The DB Applicability Model: A GIS model for assessing catchments' suitability for the installation of Detainment Bunds[PS120] to mitigate storm water runoff

Prepared for:

Bay of Plenty Regional Council and Ministry for the Environment

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A live example of the functioning DB Applicability Model, operating from an Excel spreadsheet platform is to accompany this paper.

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1. Introduction

1.1 Purpose

This paper presents a Geographic Information System (GIS)-based model to assess the suitability of catchments for the installation of Detainment Bunds^{PS120} [1]. Detainment bunds (DBs) mitigate the impacts of storm water run-off from farmland on water quality, and can reduce erosion and flooding, by temporarily retaining storm water. However, DBs are only viable in locations with particular physical characteristics. The motivation to develop this model was the lack of an efficient and automated way to find suitable specific sites for DBs which remains problematic. This paper describes a model that is relatively automated and accurate for measuring landscape characteristics for assessment of general DB applicability to any given catchment. This model will assist prioritisation of land management interventions and planning processes that may seek to use DBs as a mitigation practice.

Figure 1 illustrates a conceptual diagram of the DB Applicability model. For a 2km by 2km ($4km^2$ or 400 ha) plot, eight physical attributes based on GIS datasets, including Light Detection and Ranging (LiDAR) data, are derived. These are then scored based on whether they are conducive to DB placement. The output is an estimate of the percentage of the catchment that is likely to be treatable by DBs.

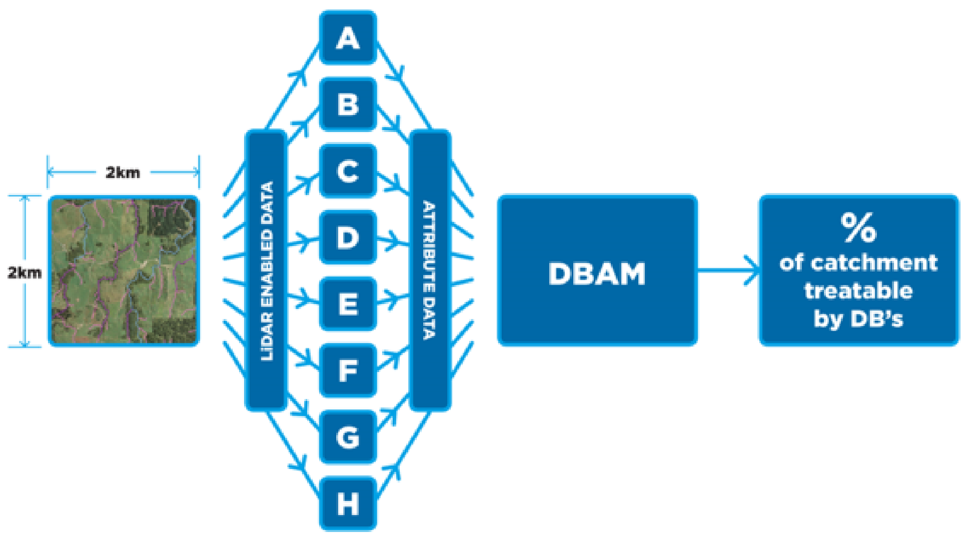


Figure 1 - Conceptual diagram of DB Applicability Model

[1] The PS120 suffix relates to a specific DB design and consistent site selection, construction and operating protocols to ensure a predictable and comparable performance. Key design elements are a minimum threshold of 120 cubic meters of storage per hectare of contributing catchment and consistency with Bay of Plenty Regional Council permitted activity conditions for earth dams. This report refers specifically to DBs^{PS120} structures.

1.2 Context: Farm run-off during rain storm events affects water quality and exacerbates erosion and flooding

Storm water run-off from farmland can be a significant pathway for contaminants (pathogens, nutrients and sediment) to enter fresh water. Once in fresh water, these contaminants reduce water quality and affect the values of receiving water bodies (Parliamentary Commissioner for the Environment, 2012). Storm water run-off from farmland can also exacerbate erosion and downstream flooding, resulting in a range of economic, environmental and cultural impacts on farmland itself, downstream receiving environments and floodplains (Dorner et al 2018).

There are a range of possible actions to mitigate these impacts. These include actions that reduce the generation of contaminants in the first place and actions that reduce run-off velocity and prevent contaminants from entering waterways. Examples of the first ones include improved land use choices (e.g. afforestation, wetlands) and improved management of stock, crops, fertiliser, irrigation and effluent while examples of the second ones include riparian fences and buffers, wetlands and run-off retention infrastructure, such as DBs (Matheson et al., 2018).

Choices about the most appropriate mitigation actions must be informed by established cause-effect relationships (i.e. 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. As described in section 2, DBs are only viable (and effective) in locations of certain physical characteristics. It is anticipated that the model presented in this report will help inform decisions about appropriate mitigation, by allowing an efficient assessment of locations where DBs could be considered.

1.3 Scope and structure of this report

This report describes a GIS-based landscape interpretation tool, the DB Applicability Model (DBAM). The model enables land management practitioners or planners with a basic knowledge of GIS software (or support from a GIS technician) to accurately estimate how applicable the concept of treating storm water with DBs will be in any type of New Zealand farming landscape. The DBAM reports applicability of DBs shown as the percentage of the targeted catchment area that can be 'treated' with DB installations versus the 'untreatable' area. This involved the development of:

- a GIS based process using LiDAR data to derive eight physical catchment attributes from fourteen representative 4 km^2 landscape plots; and
- a spreadsheet-based calculating tool which digests the eight attributes and accurately determines the percentage of the selected catchment area potentially treatable with DBs.

Section 2 describes DBs, their operation and the physical characteristics of locations that would be suitable for them. Section 3 describes previous and current methods to establish landscape suitability for DBs, and the development of the applicability model. Section 4 provides some concluding remarks, including suggestions for further development of the model.

2. Detainment bunds

2.1 What is a detainment bund?

DBs are low earth berms placed across ephemeral storm water flow paths on farms to temporarily detain storm water run-off. 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. During high intensity rainfall events, DBs briefly pond a significant volume of storm water run-off. Figure 2 illustrates the main features of a DB. The numbered notations in Figure 1 show three routes of storm water exit: (1) the choke hole (usually plugged for up to 3 days); (2) the upstand riser that decants off overflow during most large storms; and (3) the overland spillway contingency that is rarely needed. A fourth route not illustrated in the diagram is infiltration through the ground on the floor of the ponding area. Figure 3 illustrates the construction of a DB.

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.

