable and productive pasture paddocks as these areas are often where ponding opportunities can be optimised with the least earthwork requirements. They are generally not located on permanently flowing waterways. Key features are summarised in Table 1 below.

Table 1 Key features of DBs include:

DB Themes	Key Features
Targets	High intensity rain storm event interception and ponding.
	Treatment of phosphorus and sediment loads in run-off water.
Farm Fit	DB structures are a seamless part of the farm pasture landscape.
	DB locations are on prime pasture and in mid-farm situations.
	Pasture productivity in the DB ponding areas are not unduly compromised.
	Permeable soils are needed in the ponding area.
Capability	Requires a storage to catchment ratio ≥120 m³ per hectare of catchment.
	Ponding volume up to 5,000 m³ and catchment size less than 42 hectares.
Temporal	Ponding duration is limited to a maximum of three days.
Regulation	DB construction is a usually a permitted activity (but check with your regional council regarding earthworks requirements).

The ponding area of a DB holds water only during occasional high intensity rainfall events when storm water run-off occurs. Ponding can last from a few hours up to, but no more than, three days depending on the severity of the rain storm event and the infiltration rate of the soils under the pond. If the ponded water is not already completely infiltrated after three days, and it often is, the farm manager releases the residual water to ensure the good health of the pasture in the ponded area.

Unlike other dedicated mitigation structures such as constructed wetlands and other forms of sediment trapping ponds or dams, DB ponding areas are seamless with the pastured fields they occupy. These pastured ponding areas are generally some of the most valuable and productive land on the farm. The farmers operating DBs in the Rotorua District report that the infrequent temporary inundation with storm water does not unduly compromise the productive capacity of the pasture within the ponding area.

During high intensity rainfall events, DBs pond a significant volume of storm water run-off. Figure 3 below illustrates the main operational cycle of a DB featuring; location on the farms prime productive land (Figure 3.1), storm water capture and treatment (Figure 3.2), release of treated residual (Figure 3.3) and return to fully productive land use (Figure 3.4).

Figure 3.1 DB located on storm water flow path.

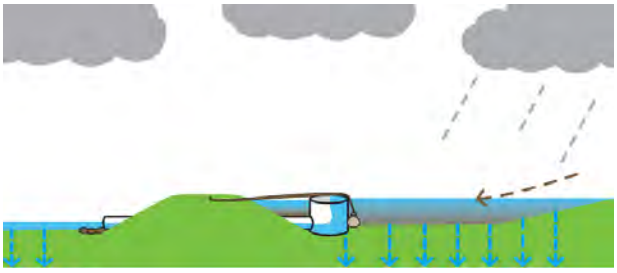


Figure 3.2 Storm water run-off capture and infiltration.

Figure 3.3 Residual release after three days of ponding.

Figure 3.4 DB and ponding area back to full productive use.

An essential feature of a DB pond is the sustained infiltration of water into the ground as illustrated by the vertical blue arrows in Figure 3.3 above.

In a typical DB, water residency and release is controlled by three features as illustrated in Figure 4 below.

- A small 'drain hole' that is plugged for up to three days.
- A 'Primary Spillway' that decants or skims of any excess storm water arriving during a storm event.
- A 'Secondary Spillway' serves as an outlet and is only active during exceptionally large events.

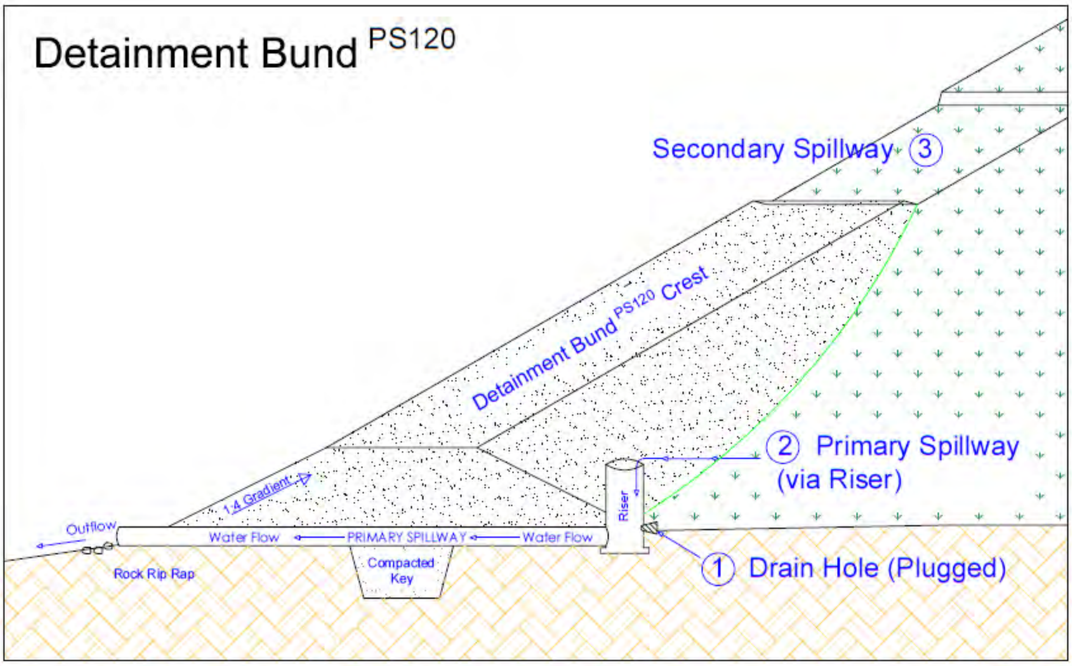


Figure 4 Sectional diagram of a Detainment Bund^{PS120} featuring the three water release provisions; 1 - Drain Hole, 2 - Primary Spillway, 3 - Secondary Spillway. *(Drawing by J. Longbottom)*

Surface run-off: an opportunity for interception

Surface run-off of rainwater occurs during high intensity rain storm events and the proportion of run-off versus infiltration depends on the type of storm, the duration, and intensity of the rainfall and the drainage rates of the soil type. On light soils in the central North Island run-off generally occurs when rainfall intensity exceeds 10 mm per hour continuously for several hours. On clay soil types, run-off may occur when the rainfall intensity is much lower.

These short periods of rain storm run-off offer a unique, but brief opportunity for farmers to intercept and treat the run-off water's contaminant loads of phosphorus and sediment before this storm water leaves the farm boundary.

In summary

- **your farm is strongly connected to the water quality status of local water bodies.**
- **contaminants that most commonly influence water quality are; nitrogen, phosphorus, sediment and E. coli.**
- **two distinct pathways of contaminant escape from the farm, leaching and surface run-off create various opportunities for interceptive actions.**
- **nitrogen predominately leaches through the soil while nitrogen losses in surface run-off are relatively minor.**
- **phosphorus, sediment and E.coli are predominately transported in surface run-off during rain storms.**
- **good opportunities for intercepting and treating run-off with DBs may exist on farms.**

The table below (Table 2) summarises the opportunities and contaminant loads that can be effectively treated with appropriately placed and sized Detainment Bunds^{PS120}.

Table 2 On-farm opportunities to intercept contaminants in storm water run-off.

Storm water contaminant	Mitigation structure	Mode of transport		Interception opportunity
		Run-off	Infiltration	
Nitrogen (N) (in run-off)	Constructed wetlands	√ (minor)	√ (minor)	The majority of loss from farming is coming from leaching from animal urine patches. Nitrogen lost in surface run-off is minor.
Nitrogen (ex mole and tile drains)	Constructed wetlands	(NA)	√	Occasionally it is possible to treat re-emerging groundwater (for leached N) (Figure 27).
Nitrogen (in ground water)	Woodchip biodigester wall	(NA)	√	In-ground treatment opportunities are possible with wood chip denitrifying wall (Figure 28).
Phosphorus	DB	√	√ (minor)	Interception and treatment of surface run-off on-farm is readily possible with Detainment Bunds^{PS120} (Figure 5).
Sediment	DB	√	X	
E. coli	DB	?*	X	

*The efficacy of DBs for E.coli mitigation may be similar to sediment but is yet to be confirmed.

How does a DB work?

There are several treatment mechanisms at work when contaminant laden storm water is arrested in a DB ponding area; settling, P sorption, and infiltration.

Settling

Strokes law defines the relationship between water velocity and particle size settlement, is now known as Stokes Law. Velocity, as well as, particle density, shape, water viscosity, and electrostatic attraction, all affect settling rates. Storm water run-off velocity is effectively reduced to zero in a DB pond so settling out processes are optimised. Finer clay-sized sediment particles take longer to settle than more coarse silt-sized particles and much longer than large sand-sized particles. Particles less than 10 µm tend not to settle by themselves but may flocculate, and settle as part of a cluster. Results from the applied field trials found that 'settling' was a component of the mitigation capabilities of DBs in the Rotorua area. However, in farming districts with greater erosion driven by farm practices and storm water, e.g. break feeding of winter crops, 'settling' could be a more important factor affecting the ability of DBs to mitigate sediment and phosphorus losses from farms. During the field trials, a storm event coincided with sub-optimal farm management practices, and resulted in 2.7 tonnes of sediment and 6 kg of P deposited in a DB ponding area during a single event. This is around 30-fold more than loads recorded leaving pasture.

P sorption

Dissolved phosphorus can stick to soil particles suspended in the stationary run-off water in the DB. This is known as 'P sorption' and occurs in the DB pond due to electrostatic attraction. The quantity of P sorption that occurs in a pond depends on the concentration of P dissolved in storm run-off, and the phosphorus enrichment of the eroded soil particles. As with settling and soil infiltration, P sorption was found to contribute to the mitigation performance of DBs. Further trials are planned where we propose to introduce a flocculant to enhance P sorption processes.

Infiltration

Our trials found that infiltration of ponded storm water through permeable soils in the ponding area was the main treatment mechanism at work in DBs. The on-pasture ponding of storm water treatment cycle utilising a DB is fully illustrated with the series of figures below.

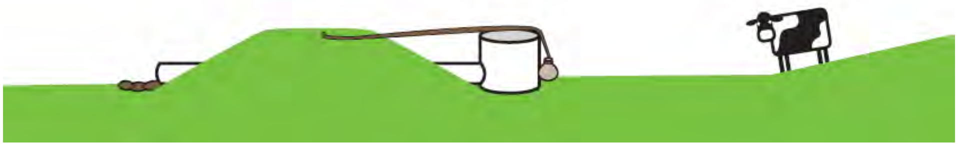


Figure 5A DBs occupy prime pasture locations without unduly compromising pasture quality.

With the occurrence of a high intensity rain event, storm water run-off occurs and is totally or partially captured in the ponding area (Figure 5B).

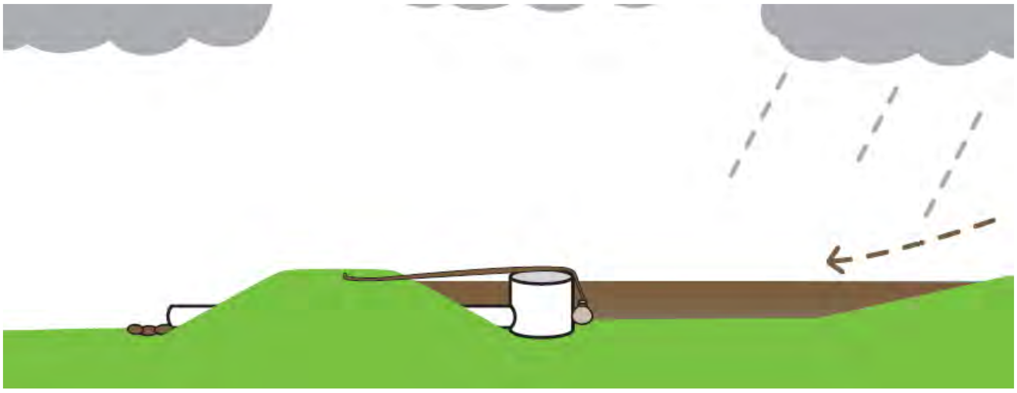


Figure 5B DBs capture dirty storm water run-off during high intensity rainstorm events.

During storms that deliver run-off that exceeds the capacity of the pond, the upstand riser skims off the excess which then escapes through the high capacity culvert in the bund wall to the pasture paddocks below the bund (Figure 5C).

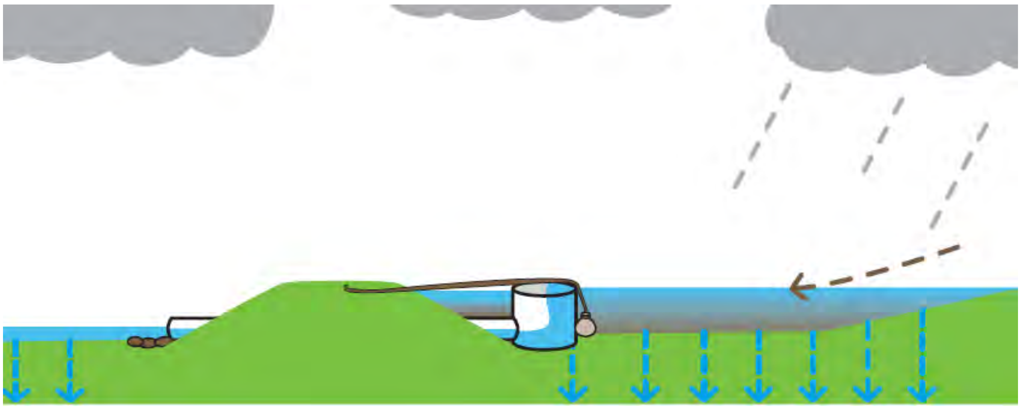


Figure 5C Temporary storage settlement/infiltration of dirty storm water (Day one to Day three).

From the moment storm water arrives, coarse sediment and suspended sediment (fine particles) begin settling out of the water column, and run-off infiltrates the soil in the bed of pond.

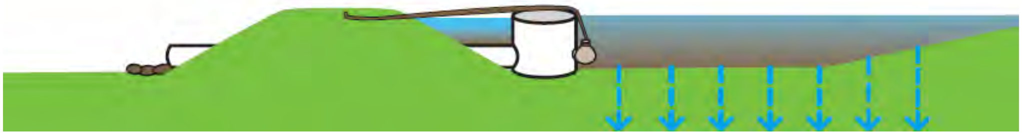


Figure 5D Sediment particles start to settle and pond water infiltrates into the underlying soil.

Figure 5E Sediment settling and pond water infiltration continues for up to three days.

If the soils in the ponding area are free draining, the majority of ponded water can infiltrate into the soil after a few days. As pasture might be damaged by sustained flooding, it is recommended that on the third day of ponding, any remaining ponded run-off is released by opening the plugged hole of the riser. Since the soils downstream of the DB have likely dried from the previous storm, much of the remaining ponded run-off that is released on the third day of ponding is likely to infiltrate the soils downstream of the DB before reaching a connected waterway. This additional soil infiltration enhances to the overall performance of DB phosphorus mitigation.

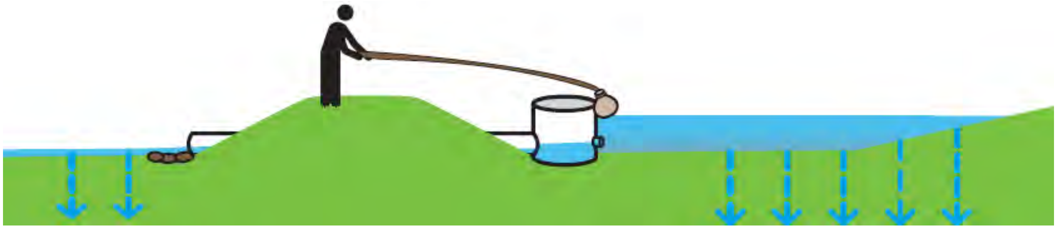


Figure 5F Release of any residual water (at Day three) to ensure pasture health and productivity.

Figure 5G Rest period while soils dry sufficiently to allow grazing to recommence.

Figure 5H Return of the bund and ponding area to full pastoral utilisation.

Figure 6 (left) DB full and skimming off overflow. (Photo D. Clarke)
(right) DB empty, and growing grass, its usual state. (Photo J. Paterson)

Multiple benefits of DB installations

The benefits of DB installations are not just limited to mitigating phosphorus and sediment loss.

Table 3 illustrates seven co-benefits from intercepting storm water run-off on-farm and summarises the validation steps taken for each benefit.

While some of the DB benefits are now validated by the **r**ecent applied research, other benefits are yet to be validated by credible science work (e.g. *E.coli*) but are anecdotally accepted as worthwhile with evidence of actual uptake (e.g. storm water peak flow management).

Table 3 Multiple benefits of DBs and their performance evidence.

	Issue (cause)	**DB Benefits**	**DBs result in**	**Validated by**
1	**Water quality** (phosphorus)	Phosphorus (P), in farm run-off captured in DBs.	Proven[1] 47% to 68% reduction of P load in storm water run-off	[1]Completed research (Levine PhD 2020 and Clarke MSc 2013).
2	**Water quality** (sediment)	Sediment captured in DBs.	Proven[2] 51% to 59% reduction of sediment in storm water run-off	[2]Completed research (Levine PhD 2020 and Clarke MSc 2013).
3	**Human health** (E. coli)[3]	Possible pathogens capture, reducing risk to potable water and downstream "Swimmability".	[3]Validation trials 2020 – 2022. Likely similar to TP and SS results i.e. >50% reduction. Result pending.	Known association of Escherichia coli (*E.coli*) with sediment in run-off. [3] Pending applied research project.
4	**Erosion** (sediment)	Moderation of erosive peak flows by DBs.	Limiting downstream erosion (banks, head wall gullying).	100+ historic Detainment Dams (DDs) built 1980 – 2000 in BOP.
5	**Flood** (safety)	Moderation of peak flows by DBs during floods.	Limiting injury and loss of life from flooding induced road accidents.	Some DB works funded for peak flow risk reduction to public roads.
6	**Flood** (destruction)	Less downstream infrastructure maintenance cost.	Limiting damage to housing, bridges, culverts, roads, pasture and water supply.	As above. Works funded for this reason.
7	**Aquifer Depletion** (ground water)	'Aquifer recharge' through run-off residency in DB ponding area.	Proven[4] 43% to 63% infiltration through up to 72 hour DB ponding residency time.	[4]Completed research (Levine PhD 2020 and Clarke MSc 2013).

Risks

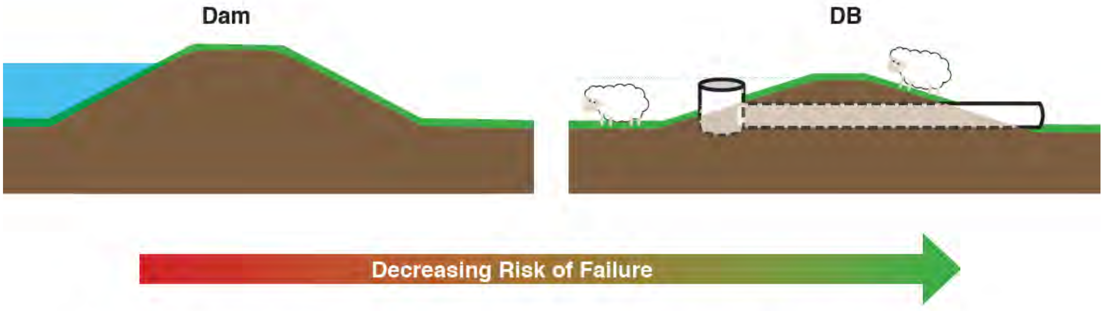
Balancing risks with benefits and ‘greater good’

It is important consider all of the risks associated with DBs in balance with the benefits of installing a DB on the farm (previous section). Once the risks are properly assessed, how do they compare with the benefits and “greater good” (for water quality) achieved by the interception and treatment of a farm’s storm water run-off?

While we advocate DBs are not dams due to their typically dry status, the risk dynamics are similar during rare storm events. Some of the main causes of earth ‘dam’ failure are:

- Piping erosion (often around the culvert pipe).
- Overtopping (eroding the downstream dam wall batter).
- Structural (cracking, slumping).

We discuss embankment failure risks in more detail in Appendix 7. A DB builder needs to be fully aware of the potential for embankment failure and approach the DB earthworks project using appropraitely qualified professional advisors.



Small Dam risk features:
- Water – 100% occupancy time
- Up to 4m high embankment
- Up to 20,000m^3 volume
- Permanent water head pressure

Detainment Bund ^{PS120} risk features:
- 1% full occupancy, 100% pasture
- Up to 2.5m high embankment
- Up to 5,000m^3 volume
- Occasional water head pressure

Figure 7 Decreased risk is inherent with DB design, size, pasture and limited water occupancy.

Detainment Bunds pose less risk than a dam but is not without risk, refer to Appendix 7.

Infiltration rate of soil underlying DBs

DBs are characterised as being dry most of the time, and remaining productive (100% pasture cover in ponding area). Only during very short durations is the pond filled to maximum storage capacity (<10 hours throughout the entire year).