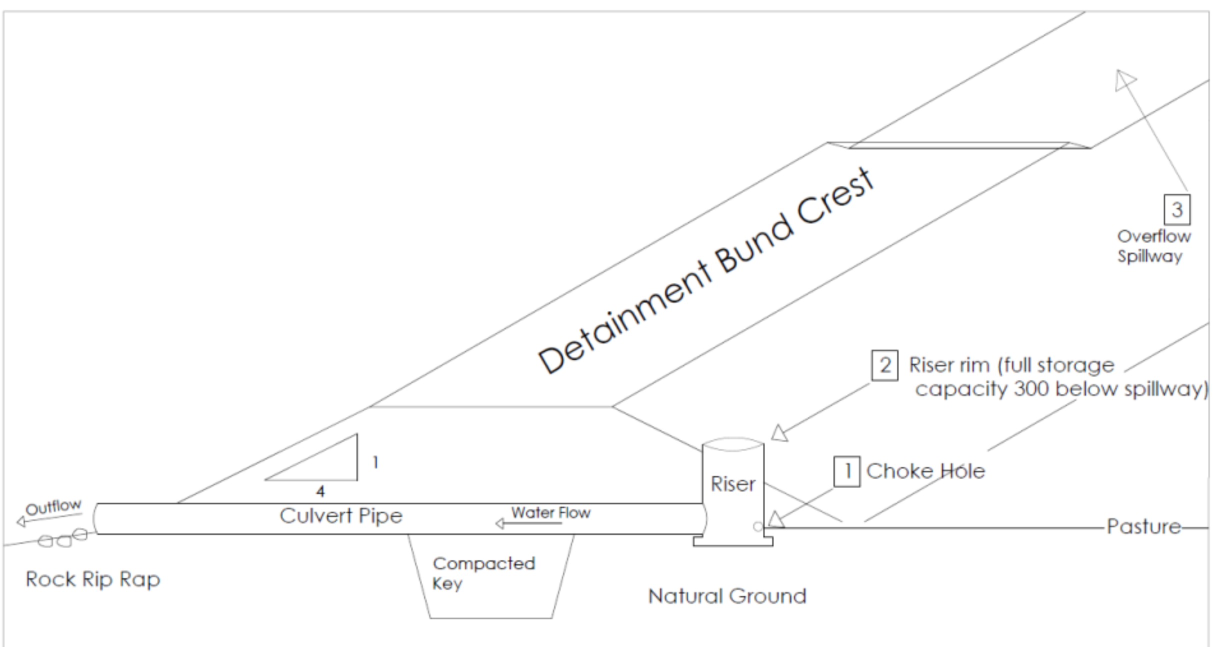


Figure 2 - Sectional diagram of a detainment bund

1. Ephemeral flow path on farmland (suitable location).

2. Dig a key slot below ground level and refill soil in compacted layers.

3. Lay appropriately sized pipe.

4. Build up bund wall with compacted thin layers of fill until full height, cover with top soil and sow with grass.

5. Add upstand riser, including a restricted drain hole at its base with a plug for release.

Figure 3 - Detainment bund construction

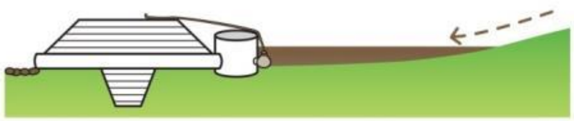
If DBs installed for phosphorus and sediment loss mitigation are to be credited with reportable performance benefits, they need to have consistent criteria around their design elements and functioning principles so that performance measures at various DB sites can be assured. This ‘standard’ for DB design and its inherent link to the applied research that validates their performance (see section 2.3), will help ensure confidence that this type of structure, the DB^{PS120}, can be replicated as a bona fide mitigation tool when applied into landscapes around New Zealand. The suffix (^{PS120}) designated to the name, Detainment Bund ^{PS120}, is a means of ensuring that consistency of design, site selection, construction, and operating protocol will produce credible predictability of performance when DBs are applied in farming districts for reportable water quality objectives.

A critical design element of DBs^{PS120} is a minimum threshold of 120 cubic meters of storage per hectare of contributing catchment, otherwise referred to as the 120:1 DB design ratio. Another important design consideration is that DBs^{PS120} are constructed as a ‘permitted activity’ under the Bay of Plenty Regional Council’s Natural Resources Plan. This means that a resource consent is not usually required provided certain limitations on bund wall height and ponding volume are not exceeded. In the Bay of Plenty Region, the ‘permitted activity’ limits are 2.5m high for an earth dam wall height and 5,000m^3 of ponding volume. The permitted or consenting requirements for such water impounding earthworks vary throughout New Zealand.

The DB applicability model presented in this report is specific to the DB^{PS120} design parameters.

2.2 How does a detainment bund work?

Figure 4 illustrates the operation of a DB. The velocity of 'dirty' storm water run-off flowing over farmland enables it to carry suspended sediment (SS) including particulate phosphorus (PP), and potentially other contaminants (e.g. pathogens and nitrogen). When the velocity of storm water run-off is interrupted by a DB for a sufficient period of time, in a sufficiently sized ponding area (relative to catchment size), infiltration into underlying soil and settlement of SS occurs.

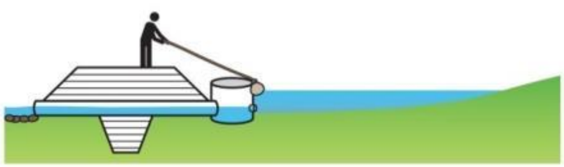


1. 'Dirty' storm water load arrives, carrying sediment, phosphorus and potentially other contaminants.

2. Once ponding maximum is reached with large storms, excess ('cleaner') water is skimmed from the surface through upstand riser.

3. Skimming continues until water level drops, water is stored for up to three days, allowing contaminant settlement to occur.

4. After three days, some infiltration leads to a reduction in stored volume, contaminants settled at the bottom of the ponding area.



5. After three days the plug is opened to protect pasture production.

6. Plus is reset ahead of next high rainfall event, pasture is spelled briefly from grazing.

7. Stock returns to storage area, pasture production not compromised and takes up some of the settled nutrients.

Figure 4 - Detainment bund operation

The suspended solids and particulate phosphorus mitigating potential of DBs are thought to be enhanced by the following four mitigation mechanisms integral with the DB^{PS120} design:

- High Storage Volume
- Infiltration
- Surface decanting
- Residency Time – Settlement and sorption

2.2.1 High storage volume standard for DBs

If ponding areas of storm water detainment structures are relatively small, they can fill up quickly and flood water can continue to move through them with little reduction in turbidity (Stokes' law). Water stillness (rather than movement) and residency time are directly dependent on DB ponding size; the bigger the ponding volume, the greater the mitigation opportunity.

Structures previously promoted by the Bay of Plenty Regional Council (BOPRC) for erosion protection purposes advised a minimum storage capacity of 60m³ per hectare of catchment. The Phosphorus Mitigation Project Inc. has adopted a much higher minimum threshold for sufficiency of DB storage volume which is based on both the findings of the earlier P-Project (Clarke 2013), physical practicalities of fitting ponding areas into the pastoral farming landscape and 'permitted activity' regulations.

2.2.2 Infiltration

Commonly when DBs are constructed in areas where soils have good drainage characteristics, a lesser amount of storm water will flow out of the piped DB outlet or its spillway than the amount that flowed in during a rainfall event. The inflow / outflow difference can be attributed to infiltration through the floor of the ponding area and in some circumstances some losses to evaporation can also occur. The inflow / outflow difference means that a similar proportion of the contaminant load is also retained in the ponding area.

In particularly small rain events where DB capacity is able to capture the entire runoff amount, then all of the phosphorus or sediment load of that event will be prevented from reaching the usual receiving water body downstream of that DB treated catchment. However generally the majority of run-off events exceed the capacity of the DB and the other mitigation mechanisms inherent with DBs come into action, as described below.

2.2.3 Surface water decanting

The design of the DB's overflow includes a 'riser' on the DB's high capacity drain pipe (refer to Figures 1 and 2). This riser outlet creates ponding of the first arriving run-off and then effectively skims / decants excess later arriving storm water from the surface layer of the ponded water. It is assumed (pending validation by ongoing research, see section 2.3.2) that the pond's top surface water layer is the cleanest fraction of the standing water column.

2.2.4 Residency time – settlement and adsorption

The duration of the residency time of storm water run-off captured in a DB's ponding area is reliant on both the farmer's good will, to voluntarily flood his pasture, and apply good management practice (GMP) for operating the farm's DB's. For maximum efficacy, the DB's restricted drainage outlet should be plugged prior to high intensity rain events to enable immediate ponding of run-off and maximise ‘residency time’. After a maximum of three days the plug is pulled to release the residual ponded water.

With the 22 DBs currently in use on farms in the Rotorua District, there are signed Memorandums of Understanding with the DB owners that ensures pond water does not reside longer than 3 days. This limit to ponding time averts the risk of pasture damage in the ponding area. Farmers do not want their pasture in the ponding area damaged and this creates an effective self-policing mechanism for farmer behaviour that helps ensure the plug is pulled in a timely manner.

2.2.5 Settlement

Storm water run-off, by nature of its velocity, is able to carry a suspended load of sediment. When the runoff stream’s velocity slows or stops the suspended load and bed load begin to drop out of the still water column standing in a DB. Stokes' law applies in this situation and explains the sedimentation of small particles in water, under the force of gravity (Stokes 1851).

Sediment and particulate phosphorus capture in DBs will still occur to some extent even if the DBs are operated without plugging. This is due to the restricted size of the drainage hole at the base of the skimming riser which leads to ponding and delayed release of the rapidly arrived storm water run-off. The majority (80 to 95%) of sediment moved by storm water run-off travels as suspended load and research to date confirms that DBs can catch the majority of this suspended load particularly with small run-off events.

Figure 5 shows the proportion of suspended solids settlement over three days of detainment bund treatment, as reported by Clarke (2013).

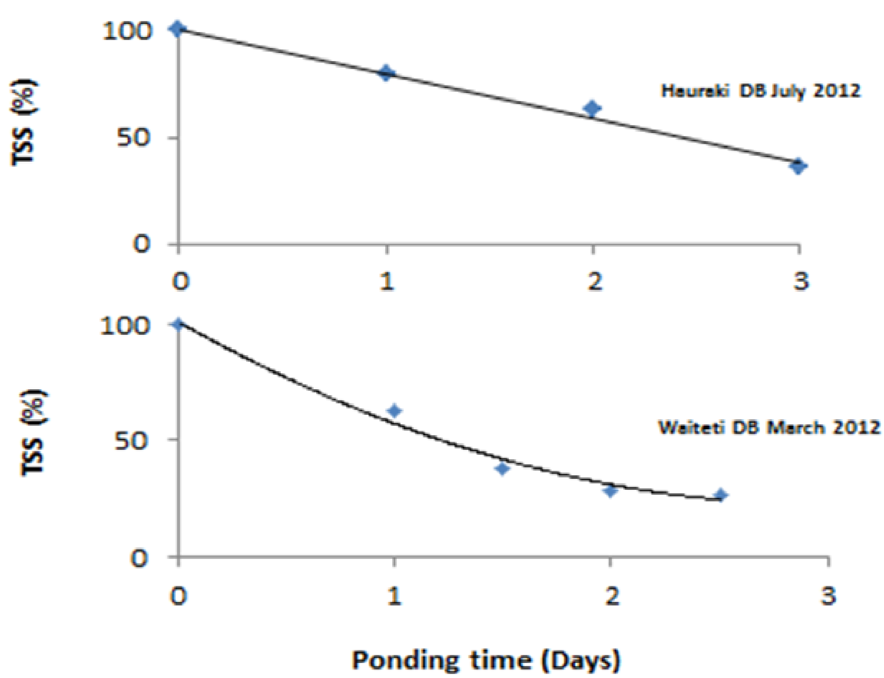


Figure 5 - Proportion of total suspended solid settlement over 3 days of DB treatment (from Clarke 2013)

2.2.6 Sorption of soluble P

Sorption/desorption of soluble P can readily occur during stormflow (Peryer-Fursdon 2014), with some soil types acting as a sink. Alternatively, some soils in intensive agriculture situations may act as a source (Sharpley et al. 1981). More understanding of this factor in DBs is still required and it's possible that flocculants could be applied in DBs in the future to accelerate the sorption benefit.

2.3 Applied Research on DBs[PS120]

2.3.1 The Rotorua P-Project

A review of the efficacy of strategies to mitigate the loss of phosphorus from pastoral land use in the catchment of Lake Rotorua was commissioned by BOPRC in 2010 (McDowell 2010). This considered cost-effectiveness of various mitigation options and other reviews have considered the cost burden to intensive farming (Abell 2010). The initial Rotorua P-Project (2010 – 2013), sought validation of the mitigation performance of DBs and initiated applied research reported in Clarke (2013), which 'qualitatively' validated DB performance at three DB sites in the Lake Rotorua catchment in 2012. This initial proof of concept research "proved that DBs do work but not how well they work" and identified a knowledge gap creating a challenge for scientists to take up work on quantifying the mitigation benefits of DBs.

2.3.2 The Phosphorus Mitigation Project Inc.

In 2015 a group of farmers took action to address the latent knowledge gap on DB performance and formed the Phosphorus Mitigation Project Incorporated (PMP Inc.) to source funding partnerships and govern further applied research on DB efficacy. This has resulted in the current PhD research programme (B. Levine, Massey University, 2016 – 2019) to fill the 'quantitative' knowledge gap identified by Clarke (2013), i.e. measuring DB ability to treat the 'load' of phosphorus and suspended solids in storm water runoff. It is expected that the results of this research will eventually provide further validation and understanding of DB performance features, and possible additional mitigation elements. Specifically, this research will make further judgement on the appropriateness of the 120:1 DB design ratio as this applied research is using three trial sites with three different ponding storage ratios; $< 120:1$, $\approx 120:1$, $> 120:1$.

The PMP-governed research is being supervised by a collaborative of expertise from both Massey and Lincoln Universities as well as the National Institute of Water and Atmospheric Research (NIWA).

2.4 Where can detainment bunds work?

Not all types of landscape are suitable for DB treatment due to extremes of terrain such as predominance of mountains or flat plains where opportunities to create extensive ponding are impractical with low earthwork embankments. Also farm based DBs are only appropriate on ephemeral flow paths in low Strahler Stream Order locations (SO1 and SO2). Given these limitations to DB applicability to landscapes, it is strategically important for those planning roll out of DB installations in new areas to be able to predict or score the applicability of DBs to determine if this type of mitigation installation will be practical in the landscapes or catchments under consideration for storm water interception. 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 significantly effective. An accurate DB applicability assessment tool will also help planners to predict the likely result for water quality improvement to meet the National Policy Statement for Freshwater Management 2014 (Freshwater NPS) goals by modelling 'what if' scenarios where targeted catchments are treated by DBs.

To date 22 DBs (with fixed design parameters to mitigate for phosphorus and sediment) have been fitted into the farming landscapes around the Rotorua Lakes District but it is unknown how applicable this DB design may be to other areas of the Bay of Plenty and wider New Zealand farming landscapes.

2.4.1 Slope Classes

Some landscapes have little or no opportunities for DB construction due to their topography. At one end of the spectrum of topography types is steep mountainous country with incised valley floors and at the other virtually flat flood plains. Neither of these two extremes have a propensity for DB installations. However, land composed of mixed slopes classes can be suitable for DB installation and such composites of various slope classes can include areas of very steep and very flat land (refer to section 3.3.2).

2.4.2 Ephemeral Flow Paths

DBs are best located in places where water flows during storm events from relatively small catchments – generally less than 50 hectares. Flow paths serving catchments greater than 50 hectares can produce volumes of water that exceed the capacity of the small 'permitted activity' earth works that farmers can undertake without need for a resource consent.

DBs are generally not able to be built on permanent waterways as these always require regulatory consent and generally flow out of large catchments meaning the storage requirement (120m^3 per hectare) would result in storage volumes needing large scale earthworks.

3. Finding sites suitable for detainment bunds

3.1 The era before GIS – redundant Dumpy Level process

Prior to GIS supported by LiDAR data, the ability of land managers and environmental management advisors to intuitively select DB sites required extensive experience and manual land surveying with Dumpy Level at possible locations to confirm if probable sites were viable, i.e. if storage capacity was adequate. This involved many hours of on-site land surveying at each possible location and follow-up geometry calculations based on those levels to measure the volumes attainable at each site. This was an expensive trial and error process that is now largely redundant due to the development of GIS tools supported by LiDAR data.

3.2 Manual assessment with GIS software and LiDAR data

GIS tools using LiDAR data allow the assessment of dozens of potential DBs in less time than it used to take to do one on-site investigation of a probable DB site with traditional land survey tools, e.g. Dumpy Level. Using 'desktop' GIS remotely enables rapid manual scoping of large catchments for possible DB sites, rapid drawing up of 'what if' DB mock-ups at possible sites and calculation of their respective volumes.

Since 2010, spatial analysis of farming landscapes with GIS has been used in the Rotorua District by BOPRC staff to map surface hydrology features on farms. High resolution LiDAR with 1 m contour capability has been an essential component enabling accuracy with this work. Two forms of mapping software, GeoView (supported with high resolution LiDAR data) and Arc Hydro, have been used to identify the extent and size of sub-catchments and the ephemeral flow paths of their storm water run-off. After sub-catchments and flow paths are identified, preliminary searching of these sub-catchments can begin to find possible DB construction sites.