One of the key findings of the research was that the contaminant removal performance (or efficacy) of DBs is dependent on the infiltration capacity, or permeability, of the soils underlying the DB ponding area. As reported on by B Levine (2020):

"The studies found the DB strategy effectively prevented 51-59% of the annual suspended sediment loads, 47-68% of the annual TP loads, delivered to the DBs from reaching the lake. Soil infiltration of 43-63% of the annual run-off delivered to the DBs occurred as a result of increased residence times on well drained pastures, and was mainly responsible for decreases in contaminant loads delivered to surface waters downstream of the bunds. Sedimentation and sorption also contributed to some contaminant load reductions"

To be assured that a DB built on your farm will have potential mitigation performances comparable to those in the PMP Inc. applied research trial sites (i.e. Average 55%-58% mitigation of sediment and phosphorus respectively), it is important to check the infiltration rates of your farm's soils in potential DB locations. Once you have measured the soil infiltration rates using methods described later in this section, you can compare them to those of the trial site soils which had mean ponding event infiltration rates of 13 mm/h (range: 5 mm-24 mm/h) and 9 mm/h (range: 3 mm-16 mm/h) for two sites as shown in Figure 8 below. Note: there was considerable seasonal variation with the calculated infiltration rates during the trial study, with lowest rates tending towards late winter/early spring (July-September).

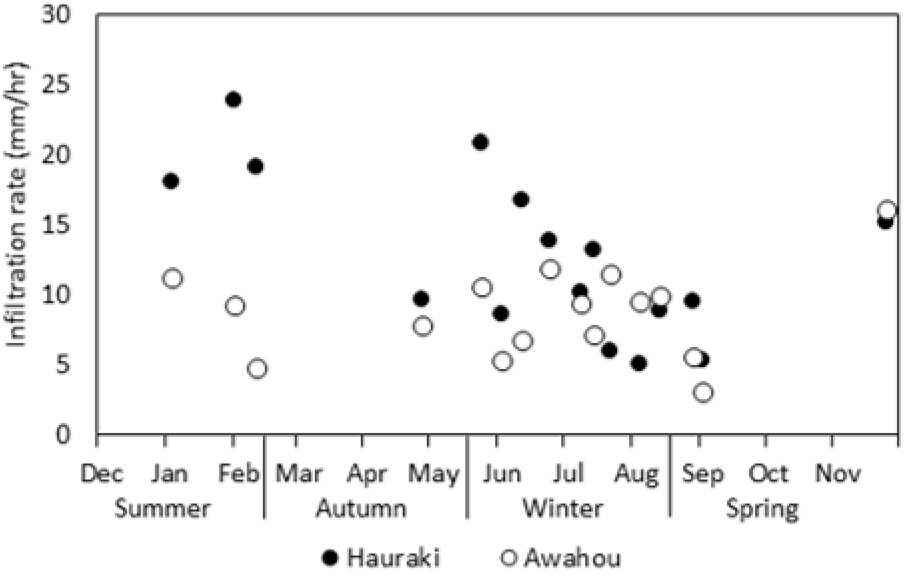


Figure 8 Seasonal ranges of calculated infiltration rates at two trial sites – from Levine 2020.

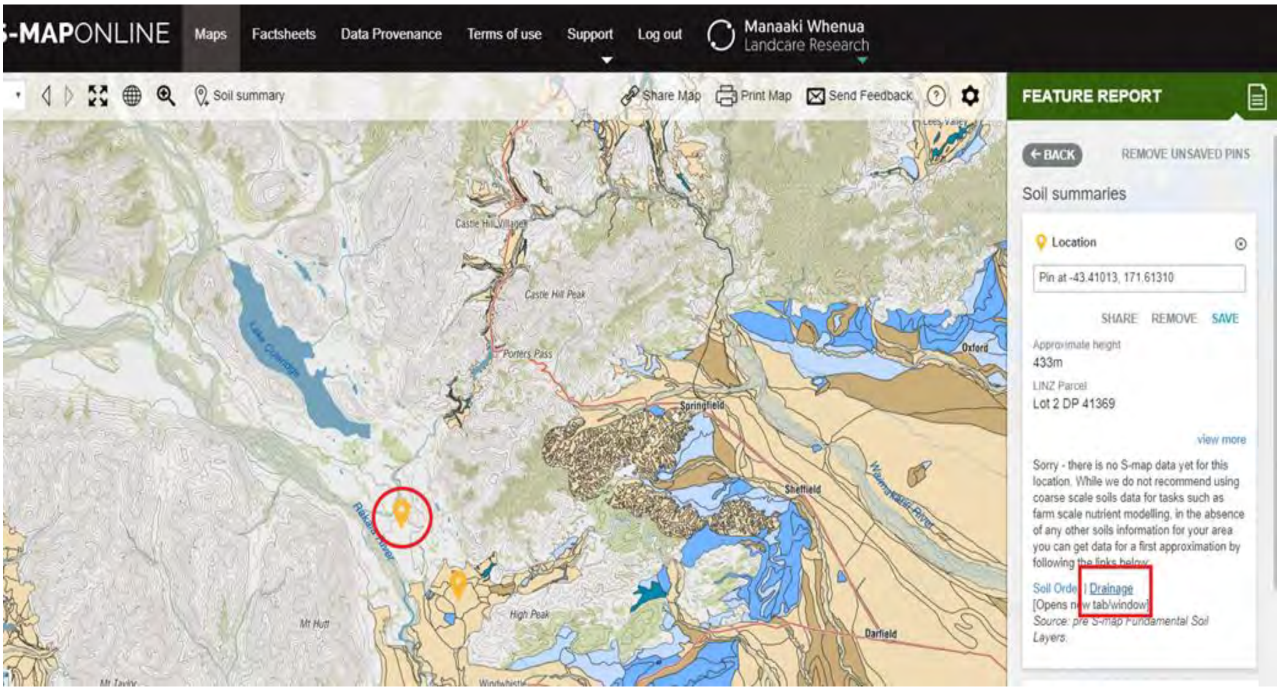
Here are two ways you can find more specific soil permeability information for your farm:

- Look up S-map – by Manaaki Whenua - Landcare Research's S-map Online Service.
- Infiltration testing on your site.

Descriptions of these two methods are detailed below.

Using S-MapONLINE

To access S-MapOnline you are required to register, but it is free for non-commercial use. Go to - https://smap.landcareresearch.co.nz/support/first-time-here/. Turn on the soil drainage layer listed in the left column under the ‘layers’ section. If S-map does not have the data needed for your area it will direct you to the older Fundamental Soil Layer (FSL) soil viewer that has national coverage but the information is older and less accurate.



Location
Pin at -43.41013, 171.61310

Approximate height
433m

LINZ Parcel
Lot 2 DP 41369

Sorry - there is no S-map data yet for this location. While we do not recommend using coarse scale soils data for tasks such as farm scale nutrient modelling, in the absence of any other soils information for your area you can get data for a first approximation by following the links below.

Soil Orde | Drainage
[Opens new tab/window]
Source: pre S-map Fundamental Soil Layers.

Figure 9 A screen shot example from S-map online with example site and link to drainage data. From Manaaki Whenua - Landcare Research (2018).

The above figure shows an example location (red circle) on the map where there is no S-map data for the query. However, the FSL soil drainage can be found by following the ‘Drainage’ link in the red rectangle in the right column. The various ‘drainage classes’, describe soil properties that relate to how long a soil is saturated during the year. This gives a useful indication of the winter/spring water table depth. Permeability classes, on the other hand, give a better estimate of soil infiltration rates. Permeability is a lab-based measure of flow through an intact core. The measurement relates to a particular soil horizon, so for example you could have rapid permeability of a surface horizon over a slowly permeable sub-surface horizon – described as ‘rapid/slow’.

Soil physical properties

Depth class (diggability)
Deep (> 1 m)

Potential rooting depth
Unlimited

Rooting barrier
No significant barrier within 1

Depth to hard rock
No hard rock within 1 m

Depth to soft rock
No soft rock within 1 m

Depth to stony layer class
No significant stony layer within

Texture profile
Sandy loam over loam

Topsoil stoniness
Stoneless

Topsoil clay range
10 - 15 %

Drainage class
Well drained

Permeability profile
Rapid

Depth to slowly permeable horizon
No slowly permeable horizon

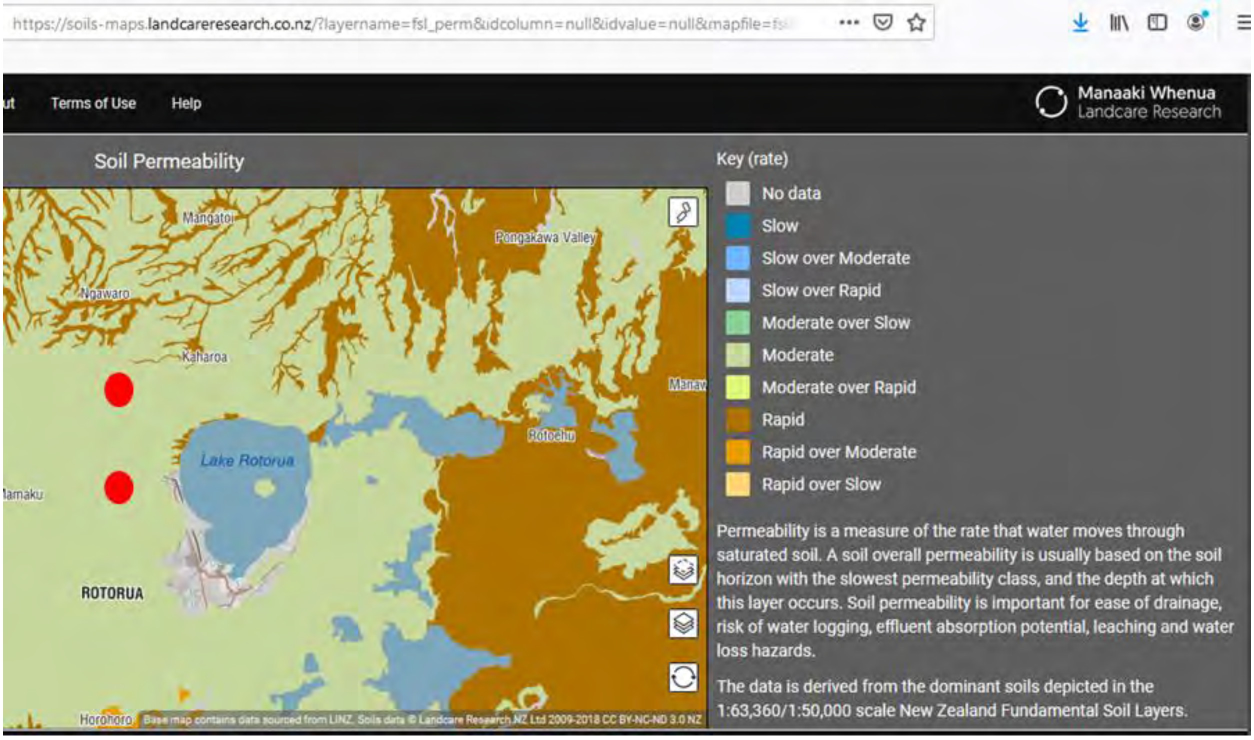
Permeability of slowest horizon
Rapid (> 72 mm/h)

Aeration in root zone
Unlimited

Figure 10 Screen shot example - Soil physical properties – relating to water infiltration. From S-map. Manaaki Whenua - Landcare Research (2018).

Where S-map is available, the fact sheet information shows the Soil Physical Properties for your location including the Drainage class, (DBs are best on ‘Well drained’ soils), Permeability profile (DBs are best on ‘Rapid’ permeability areas). The listed infiltration rates (e.g. <4 mm/h, 4 mm-72 mm/h, >72 mm/h), can be variable from place to place and seasonally. The permeability and hydraulic conductivity (saturated and unsaturated) information is also not very accurate and has very high spatial (and to a lesser extent temporal) variability. **However, this S-map information is useful for a general indication of the potential performance of storm water run-off treatment with DB installations on your farm.**

If S-map information is not available for your farm, the S-map site will link you to the older and less complex information. An example of this from the older FSL viewer is illustrated in Figure 11 below.



https://soils-maps.landcareresearch.co.nz/?layername=fsl_perm&idcolumn=null&idvalue=null&mapfile=fs

Soil Permeability

Key (rate)

⬜ No data
🟦 Slow
🟦 Slow over Moderate
🟦 Slow over Rapid
🟩 Moderate over Slow
🟩 Moderate
🟨 Moderate over Rapid
🟫 Rapid
🟧 Rapid over Moderate
🟨 Rapid over Slow

Permeability is a measure of the rate that water moves through saturated soil. A soil overall permeability is usually based on the soil horizon with the slowest permeability class, and the depth at which this layer occurs. Soil permeability is important for ease of drainage, risk of water logging, effluent absorption potential, leaching and water loss hazards.

The data is derived from the dominant soils depicted in the 1:63,360/1:50,000 scale New Zealand Fundamental Soil Layers.

Base map contains data sourced from LINZ. Soils data © Landcare Research NZ Ltd 2009-2018 CC BY-NC-ND 3.0 NZ

Figure 11 *Example from the older soil map viewer showing Rotorua area ‘Soil Permeability’. The DB trial sites, marked with red dots above, are all on soils classed with ‘Moderate’ permeability. From Manaaki Whenua - Landcare Research.*

S-map information is indicative of the general range of soil infiltration on your farm; however, prior to site finalisation (and construction) we recommend confirming infiltration rates using the simple method outline in the next section.

Measuring the infiltration rate of your soil

Infiltration refers to the passage of water into the soil profile under both unsaturated and saturated conditions. The rate at which water infiltrates the soil is influenced by several factors including gravity, capillary action, and the soil properties on your farm. The infiltration capacity becomes constant at the saturated hydraulic conductivity in the ponding area of your DB after it fills with water. This is a consideration if you measure the infiltration rate of the DB ponding area during relatively dry conditions.

Figure 12 Measuring the infiltration rate of pasture soil with a double ring infiltrometer.

Double ring infiltrometer test methodology

This method involves driving two rings into the soil as shown in Figure 12 above. When both rings are filled, water infiltrates both vertically and laterally from the outer ring' as illustrated in Figure 13 below. The soil saturation contributed by water from the outer ring partly limits the lateral migration of the drainage from the inner ring giving a more accurate measurement of the vertical infiltration rate.

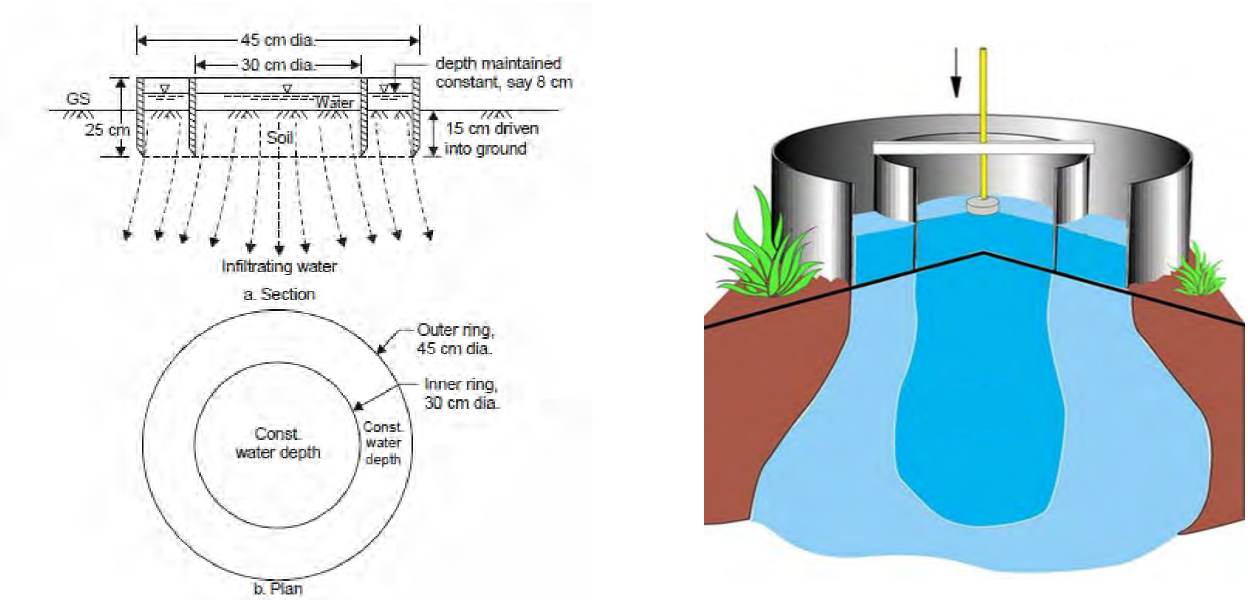


Figure 13 Diagrams of the functioning of the double ring infiltrometer. [Seabrook 2020 & SDEC France]

The double ring infiltrometer effectively measures the saturated hydraulic conductivity of the topsoil, and thus provides a measure of a soil's minimum infiltration capacity (Taylor 2008). However, the method does not provide an exact measure of a soil's infiltration rate of an entire paddock, but is instead an estimate for that specific test location. Therefore, the infiltration test should be repeated in several places within the DB ponding area to obtain the best estimate possible. Another factor to consider in regards to soil infiltration rates is the variable water depth during a DB ponding event which affects the 'head pressure' and therefore, the actual pond event infiltration rates.

"JP bean can" single ring infiltrometer method

Unlike the double ring infiltrometer, the single ring method does not control lateral movement of the infiltrating water and is therefore, not as accurate an estimate as the double ring method. While imperfect, this method has the advantage of being easy, cheap, and a DIY method (see Figure 14 below), and is still a useful indicator of your soils permeability and is better than doing nothing!

Figure 14 JP bean can single ring infiltrometer (best used in sample plots of 10 cans).

Because the bean can diameter is so small (70 mm) and soil infiltration properties can have high spatial variability, it is important to take a good number of separately located measurements (say five to 10) in a sample plot at the same time, and repeat in several locations through the DB ponding area. The steps for the bean can method are as follows:

First, eat plenty of beans, then take the used food cans and carefully remove their bases. This creates a slightly tapered edge perfect for pushing into the soil.

Next find a location in the potential DB pond area and insert the cans into the soil. A wood turner can make you a fitted mandrel for pushing the cans into the ground to a set depth, or you can simply place a piece of wood across the top and drive them in to a set depth with a hammer.

Repeat filling the cans with water will give more accurate estimates of the infiltration rate of your soils under sustained saturation conditions, similar to conditions during a DB ponding event. In order to most accurately estimate the soil infiltration rates under saturated conditions use only measurements from the later fills at about half an hour intervals.

The full step by step process for using this method is shown in more detail in Appendix 9.

GIS with LiDAR: Is the topography of my farm suitable for DB sites?

GIS is short for geographic information system. There are two fundamental requirements, when considering DB installations on your farm; access to GIS expertise and LiDAR data.

GIS expertise

We recommend you enquire to your Regional Council about the provision of GIS services for environmental mitigation with DBs or engage a private GIS professional. With a GIS service provider, you review details of your farm's topography, storm water flow paths, various sub-catchments and then draw 'what if' mock-ups of DBs at probable sites to see if they fit, and if the threshold for storage capacity relative to catchment area can be met. A trial and error mock-up of a probable DB site can be done in a few minutes using desk-top GIS software compared to many hours out in the paddock with land survey equipment.

LiDAR data

Light Detection and Ranging (LiDAR) is a remote sensing method that provides detail of the lands surface. The component of this that we need to use is called DEM, digital elevation model, and the level of resolution needed has to be capable of producing a 1 m contour map for your farm as shown in example Figure 15 below.

Figure 15 LiDAR data enables 1 m contour detail. The red polygon is an example DB 'mock-up'.

Not all areas of NZ have this 1 m LiDAR capability but it is being rapidly rolled out as a free public asset with increasing coverage NZ wide at time of writing. If necessary, a private provider can do fly over LiDAR data provision for your farm. For an update on the evolving status of LiDAR availability for your area, contact your Regional Council or take a look at Land Information New Zealand web site (LINZ) and visit the LINZ Data Service. https://www.linz.govt.nz/data/linz-data/elevation-data.

A farmer will usually know where storm water flow occurs across the paddocks and can readily point out likely DB sites on the farms. However, planning for DBs requires measurement of the proposed catchment area together with details of the proposed DB site, its height to overland spillway, ponding extent, and a calculation of the volume of water that the proposed DB site would hold. These details are shown in Figure

16. This information enables the DB site planner to calculate the proposed DB's storage (m^3) to catchment (ha) ratio, which needs to be ≥120 m3/ha to be considered as a potential site.
Sites with a ratio greater or equal to 120:1 indicate that they may be short listed for confirmation with a field site visit.