The manual search process to find potential DB sites includes individual calculations at each hypothetical DB site to find out if that particular site can achieve the required storm water storage volumes relative to the catchment size being serviced. During this searching process, many likely locations are usually found. At each location, a complete DB construction footprint plan and a DB structure 'mock-up' are actually drawn using the mapping software and tested to determine if the site meets the storage volume to catchment size requirement of 120 m^3 per hectare. See Figure 6 for an example, where the site does qualify as a potentially viable site given the storage is 129 m^3 per hectare of catchment. Most of these manually derived 'mock ups' actually fail to reach the standard required. The time taken for this manual GIS scoping process, is usually about 1 hour per 40 hectares scoped. To date, automation of this process for finding specific DB sites has not been successful.

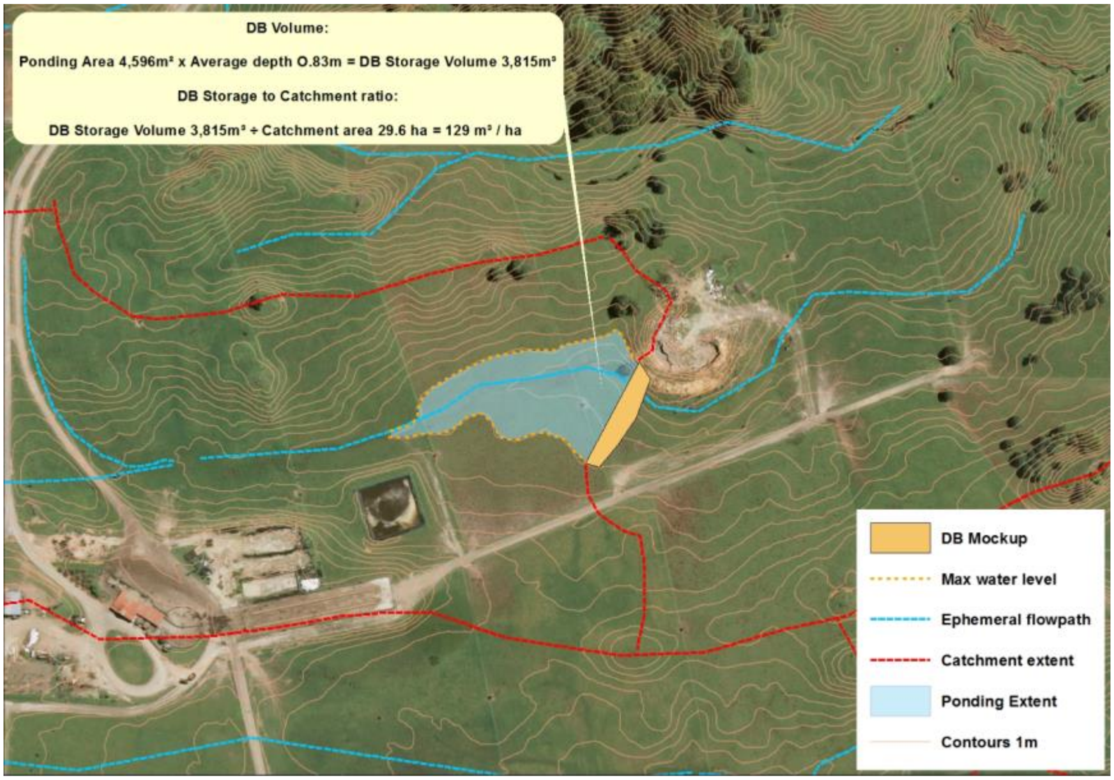


Figure 6 - Typical detainment bund 'mock up' created on desktop GIS software to test viability of a proposed detainment bund site

3.3 Development of the Detainment Bund Applicability Model

3.3.1 Control Plots

To be able to develop, test and validate an automated process for interpreting any piece of landscape type and its surface hydrology features for their ability to accommodate DB structures, it is necessary to have 'control' plots, representative of many types of landscapes and suites of landscapes, e.g. from mountainous through to plains.

Fourteen landscapes plots of 2km by 2km (400 ha or 4 km^2) were selected as 'controls' for the development process of creating the model. Each plot was assessed manually (refer Section 3.2) and its entire area fitted with DB mock ups on Stream Order 1 & 2 storm water flow-paths wherever the desired storage ratio (120 m^3/ha) could be achieved. The catchment sizes for these individual DB mock ups were generally limited within a practical range of 5 – 50 ha with an average size of around 15 ha. This resulted in approximately 20 to 30 DBs per plot actually drawn up however approximately 2 to 3 times that number were tested by the manual trial and error process. The most common failure point with each proposed DB site was not achieving the desired storage to catchment ratio of 120 m^3 per hectare.

In summary, the GIS work created around 800 probable 'mock- up' DBs to achieve around 300 confirmed DB 'mock-up' sites that met the storage to catchment area threshold. These confirmed sites, with completed storage capacity calculations, were used for the development and validation of the DB Applicability Model.

3.3.2 Landscape characterisation

The time consuming and largely manual use of the LiDAR data-enhanced mapping software to scope farm landscapes for DB sites (section 3.2) has resulted in the development of skills in identifying key geophysical features that anecdotally appear to be common to successful DB sites. These anecdotal DB precursor features are listed in Table 1 below.

One of the main challenges of this project was migrating the features learned from experience, that are anecdotally known to be common features of proven DB sites, into objective, measurable GIS attributes. These attributes then need to be suitable for input into a calculating model that is able to automatically predict an entire targeted catchment's propensity to accommodate DBs with acceptable accuracy.

These measurable and scorable attributes have been mainly derived from manipulations of GIS LiDAR data and include various classifications of slope and stream order.

Table 1- Common geophysical features of existing DB sites

Geophysical features common to proven Detainment Bund PS120 sites	
1	Valley floors at DB sites are laterally broad (commonly ~25m to ~75m wide) with gradients commonly 1.5° to 6° enabling wide ponding extent.
2	Valley floor at DB sites have low gradients longitudinally, commonly ~50m to ~ 100m long with gradients commonly 0.5° to 2° enabling extensive ponding upstream.
3	Strahler Stream Orders SO1 and SO2 ephemeral flow paths are a prerequisite for DBs .
4	Strahler Stream Orders SO3 and over are not conducive to DB sites .
5	Catchment areas are modest – usually less than 45 ha (for BOPRC 'permitted activity' DBs).
6	Ponding area usually < 6,000m² (~1.3% of 45ha) and ponding volume usually < 5,000m³.
7	Targeted catchment area has limited elevation change (50 to 120m optimal within 4km²).
8	DB ponding areas do not flood infrastructure, e.g. buildings and public roads.
9	The DB sites often occupy fields regarded by the farmer as his "best productive land".

Slope Classes

When considering the division of landscapes into various slope categories, as enabled by GIS LiDAR data, the characteristics for DB ponding sites were deemed to be most prevalent in the slope class composed of slopes from 0 to 7.9°. In most existing DB ponding areas, the longitudinal upstream gradient is usually 1° to 2.5° (and always < 8°) and the lateral (side to side between valley walls) gradient is usually < 8°. The OVERSEER® nutrient budgets model uses a practical range of 'slope classes' that is now well-established for use in its Block Data topography types (OVERSEER® 2018). The same set of four slope classes (see Table 2 below) are used in the development of this model for DB applicability and are the basis for five assessment attributes in the model (Attributes A to E, Table 3) over the 400 ha target plot.

Table 2 - Slope classes integral to the DB Applicability model (from OVERSEER 2018)

TOPOGRAPHY CLASS	ACCESS DESCRIPTION	SLOPE
Flat		0° – 7°
Rolling	Area mostly navigable by tractor	8° – 15°
Easy Hill	> 50% area navigable by tractor	16° – 25°
Steep Hill	< 50% area navigable by tractor	> 26°

Strahler Stream Order classification

As well as attributes derived from the suite of slope classifications, the development of the DB Applicability Model required identification of areas of the landscape where first riverlets of water form together and flow during high intensity run-off storms, i.e. ephemeral flow paths.