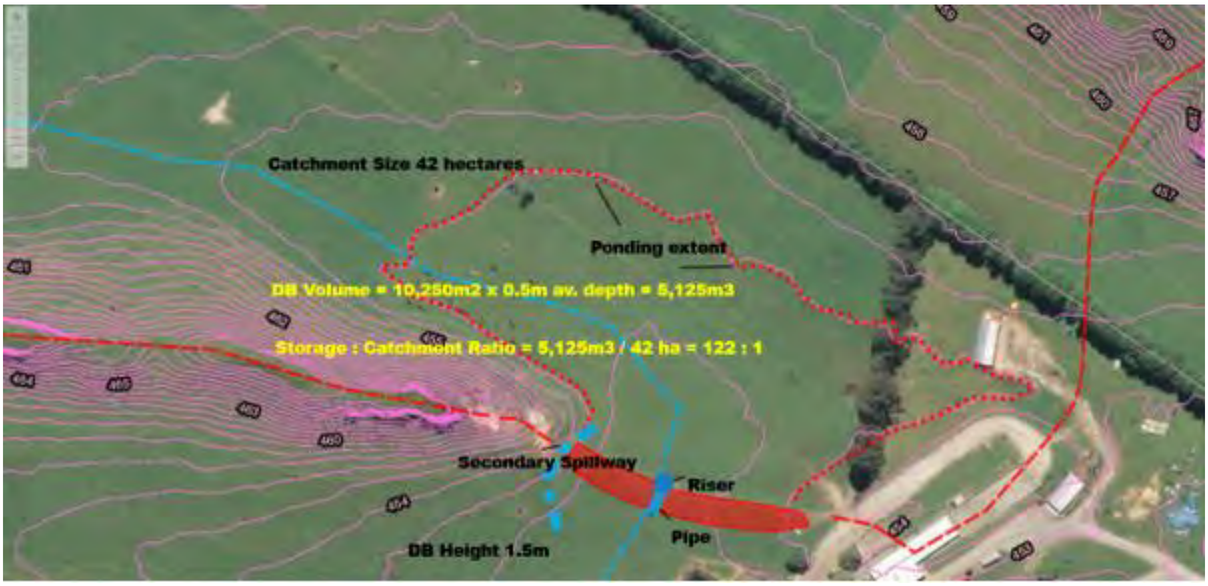


Figure 16 A DB 'mock-up' location illustrating calculation of the storage to catchment ratio.

In the example provided in Figure 16 the following measurements were made using GIS with LiDAR data:

- A possible DB mock-up site is drawn in – illustrated by the red polygon.
- This DB mock-up is spanning across one and a half contour lines i.e. it is drawn at 1.5 m high.
- The storm water flow path is drawn in – the blue dashed line.
- The DB catchment extent is drawn around the surrounding ridges – the red dashed line.
- The DB catchment is measured – it is 42 ha in this example.

The DB volume is:

The ponding area X average pond depth (i.e. one third of the bund height)

$$10,250\ m^2 \times 0.5 = 5,125\ m^3$$

The DB Storage:Catchment area ratio is:

$5,125\ m^3$ divided by 42 ha

122:1

The ratio of this mock-up site example (122:1) exceeds the minimum threshold ratio of 120:1. This qualifies this DB location as suitable provided no issues arise from on-site checks.

[Note: These manual calculations are now automated – see the recent advances section below]

When applying GIS generated DB 'mock-ups' on a whole farm scale, a large number of DB sites may be possible, or very few, depending on the topography and flow paths. If the GIS scoping exercise ran mock-ups for say 15 DB sites, it is common for only about one in three sites to meet the threshold requirements for a Detainment Bund^{PS120}, so a list of 15 probable sites, when tested with mock-ups, may be reduced to only around five that are viable.

GIS scoping work for DB sites has been undertaken since 2010 in the Rotorua district by Regional Council staff using Council's GIS map viewer built with Geocortex (GeoView) with high resolution LiDAR data enabling 1 m contour. Around 30 DBs have been successfully constructed in recent years following site selection with the GIS mock-up process. Preliminary desktop GIS scoping of whole farms and entire sub-catchments for suitable DB sites has been a time-consuming trial and error process. As described above, it requires drawing persistent mock-ups of DB structures in valley floors to test the ponding volume to catchment ratio of many drafted probable DB sites.

Several unsuccessful attempts have been made to develop an automatic DB selection tool. However, a GIS model that reads landscape geophysical characteristics and estimates a probable DB percentage treatment area for whole catchments has been successfully developed. Called DBAM (Detainment Bund^{PS120} Applicability Model) (Paterson 2019), it accurately predicts what proportion of a whole catchment can be treated by multiple DBs. While not designed for individual farm use, it is useful to those undertaking strategic planning for catchment wide DB applications for community water quality objectives. More detailed information is in Appendix 10 or contact the corresponding author for more detail about the potential use of DBAM for strategic modelling.

Recent advances with DB mock-ups

While GIS GeoView has been successfully used for DB scoping farms and larger landscapes for many years, recent development work by BOPRC GIS staff together with PMP Inc. has focused on using ArcGIS Pro. An ArcGIS Pro project (aprx) has just been completed specifically for DB assessment purposes and first trials with it indicate that it will be at least twice as fast as the former combined GeoView and excel process. More detail on the ArcGIS Pro project for DB scoping and assessment can be found in Appendix 11.

Inter-Council collaboration

Finding and testing DB site scenarios will likely be completed by both Council based Land Management Officers assisted by GIS technicians and private consultants with GIS skills. As well as GIS competency these GIS service operators need to have prior experience of farming landscapes and an understanding of the nature of ephemeral flow (run-off) pathways and their role in carrying away contaminant loads during high intensity rain storms. There is considerable potential for improving water quality objectives by expanding the roll out of DBs on farms nationally. The BOPRC GIS department, together with the Phosphorus Mitigation Project Inc. has agreed to share the knowledge relating to developing GIS techniques with other Council GIS departments and their field staff making GIS scoping for DBs more readily available to interested farmers. For more information on inter Council collaboration between GIS departments and sharing of the DB arpx GIS package, contact the corresponding author.

Pre-construction planning/assessment

Once you have confirmed the feasibility of DB sites on your farm, you are ready to progress further towards implementing storm water treatment with DBs.

Regulations/professionals

Generally DBs are a 'Permitted Activity' in Council statutes, however, this may come with conditions including size limitation or other earthworks limits. Some councils require design and oversight by an engineer. Check with your Regional Council to see what is required in your area. We recommend you use both local knowledge and experience with past constructions of comparable small dams in your area as well as consulting with the appropriate qualified professionals.

Geology/geomorphology/hydrology

The caveats and conditions for DBs will generally dictate that the sites are in 'mid-field' areas with low gradients upstream and downstream. This means that unstable geology, e.g. a propensity for hill side slumping, in the DB abutment or the slopes around the DB ponding area, are unlikely to be an issue on viable DB sites. However, caution is still necessary and particularly relating to the underlying geology at your DB site. Farmer observations of run-off behaviour and knowledge of any abnormalities, e.g. tomos, in the district need to be considered. Pre-assessment of the underlying strata can be done by a qualified professional with a hand auger to check if it is overly permeable which could result in an unacceptable risk of failure for your new bund. At the same time, also check the 'borrow pit' material you intend to use for building up the bund. You need certainty it will be suitable for compacting, will seal and will remain stable when the bund is ponding water. This is when the DB embankment comes under some pressure from a full head of water, albeit for a limited time. There is also another opportunity for checking the geology when you start your DB build as the usual practice is to cut a key trench into the ground under the DB footprint. This nicely exposes the underlying strata and further checks can be done.

Archaeology

It is unlawful for anyone to damage an archaeological site without prior authority from Heritage New Zealand. If you are aware that pre-1900 human activity may have occurred on your property you should investigate further to see if an archaeological site is registered at or near where you intend to build your DB(s).

Your Local Authority may be able to provide information on this or you can check with the New Zealand Archaeological Association (http://www.archsite.org.nz) which has an easy to use interactive map on their website. If you are all good to go, but then unearth some evidence of pre-1900 human activity during your earthworks, you are required to follow the 'Accidental Discovery Protocol'.

Detainment Bund^{PS120} design

This Guideline is <u>not</u> intended to serve as DIY manual for DB design. We advocate that you engage a suitably qualified person to undertake your DB design. Then supply them with the preliminary GIS scoping work you have had completed with the viable DB mock-up sites identified along with their drawn-up specifications.

For each viable DB site, the ‘mock-up’ drawn by your GIS professional will effectively constitute a ‘plan view’ scale drawing with:

- The catchment size (in ha)
- The length and height footprint of the bund’s earthworks (m),
- The ponding extent and its measured area (m^2),
- The DB volume (m^3),
- The specific storage to catchment ratio calculation (optimal is ≥120:1),
- ‘Run’ Distance - The longest water run path (m) from the top of catchment to the DB,
- ‘Rise’ - The change in elevation (m) from the DB site to the highest point in the catchment, and
- Rise/Run x 100 = % Slope.

The results of this preliminary GIS work done with high resolution data provides most of the essential site parameters needed by the engineer you have appointed to produce your DB/s design. In our experience, provided high resolution LiDAR is used, it is unnecessary to have manual on-site survey work done, e.g. shooting levels for marking out and calculating ponding areas, which saves considerable expense.

Spillway Size. An overland ‘secondary’ spillway on a DB is a contingency for occasional very large storms that may overtop the large ‘primary’ spillway culvert. Together these two large overflow contingencies should prevent DB crest overtopping with any large storm. This overland spillway is placed at one end of the DB embankment on firm unfilled ground rather than over the bund itself. A spillway floor should have a low gradient (1 to 2°) so that the velocity of water spilling over is low to minimise risk of scouring damage on the grassed spillway. A sustained water velocity of >1 m/second can start to scour out a grass spillway.

To assure adequate spillway capacity during floods, your Council regulations may require an engineer to complete several hydrological calculations. Annual Exceedance Probability (AEP) is the probability of a certain size of flood occurring in a single year. For example, a 1% AEP flood flow has a 1%, or 1-in-100 chance of occurring in any one year and a 10% chance of occurring in any 10-year period. Similarly, an ARI (Average Recurrence Interval) may be required which is the average period between floods of a certain size. For example, a 100-year ARI flow will occur on average once every 100 years.

Your engineer can calculate specific DB spillway dimensions for you based on the predicted flow volume from first principles. There are several methods for this, one of which is known as the Rational Method which estimates the peak run-off (m^3/sec).

Alternatively, where applicable*, you may be able to gauge the spillway dimensions for your DB by using the ‘look-up table’ supplied in Appendix 2.

*Note: Use of this Spillway Sizing ‘look-up table’ is subject to the list of conditions included with the table.

Pipe Size. We recommend that you use the pipe size 'look-up table', in Appendix 1. Simply look for the catchment size for your particular DB on the vertical axis and read across to the graph line and down to the horizontal axis to see the recommended pipe diameter. For example in Figure 17 below, a DB serving a 25 ha catchment will need a culvert pipe of not less than 425 mm diameter.

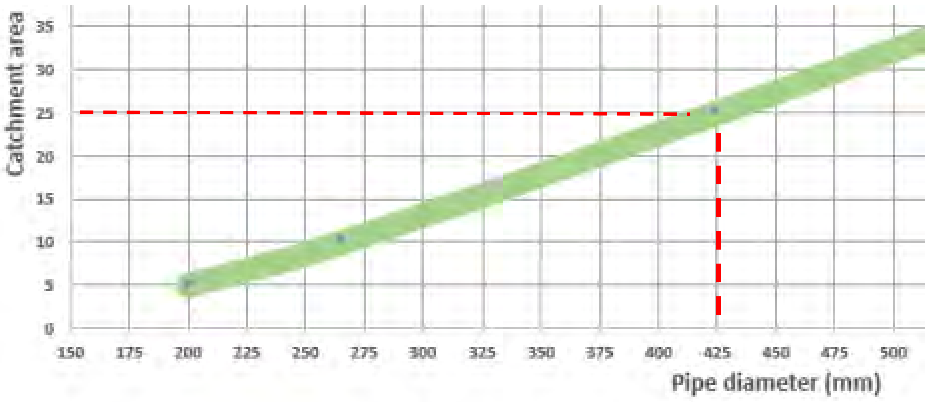


Figure 17 Snipped example from Pipe size 'look-up table'. For more detail and conditions of use see the full table in Appendix 1.

Pipe Outlet Design. Older storm water retention structures known as Detainment Dams (DDs) were usually built with one or two small (125–150 mm) drain pipes to slowly drain away accumulated storm water. With their small storage capacity (commonly around 60 m³/ha) and small outflow pipes, the overland spillways of those older Detainment Dam structures were frequently used by overflow water during run-off storm events. Figure 18 below shows the contrasting outlet controls of DDs and DBs.

Figure 18 Contrasting design features of a Detainment Dam outlet (left) and a Detainment Bund^{PS120} outlet fitted with an Upstand Riser (right). Both are pictured at time of installation, hence the disturbed soil. Note the new embankment structures in the background are well established in pasture.

Upstand Riser. A DB is fitted with a high capacity culvert attached to an 'Upstand Riser' with a limited drain hole at its base. This feature helps ensure that the overland spillways of DBs are rarely used and unlikely to have erosion issues from run-off events.

Additionally, to minimize use of the overland spillway (and erosion risks), the DB design also requires a larger ponding volume (≥120 m³/ha compared to 60 m³ for a DD). This high capacity Upstand Riser together with the relatively large size culvert pipe means that in a DB the outlet pipe acts as both a restricted drain (through the small hole when un-plugged) and a 'Primary Spillway'.

Control of the water level is set by the height of a riser attached to the culvert and control of drainage rate is determined by the size of a small diameter drain hole at the base of the riser. This system means there is more precise control of water level at the pipe rather than at the spillway and less potential for spillway erosion as the vast majority of water remains in its natural flow path route.

Riser Size. The Riser diameter needs to be much larger than the culvert pipe for several practical reasons. Appendix 3 has a simple table to read off suggested Riser pipe size depending on the culvert pipe size that it is to be fitted to. The large diameter means it has a high capacity to drain away the skimmed off flow from overflow events and add some 'head' pressure to enhance the performance of the main culvert pipe. It is also a lot easier to fit a culvert pipe to a larger diameter riser pipe. This is done by cutting a hole in the side of the riser, a few millimetres larger than the diameter of the culvert pipe, and simply slide the riser onto the end of the pipe and then thoroughly cement it in place.

DB Outflow levels. The various dimensions and levels for water outflows will be shown in a DB design cross-section that may look similar to the one shown below in Figure 19 for a 2.5 m high DB. The DB height is shown as 2.5 m which is the measurement from the bottom inside edge of the outflow pipe (know as the pipe invert) to the height of the floor of the overland secondary spillway. Note that with DBs we usually set the top edge of the Upstand Riser to be 200 mm to 300 mm lower than the overland spillway so that the large pipe performs as the 'primary' spillway. While there is a calculated width and depth for the overland spillway, it is normal practice to add height contingency to this which is known as the spillway 'freeboard'. In our example below it is nominally shown as an additional 300 mm. However, your engineer, or your Local Authority, may require a higher freeboard. Freeboard is an additional measure of safety.

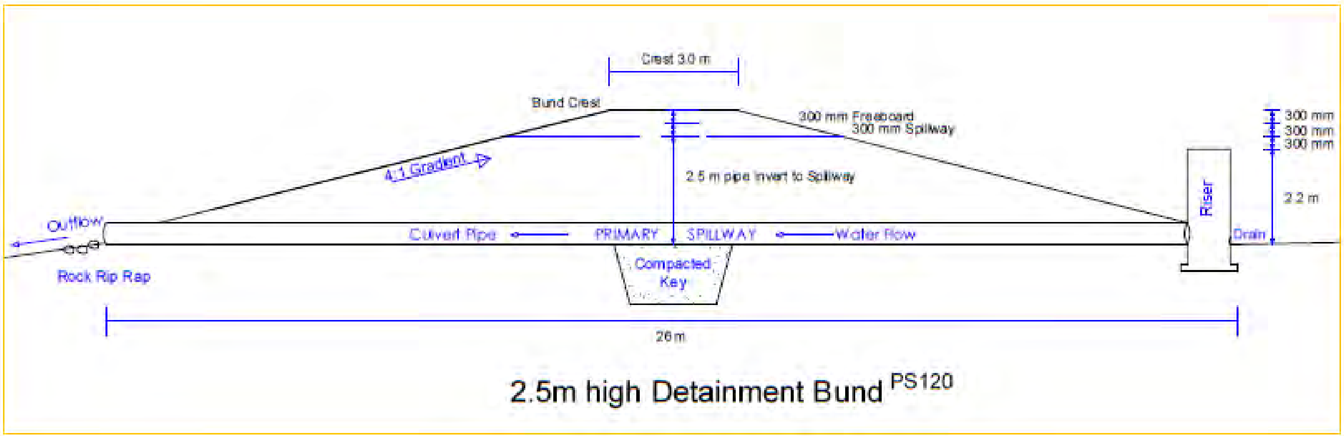


Figure 19 *A schematic cross-section of a 2.5 m DB. Other examples, smaller and larger, are shown in Appendix 14.*

Construction steps

Site preparation

The bund building season. To avoid risks of soil erosion with exposed earth, plan to "build on the shoulders of the seasons" when grass germination is most likely to be optimal i.e. mid spring and early autumn. Winter conditions are usually unsuitable for earth works and mid-summer is usually not conducive to getting a good sward of grass established over new earthworks.

Safety. Before your contractor starts, make sure contractors coming onto your farm are properly inducted about the farm's potential hazards. Also ensure your contractor has appropriate insurance and health and safety provisions. The contractor should have the work site entry points appropriately sign posted and new arrivals need to stop, be inducted, and sign a register before entering the work zone. It is standard practice for contractors to have a job safety assessment (JSA), specifically for the work site(s) on your farm – ask for a copy.

Materials. You need to be sure the earth you intend to use is suitable for compacting into the bund embankment and we recommend you seek advice from an appropriate professional about this e.g. geologist, soil scientist or engineer. With larger structures and dams it is standard practice for engineers to send samples to a lab for testing the soil's physical properties to gauge how it will behave when faced with pressure from ponded water.

Construction

Stripping topsoil. All topsoil and any organic material (vegetation, wood, roots or other decomposing material) should be stripped off the bund footprint and the quarried area. This topsoil should not be used for building up the bund embankment. Topsoil should be stock piled nearby ready for repatriating the soil layer back over the top of the earthworks as soon has construction of the embankment has finished.

For speed and efficiency, it's important to try and source materials for your bund from as close as possible to the build site rather than trucking them in from far away. Where possible an adjacent hillock can be taken off and delivered to the site or better still if the material can be shifted out from the ponding area improving the storage: catchment ratio at the same time.

Cutting a key. As shown in previous cross-section diagrams (figures 4 and 19), a key trench dug along the centre line of the bund foot print is a standard feature of DB constructions. The depth depends on the sub-strata under the DB site. If soft or permeable layers are encountered the trench may need to go deeper to cut them off. Most keys are usually about 1 m deep or until firm, non- permeable substrata is reached. If your professional advisor has done core plugs prior to construction the required depth may already be drawn into your DB design plan. Alternatively (or as well), your professional advisor may want to visit and inspect the trench when it's first cut. The width depends on the width of your on-site compaction roller. The type of infill material and the standard of compaction up through the trench is critical (see Compaction – next section).

Compaction. Earth compaction standard in the bund wall is very important. There are three common methods of compaction shown in Figure 20 below, but only two of these may be appropriate for compacting your DB:

• Tracked Machinery - e.g. a digger	**Not good**
• Wheeled earth movers - e.g. large tractor towing a large full tip trailer	**Can be OK**
• Smooth drum roller – dedicated compaction machinery	**Best option**

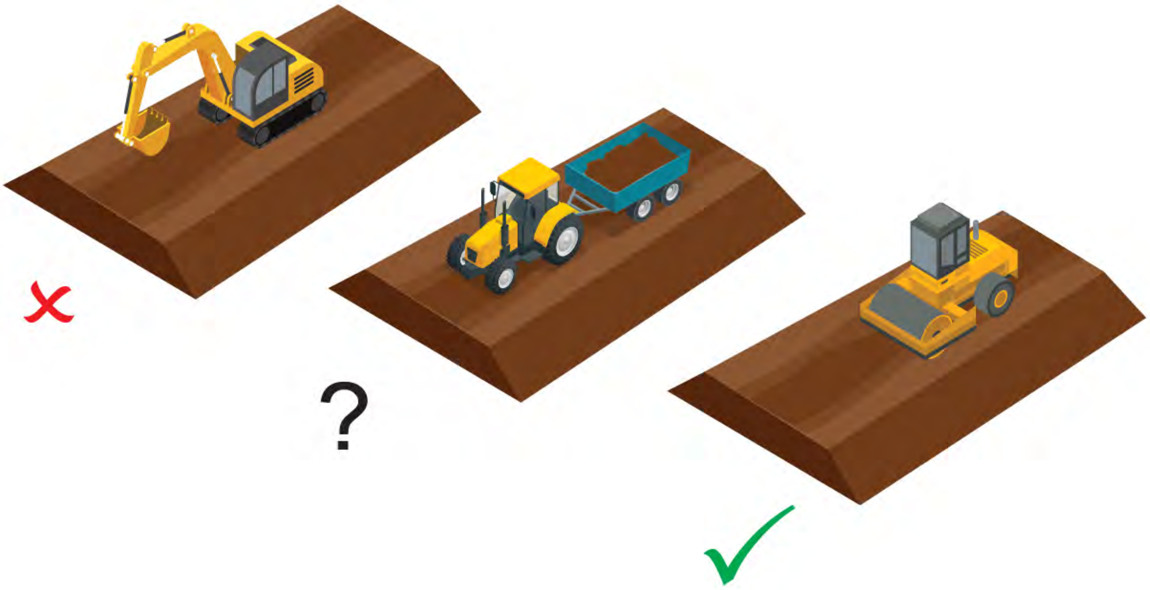


Figure 20 Common compaction options – We recommend a dedicated roller.

Material should be spread in thin layers of no more than 200 mm and fully compacted before the next layer is added. If you are using a dump trailer or truck you may need to follow with a tractor and levelling bar to avoid thick areas. We recommend a dedicated roller is kept working on the site as your earth movers come and go. Compaction should be monitored by a person independent from your contractor and photos and a log record of compaction noted at every 500 mm–600 mm rise of the bund wall. Your engineer will likely specify a compaction standard e.g. five blows per 100 mm with a Scala Penetrometer and a method to achieve this e.g. eight passes with a smooth drum roller.