Such ephemeral flow paths (see Figure 7) present opportunities for possible interception with DBs. An attribute of the DB Applicability Model (Attribute F, Table 3) is derived from Strahler Stream Order data relating to lengths of respective stream orders found in a 4 km² plot. Differentiation is made between the various grades of Stream Order with SO1 and SO2 locations enabling potential for DB sites while the larger Stream Orders (SO3 and over) are generally not conducive for DB placement. Figure 8 shows the Stream Order classification for one of the assessment plots.

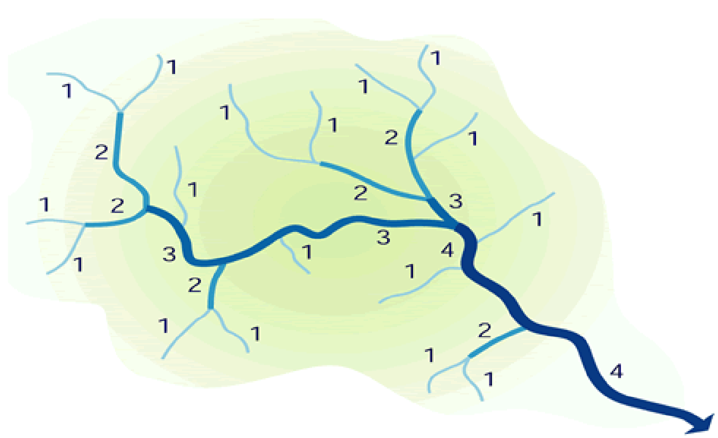


Figure 7 - Strahler Stream Order classification

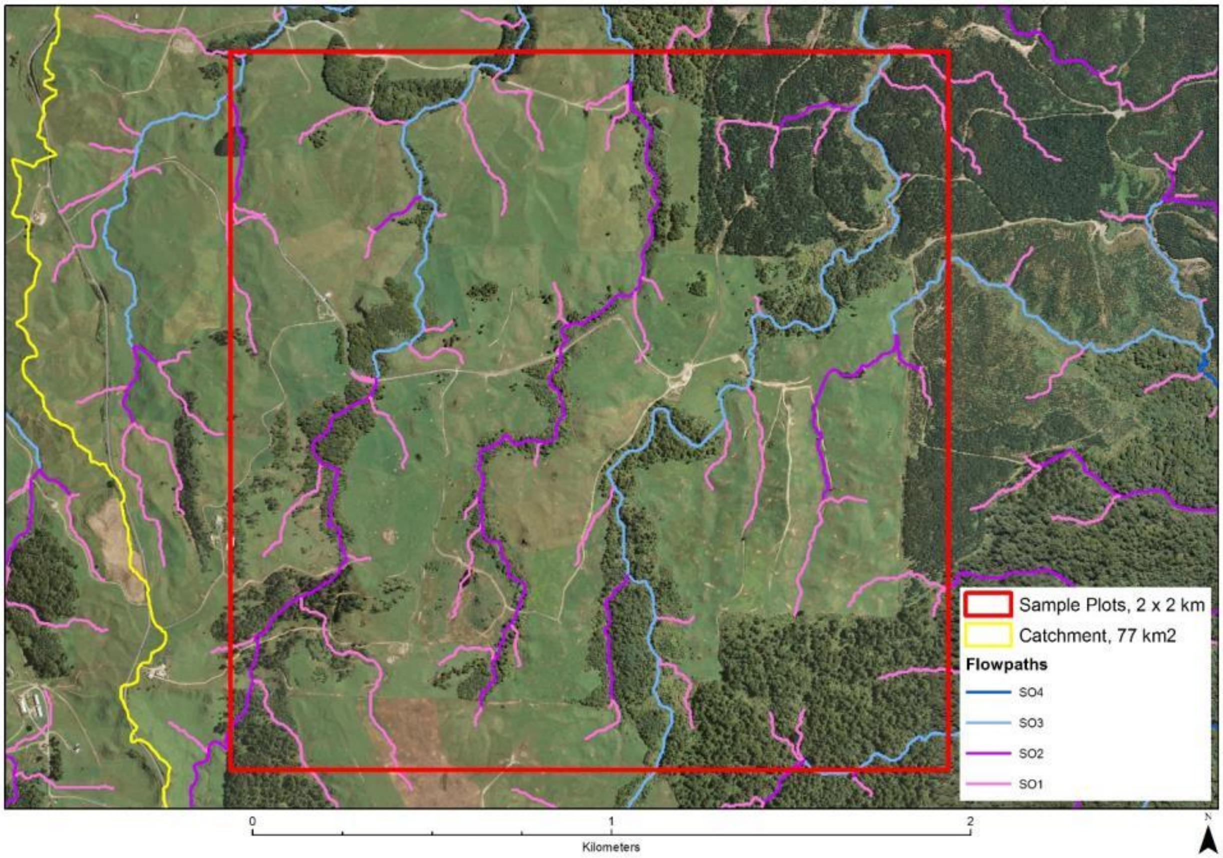


Figure 8 - A 2km x 2km assessment plot illustrating Stream Orders conducive to DB placement (SO1 & SO2) and not conducive to DB placement (SO3 and over)

The DB Applicability Model uses Stream Order assessment (1 of 8 attributes needed) and scores the prevalence of the higher order streams, SO3 and greater, relative to SO1 and SO2 storm water flow paths (refer Table 8). Low SO3 prevalence scores highly conducive to DB installation as this reflects the relatively greater prevalence of SO1 and SO2 flow paths which are conducive to DB installations.

Elevation change

Areas targeted for DB installations are best to have modest elevation change and this feature has been developed into a scoring attribute (Attribute G, Table 3) applied over the 2km x 2km square plot that the model is applied to. Both very high elevation changes (hill country) and very low elevation changes (flood plains) are scored as relatively inhibitive of DB placements.

Man-made infrastructure

Some man-made infrastructure cannot be flooded by proposed DB sites while others can occasionally be flooded over. Public roads were chosen as clearly inhibitive to applicability of DB structures. The length of public road in the target 2 km x 2 km catchment plot is used as a scoring attribute (Attribute H, Table 3) in the model.

3.3.3 Weighted scorable attributes

The Excel spreadsheet calculator underpinning the DB Applicability Model requires input of eight data attributes derived from GIS analysis of the clipped 4 km^2 sample plots of various landscape types.

The finalised selection of attributes that contribute to governing where DBs can or cannot be located in various landscape types are summarised below in Table 3 in ranked order from A to H. The most influential factor is attribute A, the proportion of 'flat' land class, and the least important attribute is H, the incidence of public roads.

Table 3 - Summary of the eight attributes used in the DB Applicability Model

Attributes (A-H)		Effect of each Attribute (A – H) to applicability of DB sites to landscapes		
A	Flat 0 – 7.9°	% of Flat (A) is entered as a scoring start point. All following attributes scores either build or deduct from initial Flat Land % figure. Relative composition of Flat (B) is scored separately.		
		Inhibitory Factor	**Neutral Factor**	**Conducive Factor**
B		> 50% Flat	45 to 50% Flat	< 45% Flat
C	Rolling 8 – 15.9°	< 16% Rolling	16 to 25% Rolling	> 25% Rolling
D	Easy Hill 16 – 25.9°	< 15% Easy Hill	15 to 35% Easy Hill	>35% Easy Hill
E	Steep 26 ≥	< 5% Steep & >15% Steep	5 to 15% Steep	Nil
F	Stream Order	% of length of Stream Orders 3 and over (relative to all streams)	N/A	% of length of Stream Orders 1 & 2 (relative to all streams)
G	Elevation Change	< 50m and > 120m Elevation Change	50 to 120m Elevation Change	Nil
H	Public Roads	>0.5km of Public Road	0 to .5 km of Public Road	Nil

The details of each scoring attribute are displayed below in Scores for attributes A and B (Table 4), the 'flat' land class, range from +65 to -30. While 45 to 50% composition of flat land has a neutral effect, a higher percentage of flat land is inhibitory.
Table 4to Table 10 below. These displays are individual snippets from the Excel spreadsheet calculator working within the model. Note the detail of the weighting scales in each attribute and the comments on their respective influences on the model's outcomes from inhibitory, through neutral, to conducive elements favouring the placement opportunity for DBs.