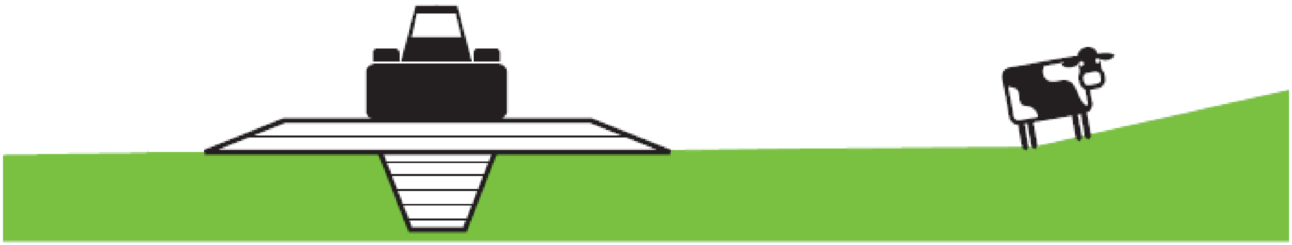


Figure 21 Compact fill in thin 150 mm–200 mm layers using a dedicated Roller.

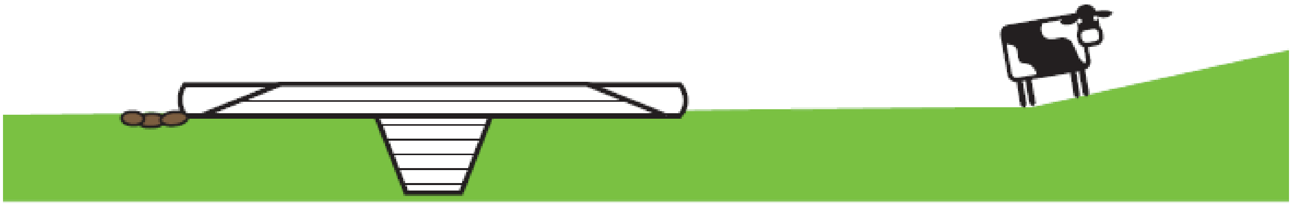


Figure 22 Compact fill up to the same height of the pipe diameter then excavate trench and install pipe.

Pipe Installation. The majority of large permanent dam failures start with leakage around pipes. We have specifically described this risk in Appendix 7, Figure 32 and Table 4. To avoid 'piping' erosion we recommend the following procedure:

- Build up the compacted layers until the bund is raised to about the same height as the pipe diameter.
- Cut a trench with the digger bucket and ensure the base is smooth, has a small gradient to the outflow end and is compacted well.
- Lay the pipe sections ensuring the joints are well sealed.

Excessive compaction along the sides of a pipe can cause the pipe to lift leaving a cavity underneath where piping erosion can easily take hold. This is a common problem when installing light HDPE pipes. As the lower half of the pipe trench is filled and compacted, some of the compaction pressure can cause the pipe to lift a little leaving a cavity underneath where water can seep along and commence a piping erosion failure. Figure 23 below illustrates this potential uplift and leak issue.

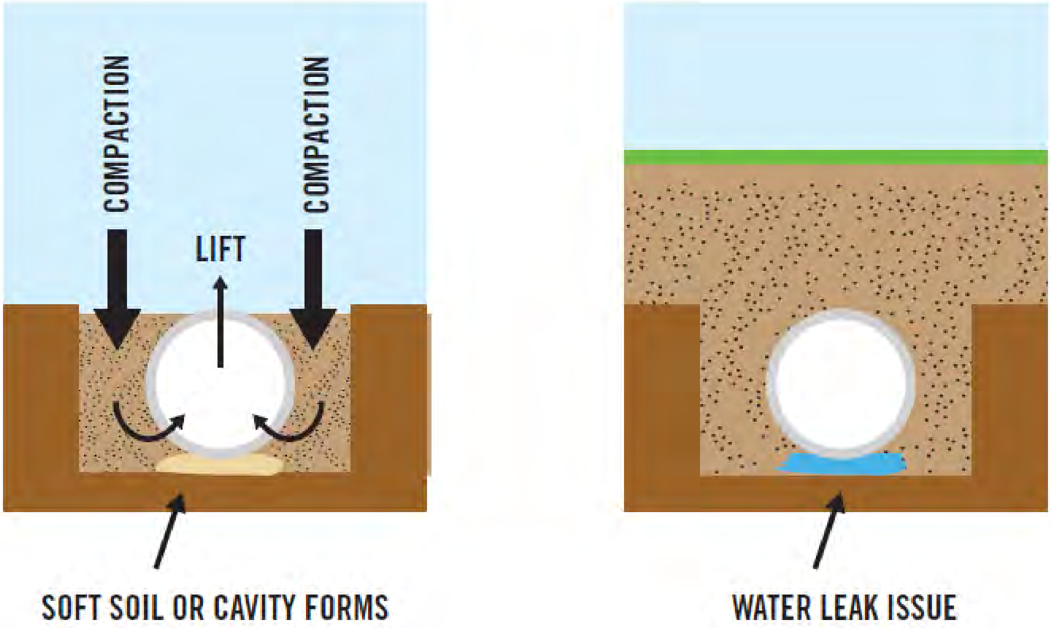


Figure 23 Pipes can lift during compaction creating a cavity that can lead to embankment failure.

This fault with haunching in pipes is avoidable when particular care is taken with placing and compacting around the pipe and using the 'Ewert Method' we advocate is illustrated in Figure 24 below.

To avoid uplift when compacting, it is important to <u>maintain downward force</u> on the pipe whilst compacting in short sections at a time down the length of the pipe. Using the 'Ewert Method' we have not had any leakage issues using this method for DB construction over the last 10 years. There are two easy ways to keep downward force whilst compacting; using the digger bucket or some other heavy weight and using piles of soil dotted along the length of the pipe.

A fencer's rammer is ideal for the initial filling against the under curvature of the pipe as the narrow head reaches around the pipe. Good idea to hire the fencer along with it! This help ensure a consistent and sustained effort along the pipe. A petrol-powered whacker is the other piece of essential equipment for compacting and working alongside the manual fence rammer in the narrow cavity each side of the pipe.

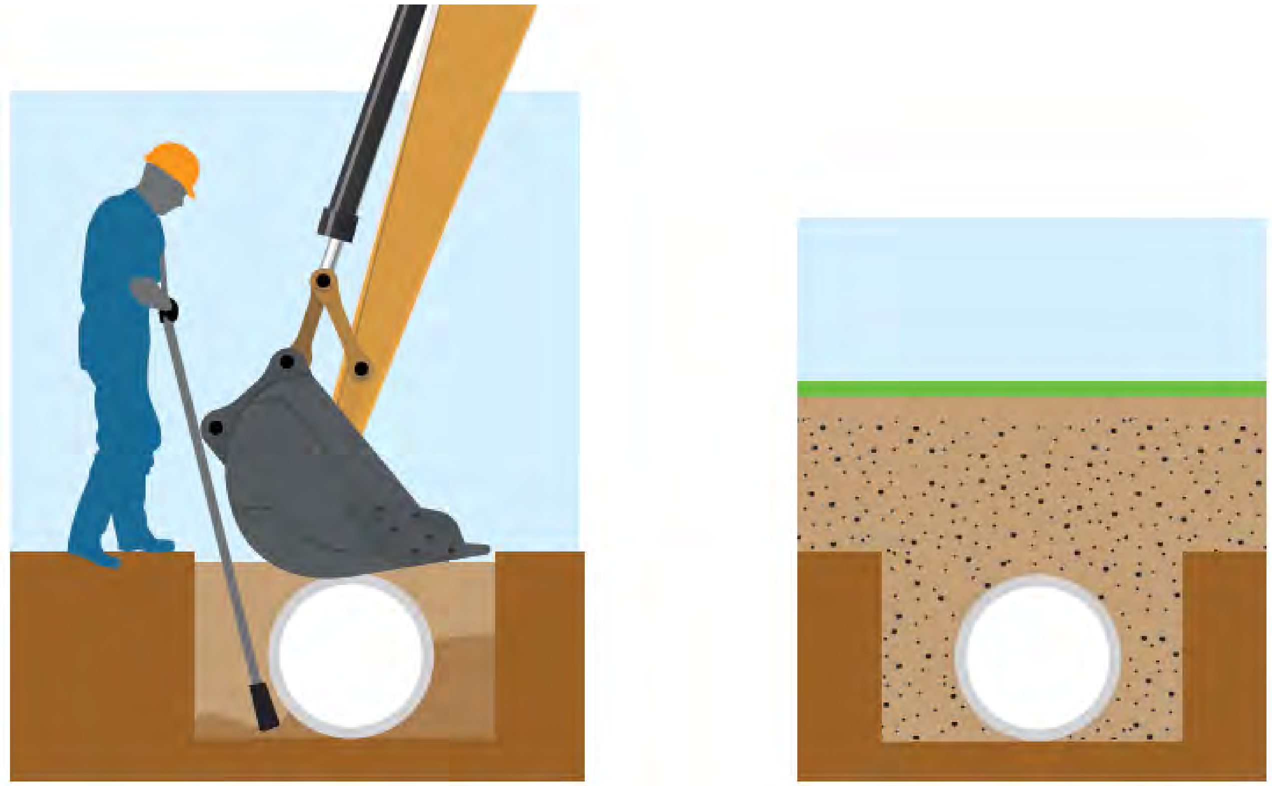


Figure 24 Maintain downward pressure when compacting around pipe to prevent any uplift voids.

Seepage sleeve drain. Your engineer or Council may stipulate a further piping failure contingency and require you to install a seepage sleeve or collar drain on the outfall section of your main DB culvert pipe. Detainment Bunds^{PS120} have usually been built without pipe seepage sleeve drains as there is no sustained water pressure in DBs and we have had no piping failures. We advocate that if the DB pipe is laid with meticulous attention to all round compaction, as detailed with Ewert Method above, there is a low risk of DB failure due to piping erosion.

A seepage sleeve drain entails placing an envelope of drainage gravel around the lower length of the DBs culvert pipe as shown in Figure 25 below. Usually about one third of the total pipe length is packed with the drainage gravel.

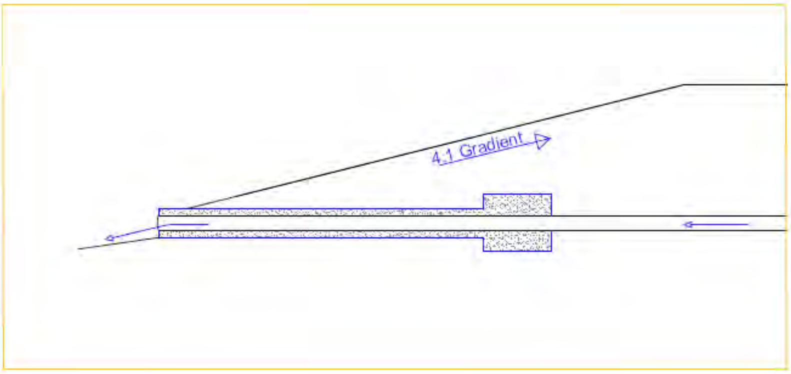


Figure 25 *Schematic cross-section showing a seepage sleeve drain on an outfall section of the DB pipe.*

Spillway. The overland secondary spillway, is an essential design feature needed in all DB structures. It is usually formed against the slope at one or other end of the DB and is best to be formed so that any overflow is not running on fill laid as part of the DB embankment. Your DB designer may have done hydrological calculations and prescribed the secondary spillway dimensions on your DB drawing. Alternatively in Appendix 2 we have provided a look-up table you can use for spillway dimensions if the DB falls within the Conditions of Use attached to the table.

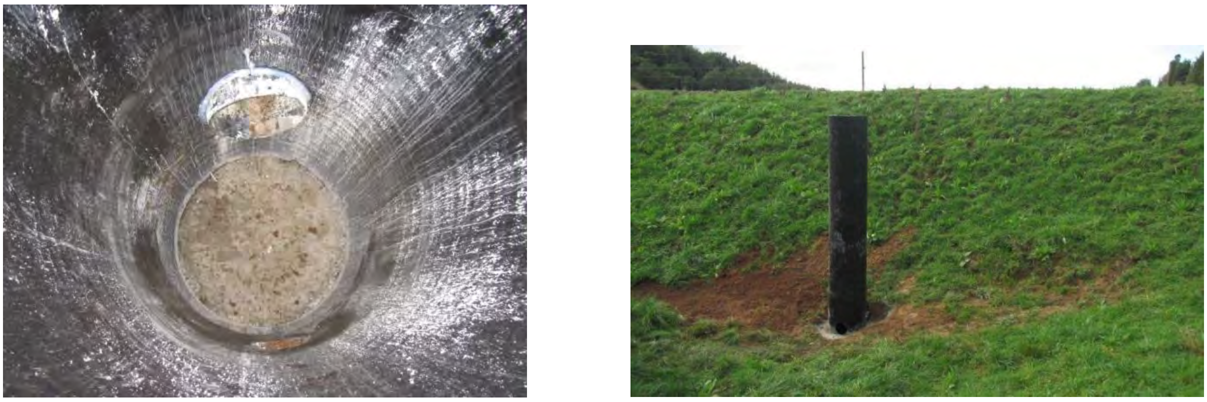
Complete Bund to full height. With the pipe safely buried, thin layers of fill can be compacted all over the bund with the dedicated roller ensuring that the compaction standard is maintained right up till the crest height is achieved.

Repatriation. Once all the fill lifts are finished its time to bring in the stockpiled soil and liberally sow both the DB and the borrow area with grass seed. This should be done as soon as practicable after completing the bund is finished and at a time of year when a good strike of the grass seed is assured. To avoid erosion from rainfall the grass needs to establish a complete cover as fast as possible. For this reason best times for DB building are usually mid to late Spring and late Summer to early Autumn. Protect the area from stock till the grass is well established.

Fitting the riser. Fitting of the upstand riser is commonly done several months after the earthworks are finished and over sown or drilled with grass. Without the riser fitted, there is unlikely to be any ponding. This protects the new earthworks from erosion caused by ponded water. When grass cover is well established over the new DB and it’s ready to work for a storm event, the appropriately sized riser (see riser size - in Appendix 3) can be fitted to the intake end of the pipe.

(a) Front view of a fitted upstand riser.

(b) Rear view – pipe/riser joint.



(c) Looking down the inside of the riser.

(d) Upstand Riser on the front of a DB embankment.

Figure 26 Upstand risers fitted onto the in-flow end of DB culvert pipes to control pond water level.

The riser will come under pressure to float up when water is ponding so it is best to extend the riser well down into the ground and attach some footings to it to prevent it lifting. The riser to pipe joint should be sealed with a suitable mortar. While builders cement will do the job, there are epoxy mixes especially made for this use that are better as they have less tendency to break free of the pipe surfaces especially when you are using HDPE pipes.

Drain hole. At the base of the riser cut a small drain hole at or just below the surface of the ground so that no ponding remains in the paddock. The size of this hole needs to be big enough so that your pond can drain completely in about four to six hours. We have some suggested plug hole diameters, related to catchment area, in the look-up table in Appendix 4.

The plug. We have tried various types of gate valves and plugs and they all do the job but perhaps the simplest is a sand bag on a sloping ramp. The ramp is set at around 45° opposite the hole so that when the bag is released down the ramp it impacts against the hole in the side of the riser and seals it off. The most important thing is that you need a plug you can extract without going for a swim. The sand bag with a stout cord attached fulfils this purpose.

Deer fence screen. Some DB outlets have no barriers or fencing around them. If safety or debris issues are a concern you can erect a deer fence screen a meter or two out from the upstand riser. Try to ensure the top of the mesh is at least 250 mm above the top of the riser rim as this will catch large floating debris and prevent it from going down the riser and potentially blocking the main outlet pipe.

DB operation/Good Management Practice

- have your DB listed on your farm hazard register e.g. dangerous during storm events.
- consider a high deer fence around the outlet upstand riser for human safety and debris exclusion.
- be aware that the sucking vortex of an upstand riser during a flood is a potentially fatal trap, and have this identified in your health and safety plan.
- be aware of when storms are coming and move stock out of ponding area accordingly.
- ensure plug is in place and rope is attached ready for pulling if need be.
- plan for water to be resident for up to three days to maximise mitigation benefit.
- if a storm is expected to be ongoing with high intensity - pull the plug earlier than three days.
- monitor the DB over the days it’s ponded.
- if upstand riser is blocked or for any other issues pull the plug early from a safe distance.
- after event exclude stock until the ponding area is dry enough. Tape off if needed.
- avoid stock concentrations in the pond area e.g. parked stock feed trailers.
- stock damage or other bare soil on the bund embankment should be repaired promptly.
- take special care to maintain good grass cover on the spillway to withstand erosion by overflow
- class the ponding area as a separate land use ‘block’ for soil testing and fertilise accordingly if at all.
- monitor bund and spillways and pipe outlets for erosion or blockages after each event. Fix damage.
- If you see evidence of silt build up – you have soil erosion upstream – review your wider farm GMPs

Final word from the authors

You deserve to take a great deal of satisfaction and pride in adopting cutting edge approaches to water quality mitigation and operating your DB(s).

The applied research on DBs undertaken through scientific investigations ensures you can be confident that you will be making a significant difference to downstream water quality with your DB installation(s).

The authors hope you will take every opportunity to be an ambassador of utilising good management practices, promoting the uptake of DBs by others and referring them to this guideline.

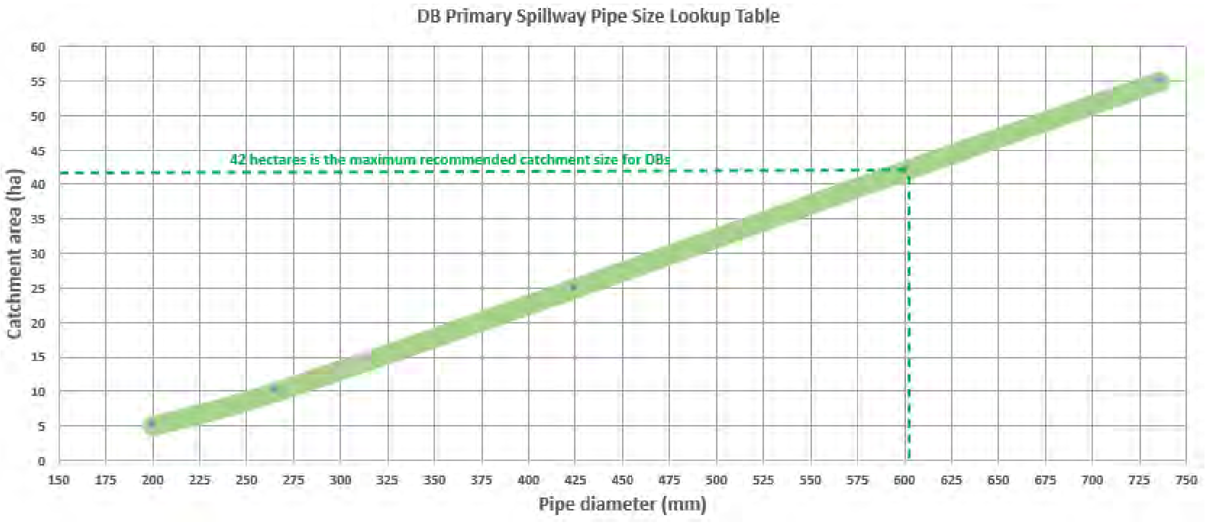
The authors are open to suggestions that may improve the implementation and performance of DBs by improving their design, build and operating procedures. Feedback that will improve the messages in this guideline are welcome.

The Authors; John Paterson, Brian Levine, and Dylan Clarke

Corespondence to: john.patersonPMP@gmail.com

Appendix 1 - The DB ‘<u>Primary Spillway Pipe’</u> look-up table

Note: Use of this look-up table is subject to the disclaimer printed on page 2 of this guideline and to Conditions for Use listed below.



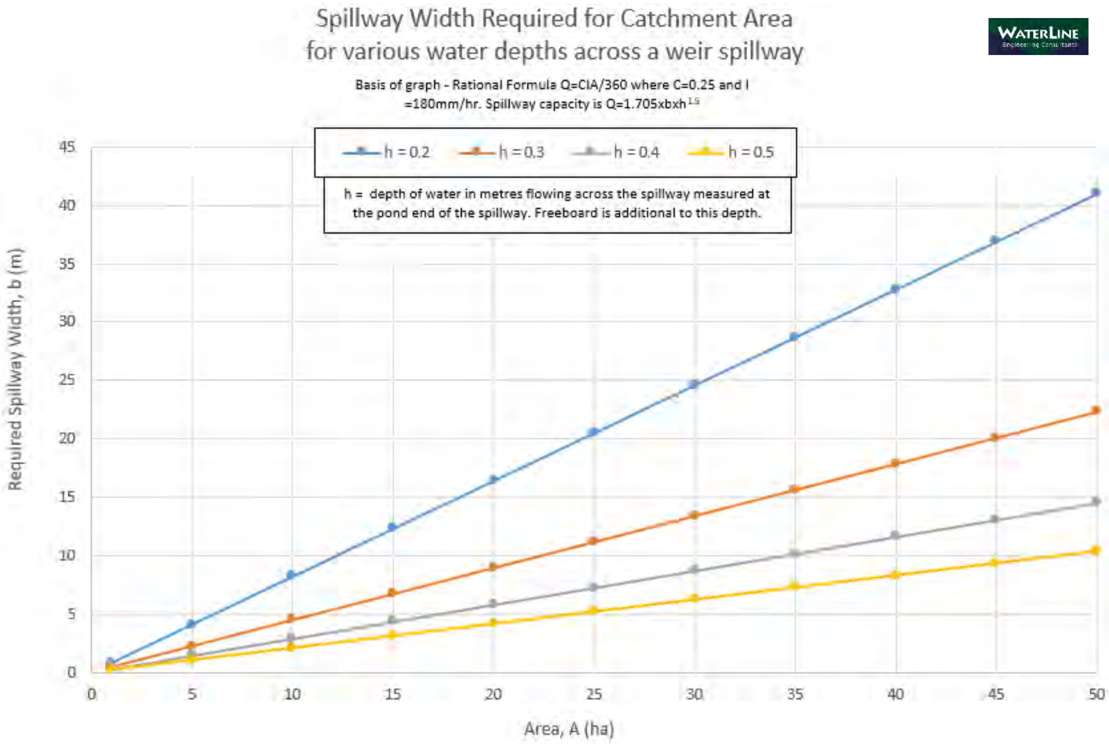
Conditions for Use of the DB ‘Primary Spillway Pipe look-up table’:

1 Only for use for DB structures with a Secondary Overland Spillway that is sized according to the specifications in the ‘Secondary Spillway look-up table’ Appendix 2.
2 Only for use for structures complying to the Detainment Bund^{PS120} brand definition e.g. not for Dams or other storm water retention structure – ref to caveats page 3.

3 The DB catchment area sizing has been calculated by use of GIS with LiDAR data and peer reviewed.
4 The DB catchment area is not greater than 42 hectares.
5 The DB attains the recommended storage: catchment threshold of ≥120 m^3/ha.
6 The DB locations are mid-farm (not near property boundary) assuring the DB landowners management responsibility for both inflow and outflow field areas.
7 Management measures are in place to reduce risk of culvert pipe blockage.
8 Soils in the catchment area are classified as, “Well drained” according to S-Map, or otherwise proven to be free draining by on-site testing.
9 The slope of DB’s catchment flow path is <5%.
10 Average slope of the DB’s flow path in the ponding area and for an equivalent distance below is <3°.
11 The annual rainfall in the district where the DB is located does not exceed 2,500 mm (98 inches).

Appendix 2 - The DB '<u>Secondary Spillway'</u> size look-up table

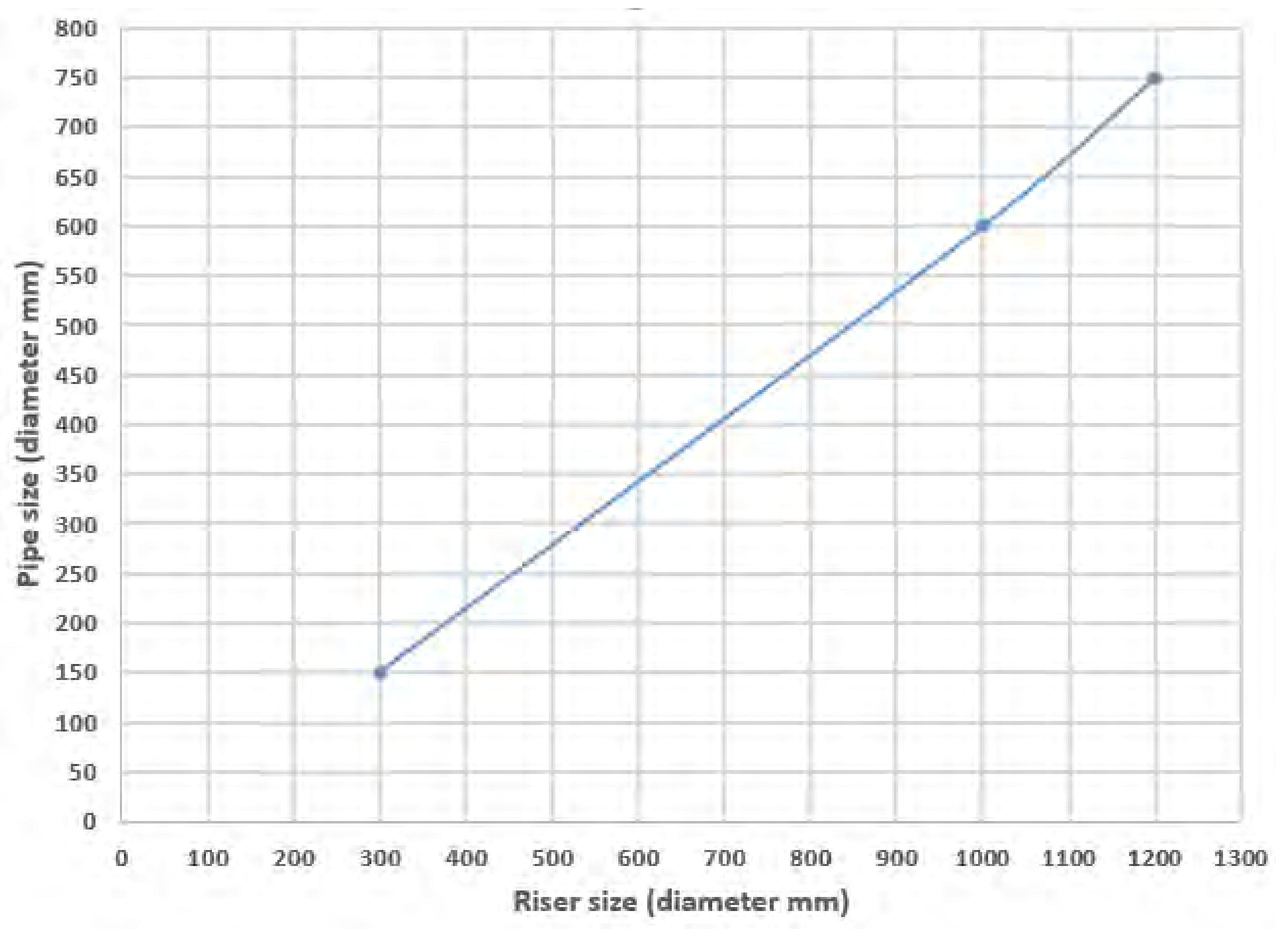
Note: Use of this look-up table is subject to the disclaimer printed on page 2 of this guideline and to the pre-conditions listed below.



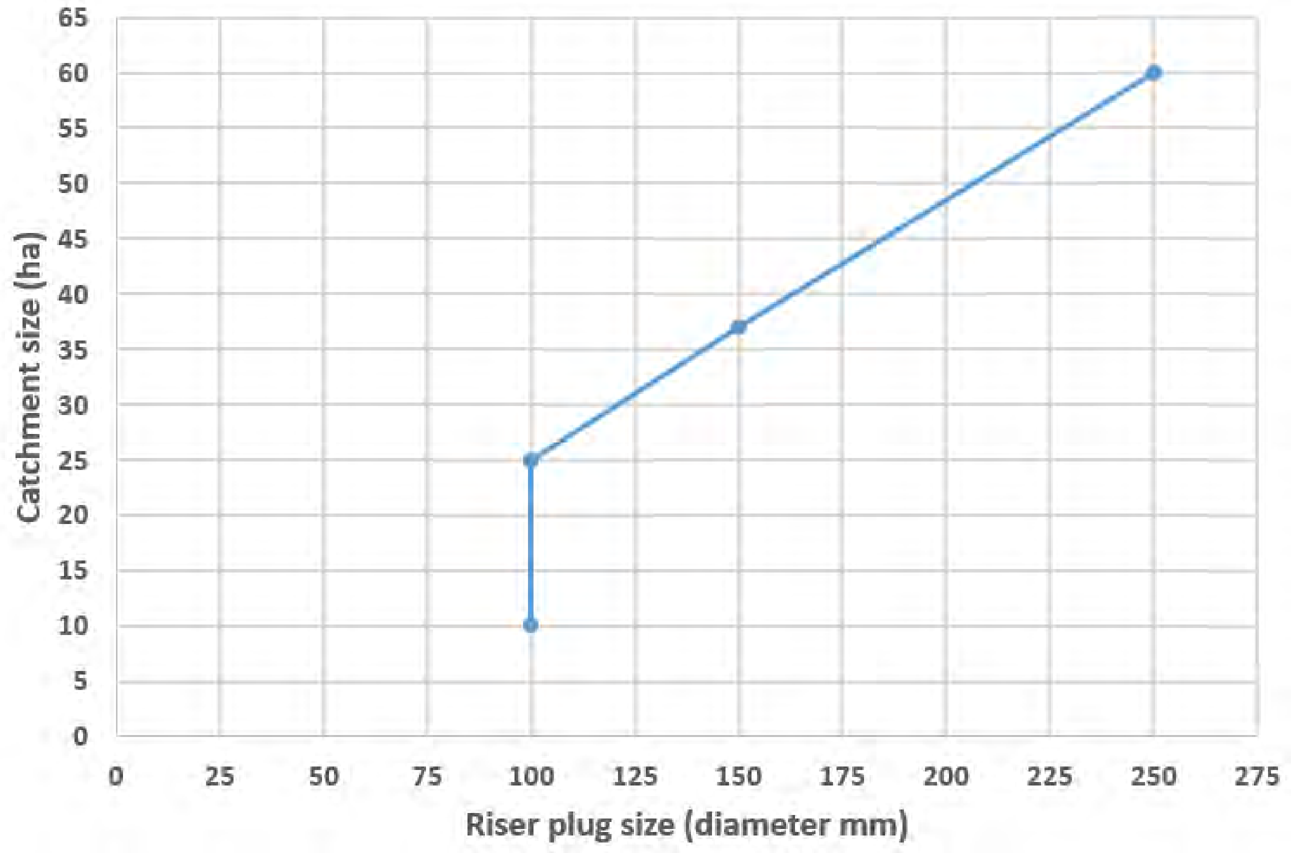
Conditions for Use of the DB 'Secondary Spillway look-up table':

1 The catchment has; medium soakage soils or better, all pasture cover and less than 5% slope.
2 Rainfall intensities do not exceed 30 mm in 10 minutes.
3 Only for use for structures complying to the Detainment Bund^{PS120} brand definition e.g. not for Dams or other storm water retention structures - reference to caveats page 3.
4 There is at least 200 mm of additional freeboard.
5 The gradient for the floor of the spillway i.e. not <1° and not >3°.
6 The spillway outfall is no steeper than one in five (11°).
7 The catchment area has been calculated by use of GIS with LiDAR data and peer reviewed.
8 The DB catchment is not greater than 42 hectares.
9 The DB has a storage: catchment ratio of ≥120 m^3/ha.
10 The DB locations are mid-farm (not near property boundary) assuring the DB land owners management responsibility for both inflow and outflow field areas.
11 Management measures are in place to reduce risk of culvert pipe blockage.
12 Average slope of flow path in the ponding area and for an equivalent distance below is <3°.

Appendix 3 - ‘Upstand riser’ sizing look-up table



Appendix 4 - Drain hole sizing look-up table



Appendix 5 - Infiltration/leaching – limited interception opportunity

Soil infiltration occurs when there is sufficient rain-fall to exceed what the ground cover plants can immediately hold and absorb. If the rain shower persists it will likely eventually drain down into an underlying groundwater aquifer. These aquifers in turn eventually spring out into streams and rivers.

Infiltration or drainage rates are strongly related to your soil type. Light soils are typically well drained and heavy soils typically have slower drainage rates. In some places there is virtually no deep infiltration due to either hydrophobic soil conditions, an impervious soil pan, an aquitard or an underlying impervious rock strata.

Soil infiltration is the primary transport pathway of the majority of nitrogen leaving the farm. Most of this nitrogen comes from animal urine patches and leaches down through the soil in the highly soluble form of nitrate-nitrogen. This nitrate passes through the root zone on its way to ground-water aquifers. Some ground water is moved in tile drains or in shallow aquifers which may re-emerge as springs. Re-emerging groundwater creates opportunities for interception by natural or constructed wetlands (Figure 27). For nitrogen moving in deeper aquifers that do not re-emerge on the farm, there is very little opportunity for interception, although in some situations denitrification walls have been installed (Figure 28).

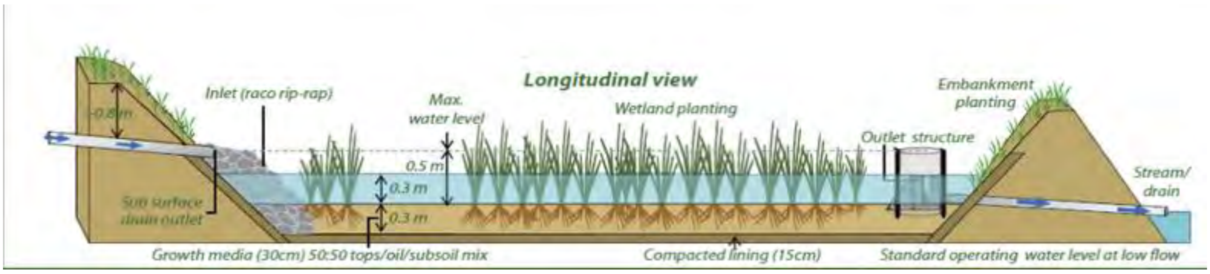


Figure 27 Constructed wetlands (Tanner et al. 2020).

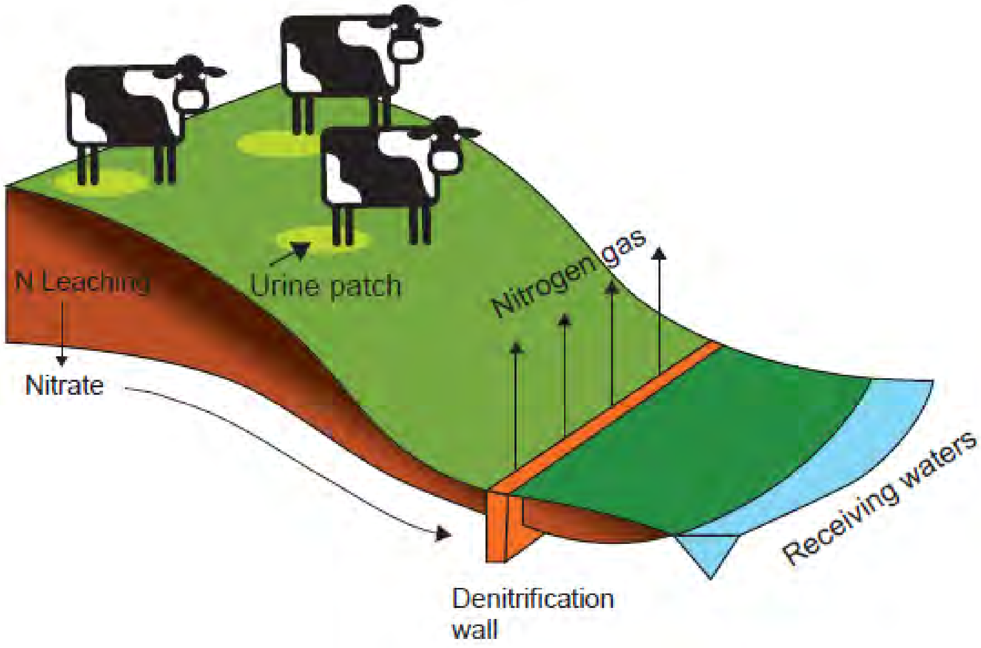


Figure 28 Woodchip denitrification wall (Adapted from L Schipper 2020).

Appendix 6 – Water quality and farm nutrient loss

It is inevitable that some nutrient losses to the environment from essential inputs will occur as a consequence of productive farming. The challenge is to minimise these losses at every opportunity with a comprehensive environment management system (EMS) supporting the farms everyday good management practice decisions and scheduling regular review and planning to integrate new measures.

There are on-going and continuous improvements being made to nutrient use efficiency in New Zealand farming. Unfortunately, even modest nutrient losses from productive farming systems can result in deterioration of downstream water quality. Aquatic ecosystems have variable sensitivity to nitrogen (N) and/or phosphorus (P) inputs. Many waterways are more affected by one or other of these two nutrients. Where water quality declines more noticeably due to increased N inputs, it is regarded as “nitrogen limited”, and where it declines more noticeably due to P inputs, it is regarded as “phosphorus limited”. Some waterways are acutely responsive to both N and P increases, but most can be classified as either more “N limited” or more “P limited”.

Nitrogen and phosphorus losses from farming generally have two different transport modes:

- Nitrogen - is typically leached through soil into ground water.
- Phosphorus - is typically transported via overland flow in dissolved or particulate form (attached to soil particles).

Farmers should be aware of the destination of water that leaves their properties and the environmental status of that public water body. Where farmers in a particular catchment know what factors are driving a perceived decline in their local water quality trends i.e. that is more N-limited or P-limited, they can have a more focused approach to mitigating nutrient losses on their own properties.

A disproportionate amount of sediment and P leaves the farm over a very short period of time during storm events.

In catchments where both sediment and phosphorus loss from farm pasture are a recognised issue for local water quality, interception of storm water run-off with DBs is likely to be beneficial for mitigating contaminants and improving water quality.

Installing DBs should not be considered as a silver bullet to fix up a messy farm operation!

The best approach to dealing with phosphorus and sediment loss is to utilise a range of GMPs that minimise their release from the soil in the first instance, such as not exceeding optimal Olsen P levels with excessive P fertiliser, and addressing Critical Source Areas for P-loss. In other words, ‘don’t let the horse bolt from the stable’ (Appendix 12 briefly summarises GMPs for mitigating P loss from farms).

Once all preventative measures have been taken and appropriate GMPs utilised DBs as an additional measure can be considered if the topography is suitable. DBs create a final opportunity for one last chance to intercept contaminants before they leave the farm.

Water quality – Your farm's connection

"Realize that everything is connected to everything else"

Leonardo Da Vinci 1452 –1519.

Rainwater and nutrients are the life blood for the profitability of your farm. Without adequate rainfall and nutrients, there would be little productivity on your farm. A daily sprinkle of rain, just enough to keep your pasture vigorously growing, would be ideal. The reality is that much of your annual rainfall arrives in events that range from barely wetting the surface through to greatly exceeding what your pasture needs. Farmers are being increasingly held accountable for losses of contaminants to waterways, much of which is caused by storm water surface run-off and infiltration. Nutrients are essential for productive use of the land. Unfortunately some nutrients will escape the farm despite the farmer's best efforts with implementing preventative actions (e.g. GMPs) in the farm's environment management system. These contaminant escapees that leave the farm and head to water ways are restricted to just two options for transport: **infiltration (leaching) and surface run-off.**

Figure 29 A storm water run-off event filling a Detainment Bund^{PS120} ponding area located on prime pasture. (Photo J. Paterson)

Appendix 7 - Risks

Failure risks – Dams vs DBs

Detainment Bunds^{PS120} are not dams

Unlike dams, there is no permanent storage of water in DBs since they only fill during high intensity run-off events. Additionally, the DB ponds only remain at full capacity for about 1% of the time compared to 100% of the time with dams. Although DBs are not dams, it's useful to recognise DBs as dam-like structures when considering possible DB embankment failure scenarios. When assessing the risk of embankment failure, it is necessary to consider the consequences of failure to people and property downstream.

In 2019, new regulations for dam safety were proposed for large dams that specifically "exclude small dams" (MBIE 2019), and presumably also exclude DBs. The proposed 'classifiable dams' are ≥4 meters in height, and 20,000 m^3 in volume, or less than 4 m in height but ≥30,000m^3. Due to their large scale, these classifiable dams are ones that in the event of failure could harm downstream populations, and damage property and the environment in the event of failure.

Most dams on farms are well below the size requirements proposed for 'classifiable dams', and the proposed requirement for assessing the 'Potential Impact Classification (PIC)' of the dam. Small dam construction is generally a 'permitted activity' governed by Regional Councils. As DBs for mitigation of water quality issues are a relatively novel technique, regulators have not yet made specific permitted activity provisions for DB structures. Without a separate distinction between DBs and dams by Council planners and regulators, DBs are usually considered to have the same permitted activity status as small dams by default (e.g. same Regional Council specified embankment height and ponding volume limits as for small dams).

Common features of both DBs and dams

Some of the main features of a dam are illustrated in Figure 30 and some of the same terms used for dams are common for DBs e.g. crest, principal spillway, emergency spillway, abutment etc.