Scores for attributes A and B (Table 4), the 'flat' land class, range from +65 to -30. While 45 to 50% composition of flat land has a neutral effect, a higher percentage of flat land is inhibitory.

Table 4 - Attributes A and B, scoring of the 'flat' land class (0 - 7.9°)

Class	Score	Weighting Logic:	
<5%	65		
5 - 9.9%	40		
10 - 24.9%	25		
25 - 39.9%	8		
40 - 44.9%	5		
45 - 49.9%	0		
50 - 59.9%	-3		>50% Flat
60 - 69.9%	-5		starts to
70 - 79.9%	-10		inhibit
80 - 89.9%	-20		DBs
90 - 100%	-30		

Scores for attribute C (Table 5), the 'rolling' land class, range from +5 to -25. A landscape with 25 to 33% of rolling land class is conducive to DB installation.

Table 5 - Attribute C, scoring of the 'rolling' land class (8 - 15.9°)

Class	Score	Weighting Logic:	
<5%	-25		
5 - 9.9%	-22		< 16%
10 - 12.9%	-20		Rolling
13 - 15.9%	-15		inhibits
16 - 18.9%	7		DBs
19 - 21.9%	7		
22 - 24.9%	5		
25 - 27.9%	10		25 - 30%
28 - 30.9%	15		Rolling
31 - 32.9%	10		conducive
33+%	5		to DBs

Scores for attribute D (Table 6), the 'easy hill' class, range from +10 to -15. A modest proportion of Easy Hill (30 to 40+%) in a landscape can be conducive to DB installation.

Table 6 - Attribute D, scoring of the 'easy hill' land class (16 - 25.9°)

Class	Score	Weighting Logic:	
<5%	0		< 20%
5 - 9.9%	-10		Easy
10 - 14.9%	-15		inhibits
15 - 19.9%	-3		DBs
20 - 24.9%	0		
25 - 29.9%	0		> 30%
30 - 34.9%	5		Easy
35 - 39.9%	10		conducive
40% +	10		to DBs

Scores for attribute E (Table 7), the 'steep' land class, range from -5 to -30. While any presence of steep land inhibits DBs, 5 to 15% composition has a relatively minor effect.

Table 7 - Attribute E, scoring of the 'steep' land class (≥ 26°)

Class	Score	Weighting Logic:
0 - 1.9%	-30	
2 - 4.9%	-25	
5 - 9.9%	-7	
10 - 14.9%	-5	
15 - 19.9%	-10	Steep
20 - 24.9%	-15	land
25 - 29.9%	-20	inhibits
30 - 49.9%	-20	DBs
50 - 69.9%	-20	
70 - 84.9%	-20	
85 - 100%	-20	

Scores for attribute F (Table 8), stream orders, range from 0 to 35 for prevalence of stream order 3 or above streams. Prevalence is measured by accumulated lengths of each respective stream order. Low prevalence of streams of stream order 3 or above is highly conducive to DB installation as this indicates relatively greater prevalence of flow paths of stream orders SO1 and SO2.

Table 8 - Attribute F, scoring of stream orders

% ≥ SO3	Score	Weighting Logic:
0 - 14	35	SO1 + SO2
15 - 18	25	conducive
19 - 22	20	to DBs
23 to 26	10	
27 -30	8	
31 - 34	5	≥SO3
35+	0	inhibit DBs

Scores for attribute G (Table 9), elevation change, range from -2 to -25. Both large and small elevation changes inhibit DB installation opportunities.

Table 9 - Attribute G, scoring of elevation change

Range (m)	Score	Weighting Logic:	
≥ 250	-25		High
200 - 249	-20		Elevation
150 - 199	-10		Change
130 - 149	-7		inhibits
120 - 129	-5		DBs
105 - 119	-3		
95 - 104	-3		
85 - 94	-3		Low
75 - 84	-2		Elevation
50 - 74	-3		Change
25 - 49	-10		inhibits
0 - 24	-15		DBs

Scores for attribute H (Table 10), public roading, range from 0 to -9. An increasing incidence of public roads in an assessment plot (400 ha) increasingly inhibits DB installation. This is generally a relatively minor factor in the fourteen 'control' landscapes used to calibrate the DB Applicability Model's eight input attributes A to H.

Table 10 - Attribute H, scoring of public roading

Km of Road	Score	Weighting Logic:	
0 - 0.4	0		
0.5 - 0.9	-1		
1 - 1.4	-2		Public
1.5 - 1.9	-3		roads
2 - 2.4	-3		inhibit DBs
2.5 - 2.9	-6		
3 - 3.4	-6		
3.5 -3.9	-6		
4 - 4.4	-8		
4.5 - 4.9	-9		

3.3.4 Sampling regime for application of the DB Applicability Model to whole catchments

The DB Applicability Model uses attribute data from representative 2 km by 2 km plots from a targeted landscape. Obviously, the more sampling plots the better for any given catchment. With smaller catchments, say 10,000 ha or less, it is probably feasible to sample as much as 15 to 25% of the targeted catchment area as this amounts to around four to six of the 2 km by 2 km sample plots.

The example illustrated below in Figure 9 is a 7,700 ha (77km²) catchment and three sample plots have been applied to it representing 16% of its total area. If the sampling area has obvious differences in its composition of landscape types (e.g. high lands, plateaus, large valley systems, low lands), then these should be sampled proportionately to the relative size of the respective landscape types.

For larger catchments with a more homogeneous landscape type the sampling rate could be reduced to around 10%. As the tool has not yet been applied to any complete catchment areas, this sampling rate discussion will need to continue and be tested in practice. In any case the required plots need to be clipped out by a GIS technician (refer to Appendix 1) and processed to produce the eight attributes required.

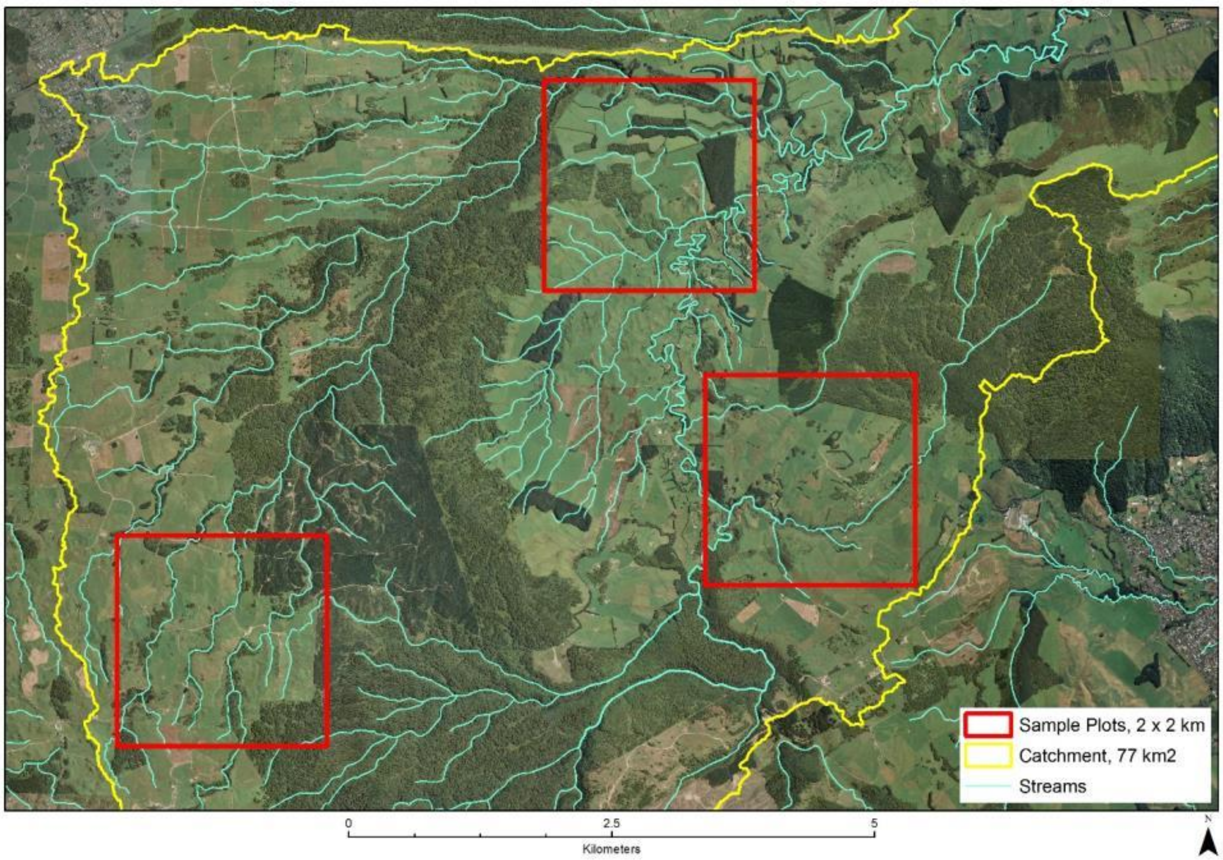


Figure 9 - Example of application of the DB Applicability Model (DBAM) to an entire catchment