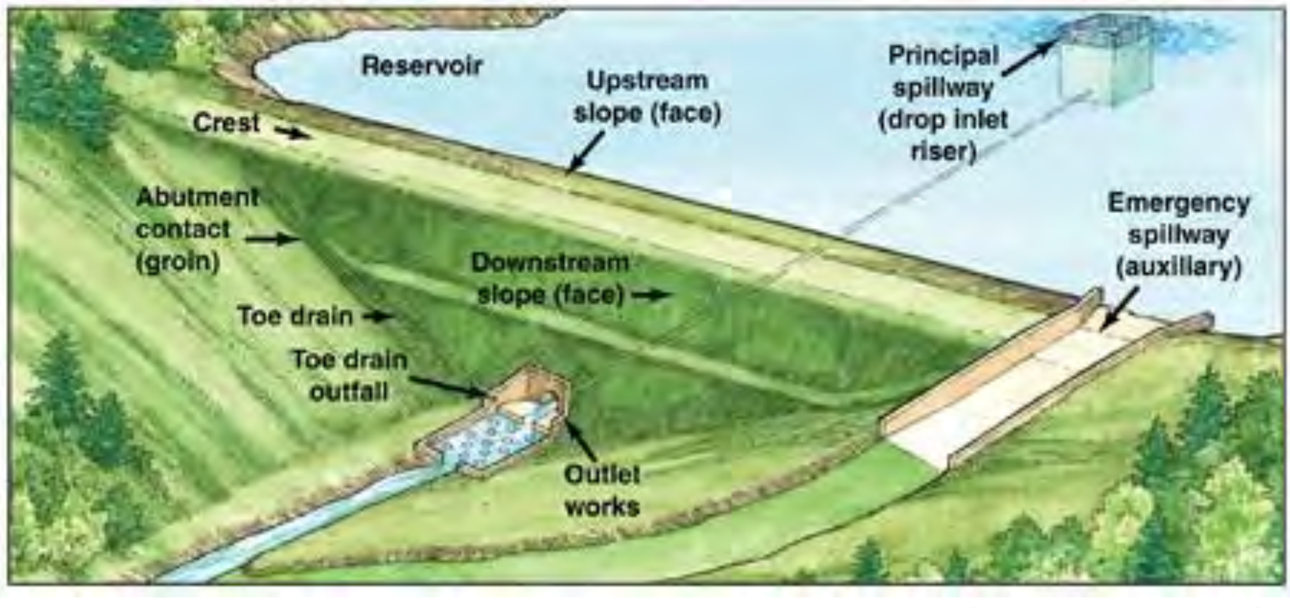


Figure 30 Typical dam diagram showing common terms. [From USDA, USFA 2012]

Dam: Failure risk features

With dams, failure issues are often related to the persistent head pressure of water. The head pressure can lead to water infiltrating the dam wall, causing liquefaction and collapse. Also imperfect compaction during construction and around outlet popes can also lead to dam failure cause by piping erosion due to persistent leakage migrating along fissures or voids. Figure 31 shows some of the main dam failure locations and terms.

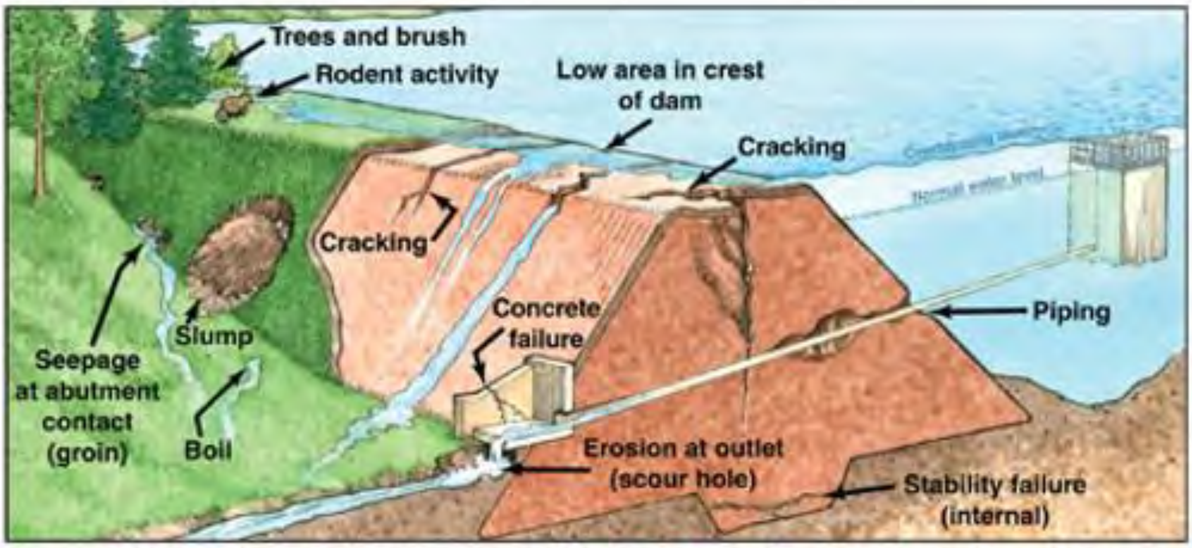


Figure 31 Typical dam failure features. *[From USDA, USFA 2012]*

The top three categories for earth dam failure are:

- Piping erosion (often around the culvert pipe).
- Overtopping (eroding the downstream dam wall batter).
- Structural (cracking, slumping).

In addition to the three main types of failure categories, others include slumping, settlement, toe and abutment leakage, hydraulic fracture and liquefactions. Most of these causes of failure are related to the dam's permanent water levels which generate sustained pore-water pressure. The higher the permanent dam water level the greater the 'head' pressure that can exacerbate these types of failures. The caveats that apply to DBs (page 3) including: brief ponding periods; limited catchment size; low embankment heights; high storage capability relative to the catchment size (≥120:1), and low gradient mid-farm locations, all serve to further ensure the inherent safety of DB structures. More detail on minimising the risk of failure aspects during DB construction is summarised in Table 4 and the key risk features are further elaborated on in more detail in the construction process (page 26).

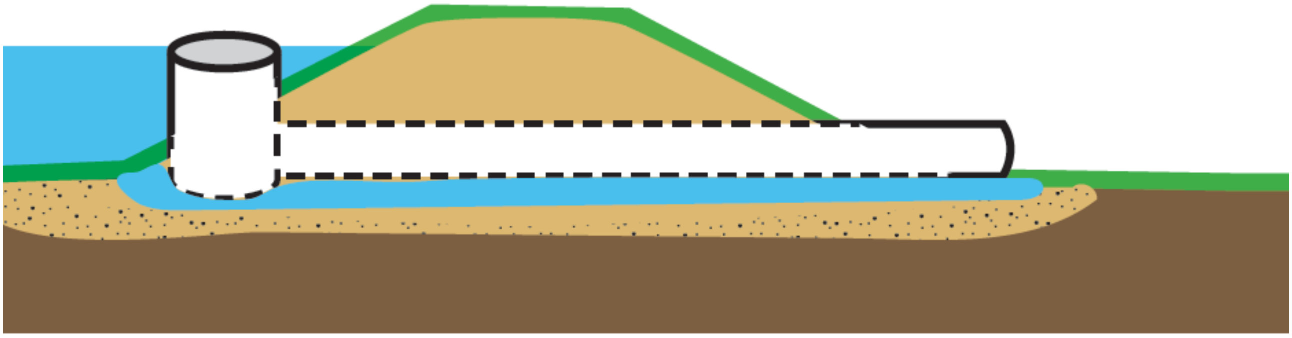


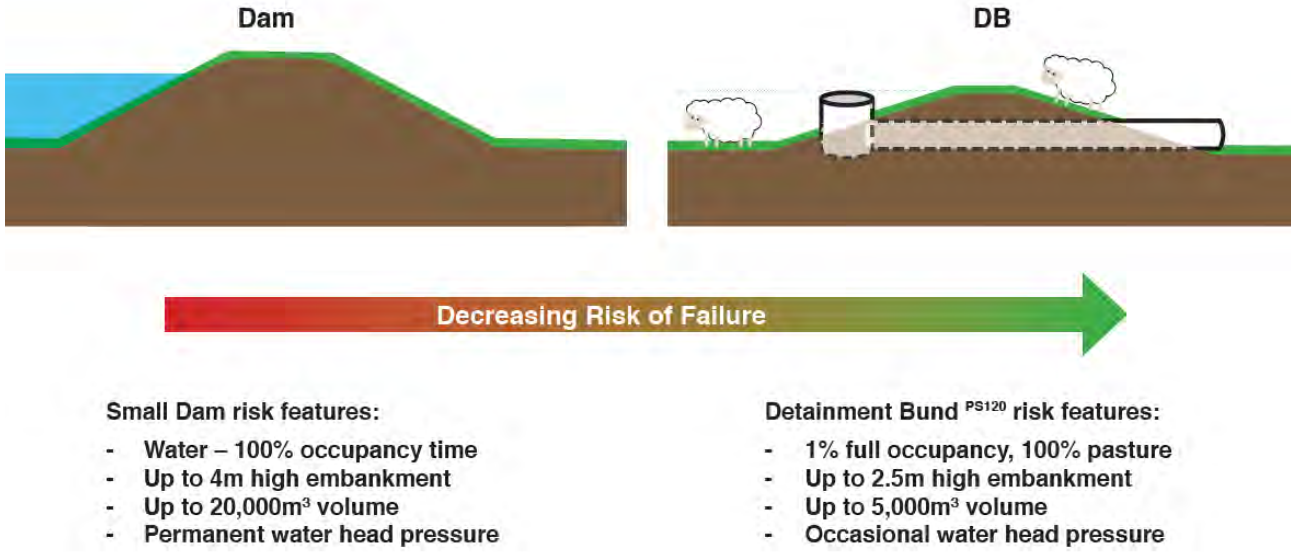
Figure 32 Piping erosion occurs due to poor pipe installation and can cause embankment failure.

Table 4 *Design and construction provisions for DBs that address the main embankment failure categories known to occur in poorly constructed dams.*

Earth dam Failure Top 3 categories	**Design** features of DB embankments that minimise risk of failure	**DB construction** methods and measures that avoid/mitigate embankment failure risk
1. Piping erosion: - Through dam embankment	High standard of compaction, appropriate fill material, engineer advice.	- Professional advice on suitability of fill materials - Compaction in thin layers (<200 mm) - Dedicated roller - Monitoring compaction during construction
- around dam culvert	Attention to manual compaction around pipe.	- Compaction around pipe - Prevent underside voids - Consider a seepage collar
2. Overtopping	Precise catchments Sizing. High capability for large events with large size of both primary spillway pipe and secondary overland spillway. Contingency for Climate Change.	- Use a skilled GIS professional for peer reviewed catchment sizing - Pipe has large capacity – the primary spillway - Good compaction of embankment fill - Use screens (not grills) to avoid blockages - Engineer advice on sizing secondary spillway - Climate change effects size contingency - Low DB embankment batters resist erosion - Maintain thick grass sward on embankment - No bare soil patches on the embankment - Remove DB plug during sustained large storms
3. Structural	High standard of compaction, appropriate fill material, engineer advice.	- Professional advice on suitability of fill materials - Compaction in thin layers (<200 mm) - Dedicated roller - Monitoring compaction during construction - No opportunity for leakage or infiltration into the DB embankment - 1% to 4% full pond occupancy/yr, (Table 5)

Figure 33 *An example of 'piping' erosion. Poor pipe haunching, inadequate compaction around the pipe during installation, causing embankment failure. (Pipe cross section diagram and photo from FEMA 2005).*

Detainment Bund^{PS120}: Low failure risk features



Small Dam risk features:

- Water – 100% occupancy time
- Up to 4m high embankment
- Up to 20,000m^3 volume
- Permanent water head pressure

Detainment Bund ^{PS120} risk features:

- 1% full occupancy, 100% pasture
- Up to 2.5m high embankment
- Up to 5,000m^3 volume
- Occasional water head pressure

Figure 34 Decreased risk is inherent with DB design, size, pasture and limited water occupancy.

While sustained water pressure is a typical cause of potential failure of both dam and DB embankments, the root cause of this potential failure is avoidable. Failure originates with initial faults in the preparation (lack of expertise or experience), inadequate standard of design, and deficient construction processes. These inadequacies can lead to structures being built with low pond storage capacities in relation to the catchment areas they are servicing and/or lead to water penetrating the embankment structure or bypass under its foundation.

These failure risks can be avoided by obtaining appropriate professional advice on: the sizing of the catchment and the capability of the proposed structure storage volume; the suitability of the chosen site including the geology of the catchment and underlying the proposed structures footprint area; the permeability of the underlying strata; the suitability of the 'borrow pit' soil properties for embankment fill purposes, and whether or not fill soil can be compacted sufficiently to prevent leakage of ponded water into the embankment structure. Also, local farmer experiences with dam structures in the district may serve as a useful indicator of likely dam success or potential issues.

The need for professional advice (e.g. GIS and Engineer) applies to both the building of dams and Detainment Bunds^{PS120}. However, the potential for failure and consequences of failure are considerably reduced with DBs due to a number of physical features related to their design and purpose.

The principal difference relates to the occupancy time of water in a DB compared to a dam, remembering that DB's, by definition, occupy pasture without undue compromise to productivity.

Risk associated to DB water occupancy time and depth

The majority of rainfall events in NZ farming districts do not result in run-off events.

The majority of rainfall events have short durations and/or low intensities.

Ground cover and soil infiltration capacities ensure the soils are capable of absorbing most or all of the precipitation during typical rainfall events. The balance of run-off versus non-run-off rain storm events will vary by region around New Zealand depending on local climate and landscape characteristics including ground cover and soil drainage properties.

In the Bay of Plenty region, 'high intensity' rain events (>10 mm per hour) lasting more than one hour typically result in storm water run-off that contributes to filling or partially filling a DB pond. These types of storms have historically occurred around five to six times per year in the Rotorua Lakes district.

Not all storms generate sufficient run-off volumes to completely fill the DB pond. The length of time water may be present in a pond depends on the volume of run-off delivered during a storm.

During smaller, partial filling events, the ponded run-off may be completely drained after one or two days due to soil infiltration, while during larger storm events, water may be present until the pond is released when the farm manager pulls the DBs plug after three days in accordance with the pasture preservation protocol. For one third of all the filling events, the water dissipates completely by infiltration within three days.

Run-off water in the ponding area may be present for the entire three day ponding duration up to 12 times throughout the entire 'extreme' year. Throughout all ponding events, the volume of run-off in the pond will gradually diminish due to soil infiltration occurring in the 'well drained' soil types commonly found in the Bay of Plenty Region. The number of ponding events occurring under two scenarios, based on trials at DB sites occurring in 2012 and 2018 in the Bay of Plenty, is shown in Table 5 below. A typical year with six run-off storms, and the other under extreme conditions with 18 run-off storms per year, along with number of events occurring with varying pond durations.

Table 5 Frequency of events and ponding residency time for normal and extreme years.

Number of ponding events in trial year and year type	Number of events requiring the primary spillway (ponded water going over the upstand riser)	Number of events requiring the secondary spillway (ponded water going over the bund)	Number of ponding events with:		
			<24 hours of ponding	24 to 48 hours of ponding	>48 to 72 hours of ponding
6 'Normal'	2	1	1	1	4
18 'Extreme'	2	2	3	3	12

This variable occupancy, from full to partially full to empty within three days, means that DBs can have various levels of ponding residency; ranging from 15 days per year in 'normal' years to 45 days per year in 'extreme' years, or 4% to 12% respectively over a one-year period. The limited ponding periods contrast with permanent dam structures that may be inundated up to 100% of the time.

On occasion, larger storms are capable of filling the pond enough to overtop the primary spillway (i.e. over the upstand riser), while even larger, rare storm events may exceed the pond storage capacity causing ponded water to go over the secondary spillway (over the bund).

When the pond storage capacity is exceeded, run-off is rapidly drained by the primary and secondary spillways so the duration of the pond being filled to maximum capacity is very short (≈ 9 hours or 0.1% over the course of the entire 'extreme' year). It is during these limited periods when the DB is completely full when water pressure on the embankment is at its highest. The pressure from a 2.5 m deep pond is approximately five times greater than for a 0.5 m deep pond (see Table 6 below).

Table 6 Water pressure variation with typical DB pond depths.

DB Pond Height (m)	Water head pressure (kPa)	Water head Pressure (psi)
0.5 m	5	0.7
1.0 m	9	1.4
2.5 m	24	3.5

In conclusion, DBs have very low water volume occupancy rates throughout the year (around 4% in normal years and in extreme years around 12%), and the time the maximum pond capacity is sustained is extremely limited (<10 hours annually or around 0.1% of the time).

These findings demonstrate that the risk of DB failure due to prolonged water pressure and piping induced erosion is almost negligible for carefully located, designed and constructed DB embankments.

Figure 35 A typical Detainment Bund^{PS120} on prime valley floor pasture.

Consequence of DB failure

There are many well recorded instances of the consequences of large dam failure on downstream communities (including fatalities) and infrastructure and it is these downstream consequences that has driven the need for regulation and standards that apply to building dams and the subsequent monitoring of them to help ensure safety of the wider community (MBIE 2019).

While DBs inherently have considerably diminished risk of failure compared to dams, it is still important to consider the possible consequences if a DB were to fail. When a DB site is proposed the landowner should assess the downstream flow path both on his own property and especially on any neighbouring property for a considerable distance downstream.

The width and length of possible damage from a failure will depend on the size of the breach and the slope of the valley floor below the bund. With DB caveats (see page 3) limiting storage to <5,000 m³ and catchments to <42 ha, most DB structures will be less than 2.5 m high and any breach is likely to be a relatively narrow section of the whole bund length (say 3 m to 6 m), rather than a catastrophic failure of the complete structure along its entire length. If the downstream area is a relatively flat pasture paddock belonging to the DB owner, the width and length of coarse debris deposit from such a failure will be mostly within a 20 m wide by 100 m distance.

If the DB is built near a boundary and the flow path is constrained by steeper side slopes to a much narrower path or incised channel, there is potential for coarse sediment deposits and infrastructure damaging forces of the escaping water to extend downstream for a kilometre or more.

For this reason, we recommend that wherever possible DBs should be built in ‘mid-farm’ locations at least 100 m upstream of the farm’s boundary. If there are neighbouring buildings, housing, or urban sub-divisions downstream from a DB, seek further advice from your local Regional Council about what further safeguard may be required.

Inherent safety of DBs

The design aspects of DBs such as; small catchments (<42 ha), brief ponding periods, the high volume capability rated to the catchment size (120 m³/ha), and preferred mid-farm locations, all serve to further ensure the inherent safety of DB structures. Unlike a dam failure, a DB failure, whilst likely to make a localised mess of sediment deposits, is extremely unlikely to pose a hazard to human life or cause injury.

Figure 36 Storm water from 500 ha. No place for a DB. Catchment of DBs are less than 42 ha.
(Photo courtesy of M & S Dibley)

Appendix 8 - Climate change considerations (risk and opportunity)

During the Detainment Bund^{PS120} applied research, exceptional rain storm frequency occurred at the trial sites during 2018. There were 18 run-off events which was three times the expected 'normal' frequency of high intensity rain storm events for that district. There is some speculation amongst local farmers that this increased frequency of high intensity storms "may be the new normal". Their views are endorsed by science evidence that climate change is impacting New Zealand now, with increased rainfall intensity and more severe storm events occurring, together with other effects including hotter days, increased droughts etc. (Pearce 2018, Cradock-Henry 2019, Foley 2019, Lawrence 2016, 2018) as illustrated in Figure 37 below.

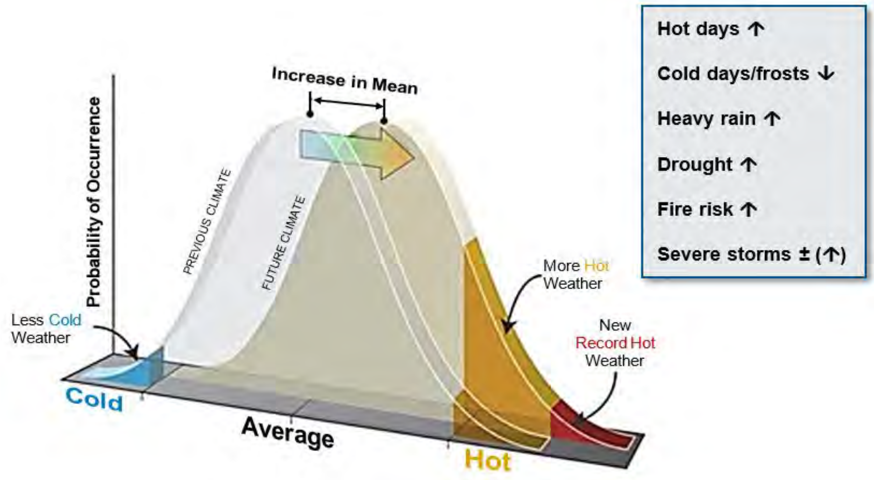


Figure 37 Changes in extremes as a result of changes in mean climate. [From Reisinger A (2009)]

A survey of 3,740 rural land owners in the Spring of 2019 (Brown 2020) showed that 50%-55% of pastoral farmers believe that climate change is already affecting New Zealand, and roughly 70% agree that if not already happening, climate change will affect New Zealand in the future.

Given that scientific evidence confirms that there are now more frequent and intense rainfall events contributing to increased run-off, there may be implications for farmers in areas where water quality issues are perceived to be caused by contaminant loads (phosphorus, sediment, *E.coli*) carried off-farm to public waterbodies by storm water. Water quality issues linked to increased run-off may create greater challenges for farmers to comply with regulations that limit contaminant losses in farm run-off. While this is clearly a risk to the farm business, there is also an opportunity associated with DB uptake.

Detainment Bunds^{PS120} provide farmers with both an ability to intercept storm water and the potential for multiple on-farm and off-farm benefits, especially with the escalating effects of climate change (Table 3, page 12). Climate change projections reveal that DBs should be built with additional contingencies now so that their spillways can cope with increased volume capacities of storms and more frequent wear and tear.

While the focus of this guideline is to enable the roll out of DBs to assist farmers in mitigating phosphorus and sediment to address water quality challenges, there are many other potential impacts, and some opportunities, to consider from the increasing number of storm water events on the wider community. Some of these impacts are summarised in Figure 38 below. The diverse range of direct and 'knock-on impacts is called 'a cascade' of effects which have immense cost implications to the stakeholders in a community (Lawrence 2018, Figure 39). Over time, when the climate change cascade effects are fully understood and accounted for, DBs may be recognised as an 'adaptive action' mitigation method that benefits entire communities, and could be integrated as part of a 'new system' approach to deal with the challenges brought about and amplified by climate change.

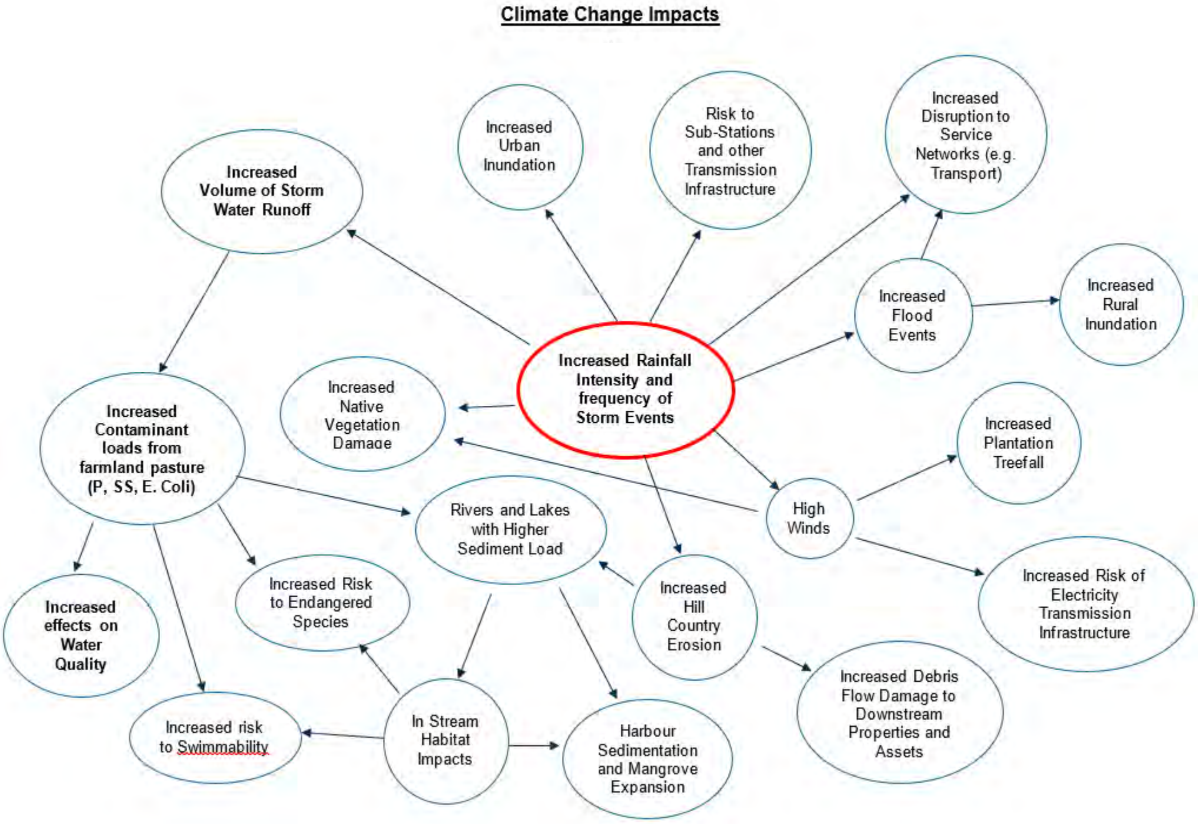


Figure 38 Impacts of Climate change. [Adapted from Lawrence et al. (2016)]

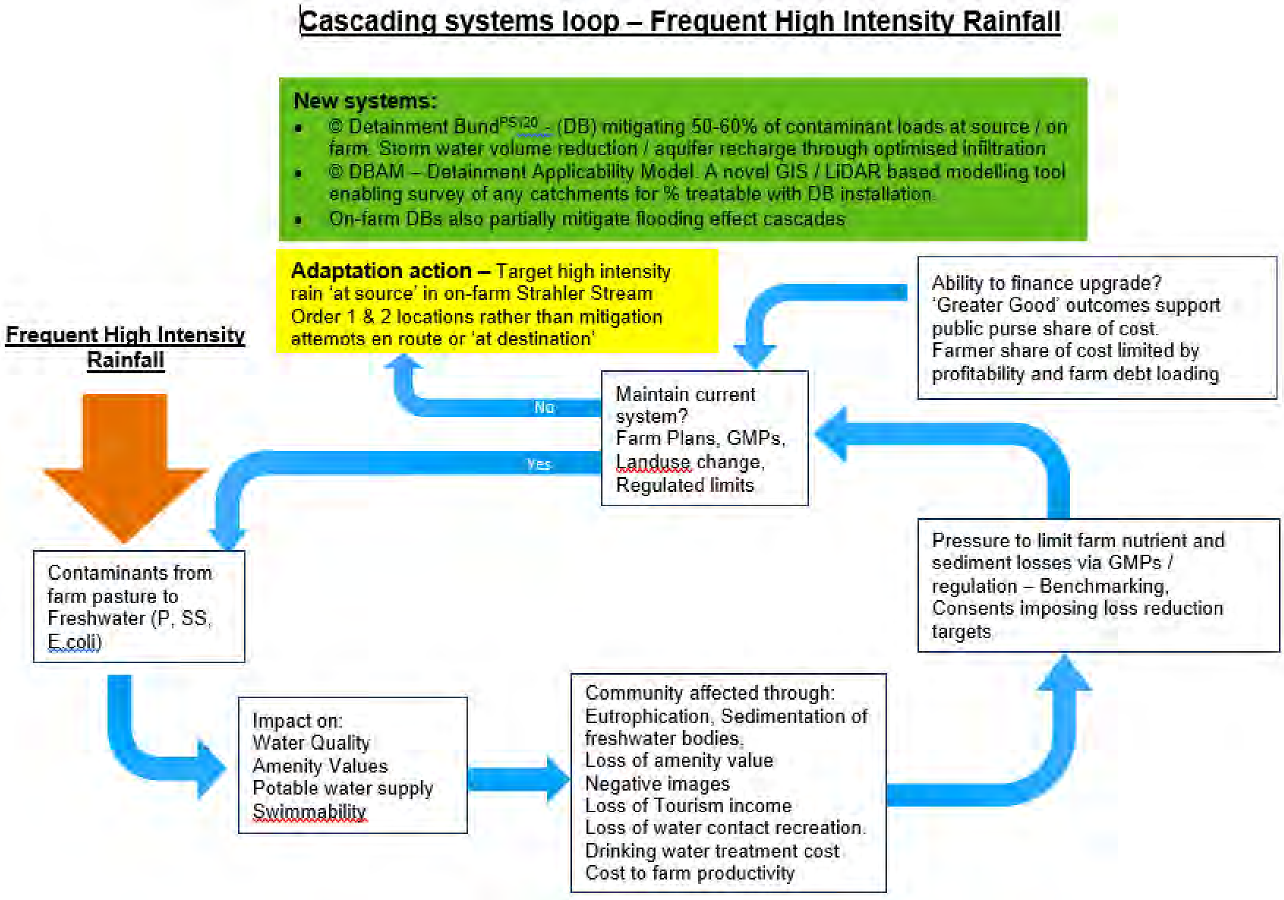


Figure 39 Intense Rain issues – The Cascade Effect. [Adapted from Lawrence et al. (2018)]

Appendix 9 - Steps for a DIY soils infiltration test


1 – Remove both ends of bean cans.


2a – Drive cans partly into the ground.


2b Option – drive in with a mandrill.

(Red length = desired water start depth)


4 – A 10 can sample plot and tools.


5 – Fill to pre-soak soil for ½ hour.


6 – Refill all 10 cans and wait ½ hour.

7 – Measure infiltration on all 10 cans and record.

8 – Result assessment - ½ hour infiltration test with 10 cans:

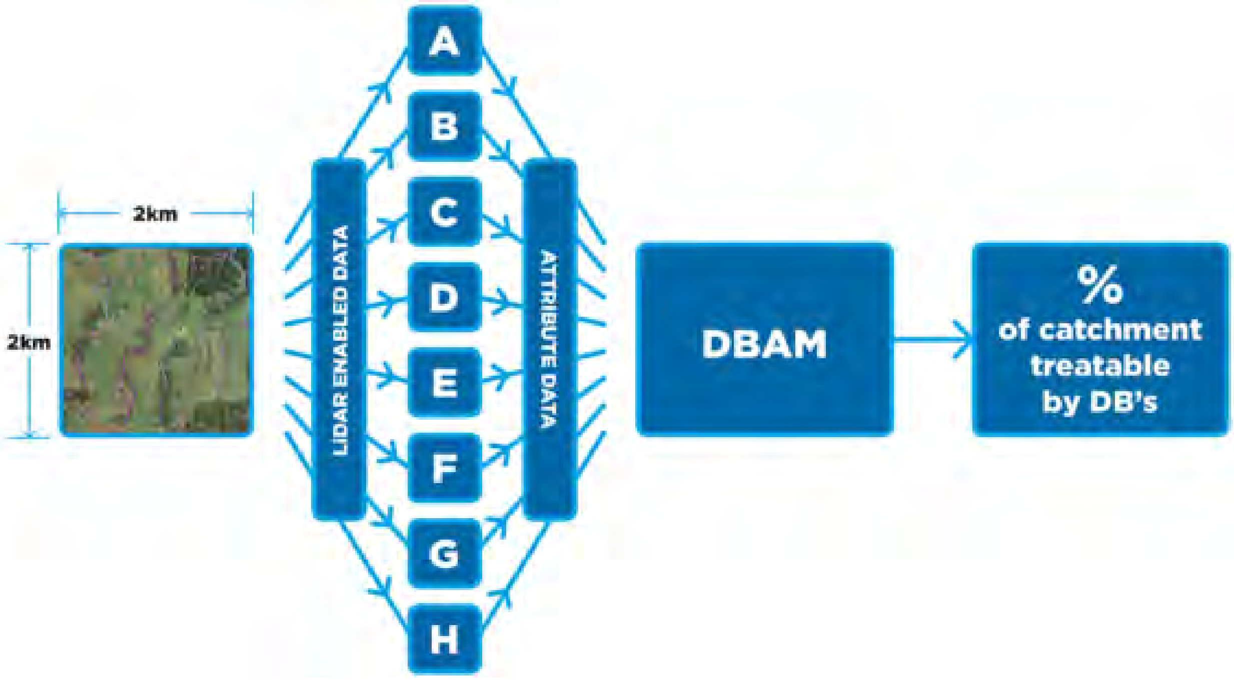
10 Can sample plot test for a ½ hour period										Totals	Average
1	2	3	4	5	6	7	8	9	10		
Depth of infiltration mm/½ hour											
75	22	26	32	2	14	21	16	4	17	229	22.9 mm/½ hour
Convert infiltration depth to mm/hour by multiplying ½ hour measurements by 2.											
150	44	52	64	4	28	42	32	8	34	458 / 10	45.8 mm/hour
Remove extreme outlying values (in red)											
~~150~~	44	52	64	~~4~~	28	42	32	8	34	~~458 / 10~~ 304 / 8	38.0 mm/hour

Average of 10 Cans	-229 / 10 = 22.9mm per ½ hour or	**45.8 mm/h**
Delete Outliers (150 and 4)	highest (atypical leak?), lowest (atypical compaction?)	
Average of remaining 8 Cans	- 152 / 8 = 19 mm per ½ hour x 2 =	**38 mm/h**

Appendix 10 - DBAM for landscape assessment

Given the limitations to DB applicability in some landscape types, it is strategically important for those planning roll out of DB installations in new areas to be able to predict the likely applicability of DBs, to determine if this type of mitigation installation will be practical in the landscapes or catchments under consideration for on-farm storm water run-off interception and treatment. Creating a measure of landscape suitability for DB applicability is important, and will ensure that resources for promotion and implementation of DB mitigation for water quality objectives are focused in places where they have potential to be effective. The Detainment Bund Applicability Model (DBAM) (Paterson 2019) is an accurate GIS based DB applicability assessment tool that can help planners to predict the likely result of DB installations for water quality improvement goals.

The DBAM algorithm was tested with fourteen different landscape type control plots, each 2 km by 2 km (4 km^2 or 400 ha). The DBAM algorithm was tested against each of the 14 controls using scores derived for eight (A to G, see diagram below) physical attributes based on GIS datasets, including use of LiDAR data. These 14 landscape types were then scored by the DBAM algorithm with its eight integral keys to produce a DB applicability percentage for the target plot of catchment. These 'control' scores were then compared with the actual percentage DB applicability derived by manual assessment of each plot. The model achieved accuracy of ±6%. The DBAM output is an estimate of the percentage of any chosen catchment, of any landscape type, that can be treated by DB installations.



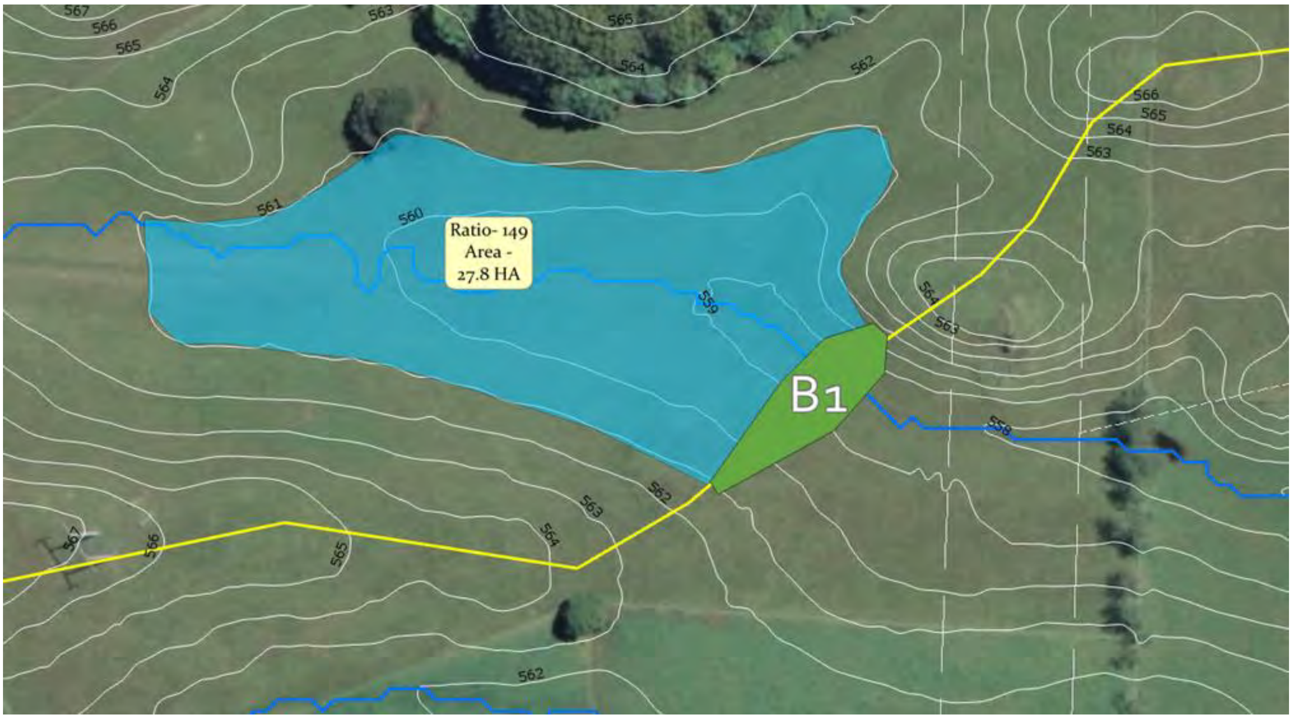
If this is your particular interest, then you can access the full DBAM paper and its separate operational algorithm at:

https://www.boprc.govt.nz/your-council/documents-and-publications/publications/ search under 'PDF documents' – 'Consultant publications' - for *Phosphorus Mitigation Project* or see at https://atlas.boprc.govt.nz/api/v1/edms/document/A3262395/content (without algorithm).

Appendix 11 - ArcGIS Pro for DB site 'mock-ups' and assessment

Introduction

An ArcGIS Pro project (aprx) has been set up to allow the Council Land Management Officer (LMO) to create and determine the viability of a prospective Detainment Bund^{PS120} (DB) site, using a drafted mock-up placed exactly on the proposed site. The project utilises ArcGIS Pro "tasks" to step the user through the process. This project can be shared via FTP.



Prerequisites

- Knowledge of GIS principles and basic ArcGIS Pro skills.
- Software licensing for ArcGIS Pro.
- Knowledge of geomorphology and skills in determining probable DB sites.

Tasks

This section provides a high level description of steps set up in the project.

1. Create the polygon feature delineating the proposed DB site.
2. Establish the proposed height of the DB (1/3 DB height = the average depth of the pond).
3. Create the polygon feature delineating the ponding area (guided by relevant contour lines).
4. Calculate Storage Volume (m^3) by multiplying ponding area (m^2) by 1/3 of the bund height.
5. Create the polygon feature delineating the extent of the DB's catchment.
6. Calculate the storage per ha ratio by dividing storage volume by the DB's catchment area.
7. Calculate status of the DB site – if Storage per ha <100:1, status = failed; if storage per ha >100:1 and <120:1, status = possible; if storage per ha ≥120, status = passed.

Layer set-up

This section provides a brief description of layers set up in the project.

Contextual layers

The purpose of these layers is to provide locational context for the LMO as well as derived layers from LIDAR as listed below. These (or equivalent) layers will need to be set up by the GIS Technician for the respective catchment areas targeted for DB application.

- Streams layer derived from 2 m DEM of the region.
- Ridgelines derived from 2 m DEM of the region.
- 1 m contours.
- Aerial imagery.

Working layers

The layers described in this section are used for the purpose of scoping the mock-up DB sites.

- **Detainment Bund**^{PS120} - Polygon feature class to be edited by the LMO to create the prospective DB site on the map. The feature class includes the fields – Unique ID, Height, Height divided by three and Status. The default value of the DB height has been set to 2.5 m. The user has the ability to change this value.
- **Flow path** – Line feature class to be edited by the LMO to create an ephemeral flow path, if the streams layer is inaccurate
- **Ponding** – Polygon feature class to be edited by the LMO to create the ponding area Fields include Storage Volume.
- **Sub-catchment** - Polygon feature class to be edited by the LMO to create the contributing DB catchment area upstream of the DB site. Fields include area ha and storage per hectare.

For more information on inter council collaboration between GIS departments and sharing of the DB GIS package, contact the corresponding author.

Appendix 12 - Good Management Practices (GMPs)

All of New Zealand's agriculture sectors and some processors/industry bodies have distributed Environment Management System (EMS) templates to farmer suppliers. While these have various names, they largely follow ISO 14001 environment management principles such as identifying risks, organising actions, practical scheduling of actions over time and reviewing progress at fixed intervals. The common denominator in all of the AgIndustry environment plan templates that farmers can access is that they are essentially voluntary and encourage 'continuous improvement'. So the most fundamental GMP is 'start with a plan' and preferably based on an AgIndustry supplied template.

The table below lists some of the fundamental good management practices that farmers may adopt for minimising P-loss from farm pastures. It is adapted from McDowell (2010), then adapted by Levine (2020), and finally again for this document.

	Strategy	**Effectiveness (%)**	**Cost** (NZD kg P^{-1} conserved)
Good Management Practices	Optimum soil test P	5-	Highly cost effective[1]
	Low solubility P fertilizer	0-20	0-30
	Stream fencing	10-30	5-65
	Greater effluent pond storage	10-30	30
	Low rate effluent application to land	10-30	45
	Detainment Bunds^{PS120}	**47-68**	**2-30**
	Grass buffer strips	0-20	>250
	Constructed wetlands[2]	-426-77	>500
	Natural seepage wetlands[2]	<10	>500

[1] depends on existing soil test P concentration, but no cost if already in excess of optimum.

[2] potential for wetlands to act as a source of P renders upper estimates for cost infinite.

Further to the above summary, other GMPs include:

- avoiding overstocking - so good pasture covers are maintained.
- avoiding pugging/compaction – exacerbates run-off generation and contaminant load.
- addressing CSA's – hot spots for P-loss can be small areas in connection with flow paths.
- pasture renewal/cropping methods - minimum/no till.
- avoiding cultivation in flow paths and on steep slopes.
- winter grazing practice e.g. break feed towards flow paths.