3.3.5 Developing accuracy in the model

Preliminary score scales were initially developed for just two GIS derived attributes (Stream Order and the flat land class) that obviously govern ability of DBs to be fitted to landscapes and these were derived from just three representative landscape plot controls. When the number of landscape type controls was increased to eight, the number of attributes bought in was increased to five but at this version 3b stage (refer to Table 11 below), more variance in accuracy was noted (-10 to +50). Version 4 added two further slope class attributes (‘Rolling’ and ‘Easy’) which improved accuracy (-12 to +10) through to version 5 (-8 to +7) with eleven control plots tested. To ensure more universal coverage for New Zealand landscape types likely to be encountered with the use of the model, more landscape types were introduced as controls in the development of the algorithm (see Table 11), finally rising to fourteen representative control plots.

Table 11 - DBAM development, from version 1 to 7 to attain acceptable accuracy

Development of the DB Applicability Model (DBAM)										**Control Plots:** Landscape Types added (4km² plots)	**Accuracy:** Variance of Modelled vs. Control
Version	GIS Attributes introduced (√) / deleted (X) to achieve accuracy										
	Flat %	Flat Score	Rolling Score	Easy Score	Steep Score	Stream Order	Elevation Change	Public Roads	50m Flat stream margin		
1	√					√				3	NA
2	√	√				√				3	-1.3 to 0.4
3a	√	√			√	√				3	-1.7 to 1.3
3b	√	√			√	√	√			8	-12 to +50
4	√	√	√	√	√	√	√			10	-12 to +10
5	√	√	√	√	√	√	√			11	-8 to +7
6	√	√	√	√	√	√	√	√	√	14	-8 to +9
7	√	√	√	√	√	√	√	√	**X**	14	-5.8 to +6

To reduce variance of the model’s predicted DB applicability to the actual DB applicability (the fourteen plots), continuous trial and error entry of variations of both linear and non-linear scoring scales were entered into the draft model. This persistence confirmed that the level of accuracy was being improved by utilising additional attributes during development of the model.

Not all trials of new attributes were successful with a GIS attribute; for example, measuring prevalence of 50m wide ‘flat’ category land around flow paths (version 6) failed to add accuracy to the model.

Further fine tuning of the model was achieved with the inclusion of an attribute measuring prevalence of public roads.

Finally, in version 7 of the model (refer to Table 12 below) and following further trial and error adjustments to the scoring scales, the margin of error of the predictive model was reduced to + or – 6% of the 'control' values for percentage of actual DB treatment area.

Table 12 - Summary results for 14 control plots, DBAM (v7) vs. manual GIS assessment

DBAM Accuracy Results - % of area mitigated with DBs				
DBAM (V7) Treatment %	Control Plot Treatment %	Accuracy / Variance	Plot Name	Plot Number
49.3	54	-4.7	Pongakawa Nth	1
50.6	54	-3.4	Pongakawa Sth	2
50.3	54	-3.7	Kaharoa West	3
-3	0	-3	Jolly Flat	4
-4	0	-4	Jolly Mountains	5
13	7	6	Rerewhakaaitu Sth	6
60	63	-3	Okaro	7
31	25	6	Paradise Valley	8
35.2	41	-5.8	Rotokawa	9
41.8	39	2.8	Rerewhakaaitu Nth	10
62.6	58	4.6	Oturoa	11
56.3	59	-2.7	Mamaku	12
43.3	42	1.3	Pikowai Sth	13
52.6	56	-3.4	Pikowai Nth	14

4. Concluding remarks

4.1 **Potential for wider New Zealand application**

It is the author's opinion that the fundamental physical aspects of landscape deciphered by the eight GIS attributes driving the model are universal criteria. This enables the model to have application in any landscape in any region of New Zealand for anyone interested in using it to assess potential for DB ponding structures.

The proviso with universal application is that this model is calibrated to assess DB applicability in areas that meet two specific thresholds, i.e., storage ratios of at least 120 m^3 per hectare of catchment and bund wall heights up to 2.5 m. In areas where those thresholds are not required, then the model will underrate applicability (i.e., in regions where the storage ratio thresholds are less than 120:1 and / or where the pond wall heights can be >2.5 m). It could also over-rate applicability if the minimum desired thresholds are >120m^3 per hectare and /or where bund wall height regulations may be more restrictive. Alternatively, the model could be recalibrated to predict DB applicability with alternative storage volume and bund height thresholds.

The model is driven mainly by universal topography factors. Land use, rainfall, soil types and particularly soil drainage rates, are not part of the assessment undertaken in this model as these factors have no bearing on the 'physical' parameters of where a DB can or cannot be placed. However, anyone applying the model needs to be aware that the rainfall character of a district may be a factor that needs to be considered as part of their risk assessment and that the soil drainage conditions will affect performance parameters of detainment bunds targeted towards nutrient, sediment, and peak flood mitigation.

4.2 **Further development of the DB Applicability Model**

The model produces a result on a per 4km^2 plot basis and although it calculates automatically from the attribute data inputs prepared for it, those input attributes themselves still have to be manually derived for each 4km^2 plot and manually entered into the model.

These remaining manual process steps deriving the attribute data could possibly be further automated to speed the application of the model. Such improved automation of the derivation of the required attributes for the individual 2 km by 2 km plots as well as their interpretation, may enable DBAM to be applied more intensively. For example, a 2 km grid could be placed over an entire target catchment for entire catchment scoring for DB applicability rather than using a limited number of representative sampling plots.

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References

J.M. Abell, D.P. Hamilton & J. Paterson (2011) Reducing the external environmental costs of pastoral farming in New Zealand: experiences from the Te Arawa Lakes, Rotorua, Australasian Journal of Environmental Management, 18:3, 139-154, DOI: 10.1080/14486563.2011.591520

Clarke, D. T., Paterson, J., Hamilton, D., Abell, J., Scarsbrook, M., Thompson, K., Moore, R., Bruere, A. (2013) Overview of using Detainment Bunds for mitigating diffuse-source phosphorus and soil losses for pastoral farmland. In: *Accurate and efficient use of nutrients on farms*. (Eds L.D. Currie and C L. Christensen). Occasional Report No. 26. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 9 pages. https://www.massey.ac.nz/~flrc/workshops/13/paperlist13.htm

Clarke, D. T. (2013). *The performance of Detainment Bunds (DBs) for attenuating phosphorus and sediment loss from pastoral farmland.* Master's thesis, University of Waikato. http://researchcommons.waikato.ac.nz/

Dorner, Z., Doole, G., Bermeo, S. and Paterson, J. (2018). *Economic assessment of options to mitigate sediment loss from New Zealand agriculture – in the context of managing freshwater quality*. Bay of Plenty Regional Council (Environmental Publication 2018/07), Whakatāne.