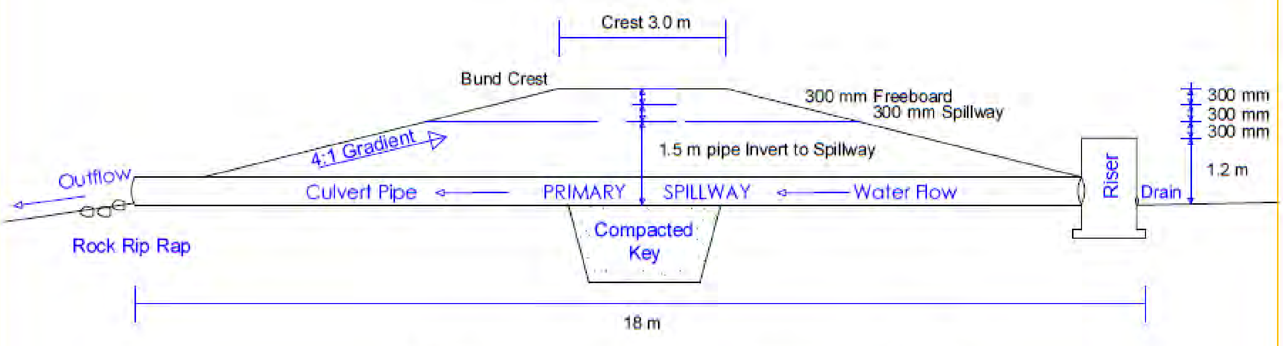
Appendix 13 - DB risk management summary

Detainment Bund^{PS120} Risk Management		
Risk identification	**Risk limitation measures**	**Assurance of remedy**
Bund failure by **Piping erosion:** • Through embankment • around culvert	Professional engineer before construction: • High standard of compaction • appropriate fill material • Compaction in thin layers	During construction: • Have a dedicated roller • Monitoring compaction • e.g. Scala Penetrometer
	Attention to manual compaction around pipe Consider drainage aggregate around the culvert.	• Compaction around pipe • Prevent underside voids
Bund failure by **Overtopping**: • Erosion of bund • - Erosion of spillway	Advice by specialist hydrological engineers. Use GIS professional for precise catchment sizing use of LiDAR data – then peer review. • High capability design (≥120 m³/ha) • Large size specs for both primary and secondary spillways. DBs have three release provisions: • A drain hole (usually plugged) • A large culvert through the DB is the Primary spillway • Overland spillway for very large storm events Additionally: • A full flow upstand riser allows water to escape before over topping of the overland spillway • Option to armour overland spillway	• Contingency for Climate Change • Good compaction of fill • Use screens to avoid blockages • Low DB embankment batters • Maintain good grass sword • No bare soil patches • Farmer can remove DB plug early during sustained large storms rather than wait 3 days Further contingency by: • enlarge drain plug hole • lower riser height • less use of plug during storms
Structural failure	As above – use of appropriate design expertise And appropriate fill materials.	As above. Short periods at high pond levels (1% to 3.3%).
Ponding time exceeds 3 days • Compromise of pasture • Soil Pugging	• Clear any pipe blockages promptly • Review of outflow choke plug hole size • Pull plug earlier with large sustained storms • Consider lowering upstand riser • Graze stock elsewhere during events	Solutions are prescribed in advance through co-funder agreement. Adjustments agreed by all parties Review farmers Good Management Practice methods.
Ponding risks to stock and crops • Drowning • Crop loss	• Avoid stocking ponding areas prior to major storms • Minimise cultivation activity in ponding area • Remove any hay or silage bales promptly when made to avoid blockage risk to the bund's pipes	Have dry land standing areas within the fenced paddock with the DB.
Entrapment by suction at riser	• Prevent children near outlet area during storm events • Screen fixed over main riser	Normal avoidance precautions.
Damage to structure	Advise any partners or co-funding parties asap Seek advice if needed.	Have contingency for prompt action to repair damage.
Failure of the bund during extreme event	Averted by appropriate 3 stage outflow provisions: • 1 Choked base flow - adjustable • 2 Manhole riser level – with large full flow pipe • 3 Overflow spillway contingencies	Professional design of structure minimises risk. ≥ 120 m³/ha rating is a safeguard.

Appendix 14 - Typical DB drawings

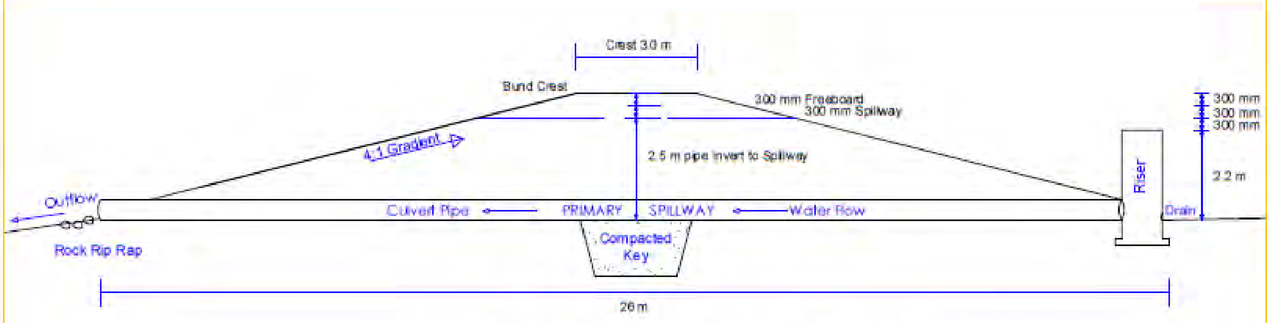
Schematic X-sections a 1.5 m and a 2.5 m DB.

1.5 m high DB



1.5m high Detainment Bund ^{PS120}

2.5 m high DB



2.5m high Detainment Bund ^{PS120}

3.9 m High Retention Dam *(Note: this is not a DB)*

The example cross section drawing below is a for 2.9 m high Retention Dam that was built upstream of a constructed wetland.

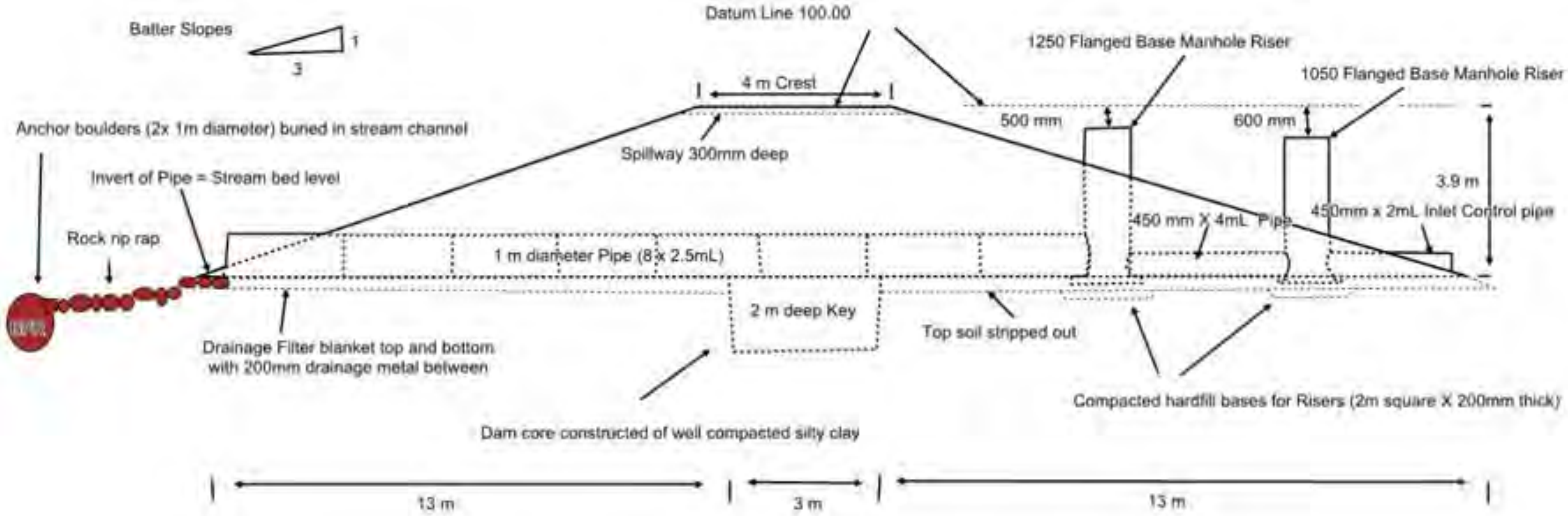
The Retention Dam straddles a small stream and therefore required a Resource Consent.

While not meeting the DB caveat requirements, its function is similar and design is similar to a DB.

Its purpose is to:

- mitigate peak storm water flows.
- protect the longevity of the constructed wetland by prior removal of sediment load.
- increase mitigation performance of the constructed wetland by spreading peak flow and reducing un-treated by-pass.

Note the dual risers to rapidly drain excess water and provide additional contingency against potential blockages.



Appendix 15 - Applied research stages

Stage 1 - Proof of DB Concept

Rotorua P-Project 2010 - 2013

The first applied research on Detainment Bunds^{PS120} for 'proof of concept' was initiated by John Paterson with the Bay of Plenty Regional Council and known as the Rotorua 'P-Project'. Between 2010 and 2013 sixteen bunds were built by willing farmers. Rotorua P-Project works co-funding was provided by the Bay of Plenty Regional Council, New Zealand Transport Agency (NZTA), DairyNZ and Rotorua farmers who have hosted DBs on their farms.

Dylan Clarke conducted the applied research and completed a Master's thesis in 2013 through the University of Waikato supervised by Professor David Hamilton, Dr Jonathan Abell and John Paterson (Clarke 2013). Participating farmers included the Waitetī Trust & manager M Scott, J & C Paterson and managers D & K Holmes, T & M Cairns and manager M Beckham, P & G Schweizer, N Saville-Wood, M & B Leyland, S Morrison and R Moore.

This applied research by Clarke confirmed that DBs do catch phosphorus and sediment and revealed the knowledge gap – how much?

Stage 2 - Quantification of Performance

Phosphorus Mitigation Project Inc. 2016 - 2020

Applied Research on Detainment Bunds^{PS120} for 'quantification of DB performance' was initiated by the Phosphorus Mitigation Project Inc. through Project Manager, John Paterson.

Brian Levine implemented the applied research completing a PhD thesis submitted in February 2020 (Levine 2020) through Massey University in collaboration with Lincoln University and NIWA. The PhD was supervised by Dr Lucy Burkitt (Massey), Professor David Horne (Massey), Professor Leo Condron (Lincoln) and Chris Tanner (NIWA).

The Levine PhD answers the question revealed by Clarke (2013) – how much phosphorus and sediment can DBs mitigate when built with the right capacity and in the right place in the landscape?

Appendix 16 - Acknowledgements

1 Acknowledging the DB Pioneer Farmers

The PMP would especially like to thank the three host farms for supporting the recently completed PhD study; D Reeves, T and M Cairns, and J and C Paterson. They gave open access to their farms for the DB monitoring from 2016 to 2020 and allowed the construction of the twin sets of monitoring stations at each site as well as an obtrusive plywood wall and V-notch weir at one location.

Thanks also to the many other farmers who have willingly participated in the DB constructions over the last 10 years. They have done with the common sense belief that intercepting dirty storm water run-off during periodic high intensity rain storm events and treating it with a relatively still ponding area, must surely be doing some good for the downstream environment. They were right!

Initially, without the quantified evidence we now have on the benefits of constructing DBs, the decision to go ahead and create ponding areas on some of their best paddocks was an act of intuitive good faith and community good will. Some of the early farmer proponents for intercepting storm water include the Waitetī Trust & manager M Scott, J & C Paterson, T & M Cairns, P & G Schweizer, N Saville-Wood, M & B Leyland, S Morrison and R Moore.

These landowners have sometimes also contributed machinery and labour to building the DBs or making adjustments to them. They also provided valuable on-going information about the day to day, and storm by storm, appropriate management of DBs whilst integrating them into their farm operations.

There have been many others who have made valuable input to the initial DB constructions and the first DB Thesis in 2013 by Dylan Clarke especially; D Hamilton, J Abell, R Moore, M Scarsbrook, K Thompson, A Bruere, C Putt, D Guinto, G Ewert, D Ozkundacki, J Peryer-Fursdon, A MacCormick, R McDowell, G Corbett, R Hensman, S Shine, L Thompson, A Woolhouse, S Anderson, M Hawke, M Cooper and members of the Rotorua Primary Producers Collective.

Following the confidence from the Clarke (2013) thesis that proved the concept – i.e. that DBs certainly do catch phosphorus and sediment, construction of DBs has continued on further farms including at D Reeves, T Cairns, Pāmu's (Landcorp) Rotomahana Station, B Mogg and Whakapoungakau Aggregated Lands Trust. At time of writing the number of DBs constructed on farm pasture is approaching 30.

In 2016, many of these DB pioneers unreservedly offered their operating DBs to the research team to choose from for the selection of the three DB field trial sites used in the PhD study. Each DB site underwent installation of multiple instruments to enable close monitoring/sampling of run-off inputs and outputs during high intensity rain storm events in 2018 and 2019.

The project was blessed with ongoing pro bono legal advice and assistance especially related to the forming of the PMP Incorporated Society. A special thank you to Chris Spargo of BlackmanSpargo Rural Law.

BlackmanSpargo
Rural Law

We are also most grateful to Harriet Bailey, Document Specialist, Bay of Plenty Regional Council for extensive assistance for creating graphs, positioning graphics and entirely formatting this document.

2 Acknowledging the PMP Governance Group

The farmer governed group (PMP) was established in 2016 to further the knowledge gained from earlier ‘proof of concept’ research completed by BOPRC with the Clarke MSc thesis in 2013. The knowledge gap was that while, in 2013, it had been well established that “Detainment Bunds do work” (for capturing P and SS), there was little quantitative information on “how well do they work”.

Quantifying the performance of DBs needed several DB field sites equipped with replicate sets of specialised equipment to both measure storm water run-off volumes and sample the loads of storm water run-off entering and leaving the trial sites DBs.

This was a particularly expensive applied science trial to set up and the inaugural farmer group formed the Phosphorus Mitigation Project Inc. specifically to explore the potential of DBs to assist farmers with the challenges they face to meet rising expectations for improved environmental sustainability of NZ pastoral farming.

The support of the Ministry for Primary Industries Sustainable Farming Fund and the wide collaboration of the NZ Agriculture sectors, Agriculture business and Regional Councils to achieve the funding levels required, was the first primary achievement of PMP Inc. Directing an applied research process with focus on the end goal, a new mitigation tool for farmers, as well as ensuring a high level of scientific credibility was the second primary achievement of PMP Inc. This was enacted by bringing together four of NZ’s leading agricultural focused research institutions to work together for the best possible outcomes for pastoral farmers.

The PMP Inc. farmer governance group:

Lachlan McKenzie	(Chairman)	(Dairy farmer / director)
Nick Saville-Wood	(Treasurer)	(Cattle farmer / CEO DHB)
Mac Pacey	(Secretary)	(Dairy farmer)
John Paterson	(Project Manager)	(Deer farmer / Sustainable farming advisor)
Robbie Moore		(Dairy farmer)
Jamie Paterson		(Dairy farmer / director)
Tony Cairns		(Dairy farmer)
J Ford		(Sheep & cattle farmer)
Bryce Heard		(Cattle farmer)
Shane Birchall		(Dairy farmer)
Chris Paterson		(Dairy farmer)
Tony Carr		(Dairy farmer)
Megan Schutt		(Dairy farmer)
Hera Naera		(Dairy farmer / director)

3 Acknowledging the Science Advisory Team

PMP formed a Science Advisory Team (SAT) for the DB applied research to peer review the applied science goals, methodology and to help assurance of the integrity of the final outcomes. Four SAT meetings took place over the four year period of the project (10/6/2016, 7/7/2017, 20/4/2018, 4/9/2019). The following list is the names/affiliations/positions of the 23 SAT participants with various fields of expertise who were invited and who freely contributed to the project on various occasions.

Name	**Agency / Role**	**Attendance**
Lachlan McKenzie	(Science Advisory Team - Chairman, Dairy Farmer / Director)	4/4
Vance Fulton	(Consultant / BOP Nutrient Management)	4/4
Bala Tikkisetty	(Waikato RC / Sustainable Agricultural Advisor Technical)	4/4
Dr Lucy Burkitt	(Massey University / Senior Research Officer)	4/4
Ian Power	(Ballance Agri-Nutrients / Sci Extn Environmental Mgmt. Specialist)	4/4
Brian Levine	(Massey University / Doctoral Student)	4/4
John Paterson	(PMP Project Mngr. / Sustainable Farming Advisor)	4/4
Dr Tom Stephens	(DairyNZ / Senior Water Quality Specialist - to Aug.2018) (Auckland Council / Principal – Integrated Catchment – current)	3/4
Prof Leo Condron	(Lincoln University / Professor of Biogeochemistry)	3/4
Dr Chris Tanner	(NIWA / Principal Scientist – Aquatic Pollution)	3/4
Assoc. Prof. D. Horne	(Massey University / Assoc. Professor in Soil Science)	3/4
Dylan Clarke	(Auckland Council / Senior Healthy Waters Specialist to Sept. 2019)	2/4
James Sukias	(NIWA / Wastewater Scientist)	2/4
Prof. David Hamilton	(UoW / Lakes Chair – to April 2017) (Griffith University / Deputy Director / Australian Rivers Institute – current)	1/4
Jamie Peryer-Fursdon	(GWRC / Land Management Advisor)	1/4
Dr. Gina Lucci	(AgResearch / Senior Scientist)	1/4
Dr Ben Woodward	(NIWA / Biogeochemist)	1/4
Fiona Clark	(MPI / Senior Advisor)	1/4
Thijs Lukkezen	(Massey University)	1/4
Tanya Robinson	(Beef + Lamb NZ)	1/4
Dr. Rebecca Stott	(NIWA / Environmental Health – Microbiology Scientist)	1/4
Prof Troy Baisden	(UoW / Chair in Lake and Freshwater Science)	1/4
Lindsay Fung	(DINZ / Environmental Stewardship Manager)	1/4
Craig Depree	(DairyNZ / Principal Water Quality Scientist)	0/4

4 Acknowledging the Science Supervision

An inaugural meeting was arranged by the Phosphorus Mitigation Project Inc. (PMP) in June 2016 and representatives from three NZ Universities (University of Waikato, Massey University, Lincoln University), and NIWA were invited and agreed to work together. Their consensus was that the most practical hosting location of the PhD would be provided by Massey University with all institutions participating in the academic supervision of the PhD. Professor David Hamilton, originally from Waikato University, assisted PMP with drafting the project concept for funding bids (July & August 2015), and was a key member of this inaugural academic supervising group until his shift to Australia in 2017.

The PhD Science Supervisors for the DB applied research were:

Dr Lucy Burkitt, lead supervisor	(Massey University / Senior Research Officer)
Assoc. Prof. D. Horne	(Massey University / Assoc. Professor in Soil Science)
Prof Leo Condron	(Lincoln University / Professor of Biogeochemistry
Dr Chris Tanner	(NIWA / Principal Scientist – Aquatic Pollution)

4 Acknowledging the DBAM Team

The creation of this novel model, DBAM - DB Applicability Model for landscape assessment, was an adjunct product of the Phosphorus Mitigation Project's original objectives. The development and completion of DBAM would not have been possible without the inputs of the following people and organisations:

- Santiago Bermeo, Bay of Plenty Regional Council, who encouraged this modelling project and the Ministry for the Environment for funding it as an extension of a wider project on practices to mitigate sediment and other freshwater contaminants in the Bay of Plenty.
- Tim Nolan, Blackant Mapping Solutions, brainstorming support and key GIS service provider.
- Natalie Miedema, Excel automation of DBAM's algorith and editing of final draft.
- Tom Stephens, Auckland Council, assistance with brain storming of concepts.
- The Phosphorus Mitigation Project Incorporated, supported by The Sustainable Farming Fund and seven AgIndustry funders, who agreed to extend administrative support and oversight for implementing this associated project.
- DairyNZ, and Mike Scarsbrook for the initial foresight to specifically fund the pursuit of a pan NZ catchment modelling tool for DB applicability.
- Simon Allard, BOPRC GIS technician for brain storming sessions and initial GIS attributes work.
- Bay of Plenty Regional Council – use of office facilities, and GIS/Lidar data resources.

5 Acknowledging the Sponsors

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The credible science-based trial of Detainment Bunds^{PS120}, as a proposed new mitigation tool for farmers, required a sustained effort to initiate, and run over a four-year period, 2016–2020. The considerable expense would not have been possible without the voluntary effort of the initiators and the on-going support of the following funding organisations following approvals by their key management staff at the initial stage.

Funding organisation	Key management staff
The Ministry for Primary Industries and the Sustainable Farming Fund	T. Allen F. Clark
DairyNZ	M. Scarsbrook T. Stephens
Bay of Plenty Regional Council	H. Creagh
Ballance Agri-Nutrients	I. Tarbotton I. Power
Environment Canterbury	J. Holland H. Shaw
Beef + Lamb NZ	G. Ridley
Waikato Regional Council	B. Tikkisetty
Horizons Regional Council	L. Brown
Deer Industry NZ	D. Coup L. Fung

Agriculture & Investment Services
Ministry for Primary Industries
Manatū Ahu Matua

DairyNZ

BAY OF PLENTY
REGIONAL COUNCIL
TOI MOANA

agri-nutrients
Ballance

Environment
Canterbury
Regional Council
Kaunihera Taiao ki Waitaha

beef+lamb
new zealand

Waikato
REGIONAL COUNCIL
Te Kaunihera ā Rohe o Waikato

horizons
REGIONAL COUNCIL

Deer Industry
New Zealand

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