Levine, B., Paterson, J. and Burkitt, L., (2017). *Phosphorus Mitigation Project; mitigation of surface P runoff using Detainment Bunds.* In: *Science and policy: nutrient management challenges for the next generation.* (Eds L. D. Currie and M. J. Hedley). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 30. Fertilizer and Lime Research Centre. Massey University, Palmerston North. New Zealand. 7 pages

Matheson, L., Djanibekov, U., Greenhalgh, S. (2018). *Recommended mitigation bundles for cost analysis of mitigation of sediment and other freshwater contaminants in the Rangitāiki and Kaituna-Pongakawa-Waitahanui Water Management Areas.* Report to BOPRC. Perrin Ag Consultants and Manaaki Whenua Landcare Research.

McDowell, R., (2010). *The efficacy of strategies to mitigate the loss of phosphorus from pastoral land use in the catchment of Lake Rotorua*. Report for Environment Bay of Plenty. August 2010

National Policy Statement for Freshwater Management 2014 (Amended 2017) http://www.mfe.govt.nz/publications/fresh-water/national-policy-statement-freshwater-management-2014-amended-2017

OVERSEER® (2018). Best practice data input standards. Version 6.3.0 2018 Section 4 Page 26 - Block Data https://www.overseer.org.nz/files/download/9ac0c71d0a896dc

Parliamentary Commissioner for the Environment (2012). *Water quality in New Zealand: Understanding the science*. Wellington.

Paterson, J., Stephens, T., Sveda, G., Nolan, T., Eikass, H., (2018). *Using GIS analysis of LIDAR data to predict best sites for construction of storm water Detainment Bunds*. In: *Farm environment planning - Science, policy and practice*. (Eds., L. D. Currie and C.L. Christensen) http://flrc.massey.ac.nz/publications.html. Occasional Report No. 31. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 9 pages.

Peryer-Fursdon, J., Abell, J.M., Clarke, D., Pearson, L.K. (2014). *Spatial variability in sediment phosphorus characteristics along a hydrological gradient upstream of Lake Rotorua, New Zealand. Environmental Earth Sciences* 73(4):1-13.

Sharpley AN, Menzel RG, Smith SJ, Rhoades ED, Olness AE., (1981). The sorption of soluble phosphorus by soil material during transport in runoff from cropped and grassed watersheds. *Journal of Environmental Quality*. 10: 211–215.

Stokes, G.G. 1851. *On the effect of the internal friction of fluids on the motion of pendulums.* vol. 9. Pitt Press. http://www.nawcc-index.net/Articles/Stokes-InternalFriction.pdf.

Appendix 1 - Guide for GIS technicians supplying sample plot attribute data

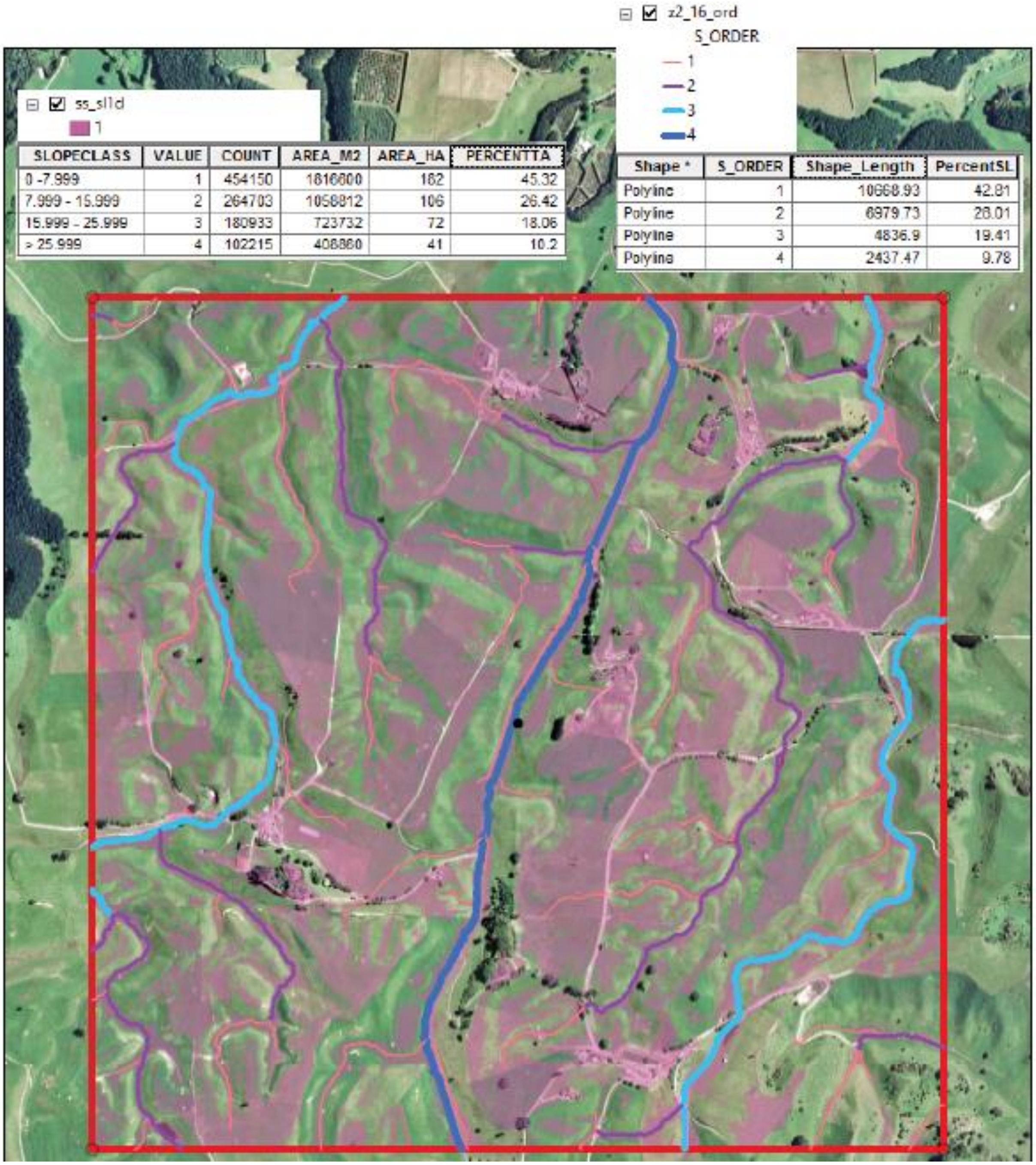
The DB Applicability Model itself does not require a GIS skilled operator but the attribute data required to operate it requires the assistance of a skilled GIS technician. Appendices 2 and 4, illustrate example plot assessment produced by a GIS technician with most of the required data shown on inset tables. Some fundamental initial requirements include:

- The target area needs to have high resolution LiDAR data available.
- The sample plots need to be appropriately located to represent the landscape types occurring in the target area / catchment.
- The number of sample plots needs to be adequate relative to both the size and homogeneity of the target area / catchment.
- Establish a latitude/longitude centre point for each plot.

Basic steps for deriving the GIS attributes required data include:

- Define the catchment extent of the area to be assessed.
- Accurately locate and clip the appropriate 2km x 2km square plots in the targeted area
- Slope analysis – calculate the areas and proportions of the four slope classes occurring within each 2 km x 2 km plot (see Table 2).
- Strahler Stream Order – identify and measure the lengths of respective stream orders within the plot. These can be aggregated into two totals; SO1 & SO2 combined and SO3 and over combined.
- Find the highest and lowest elevation points found anywhere within the plot.
- Measure the length of any public roads within the plot.

Appendix 2 – Pongakawa North plot GIS attribute data



SLOPECLASS	VALUE	COUNT	AREA_M2	AREA_HA	PERCENTTA
0 -7.999	1	454150	1816600	182	45.32
7.999 - 15.999	2	264703	1058812	106	26.42
15.999 - 25.999	3	180933	723732	72	18.06
> 25.999	4	102215	408860	41	10.2

Shape *	S_ORDER	Shape_Length	PercentSL
Polyline	1	10668.93	42.81
Polyline	2	6979.73	28.01
Polyline	3	4836.9	19.41
Polyline	4	2437.47	9.78

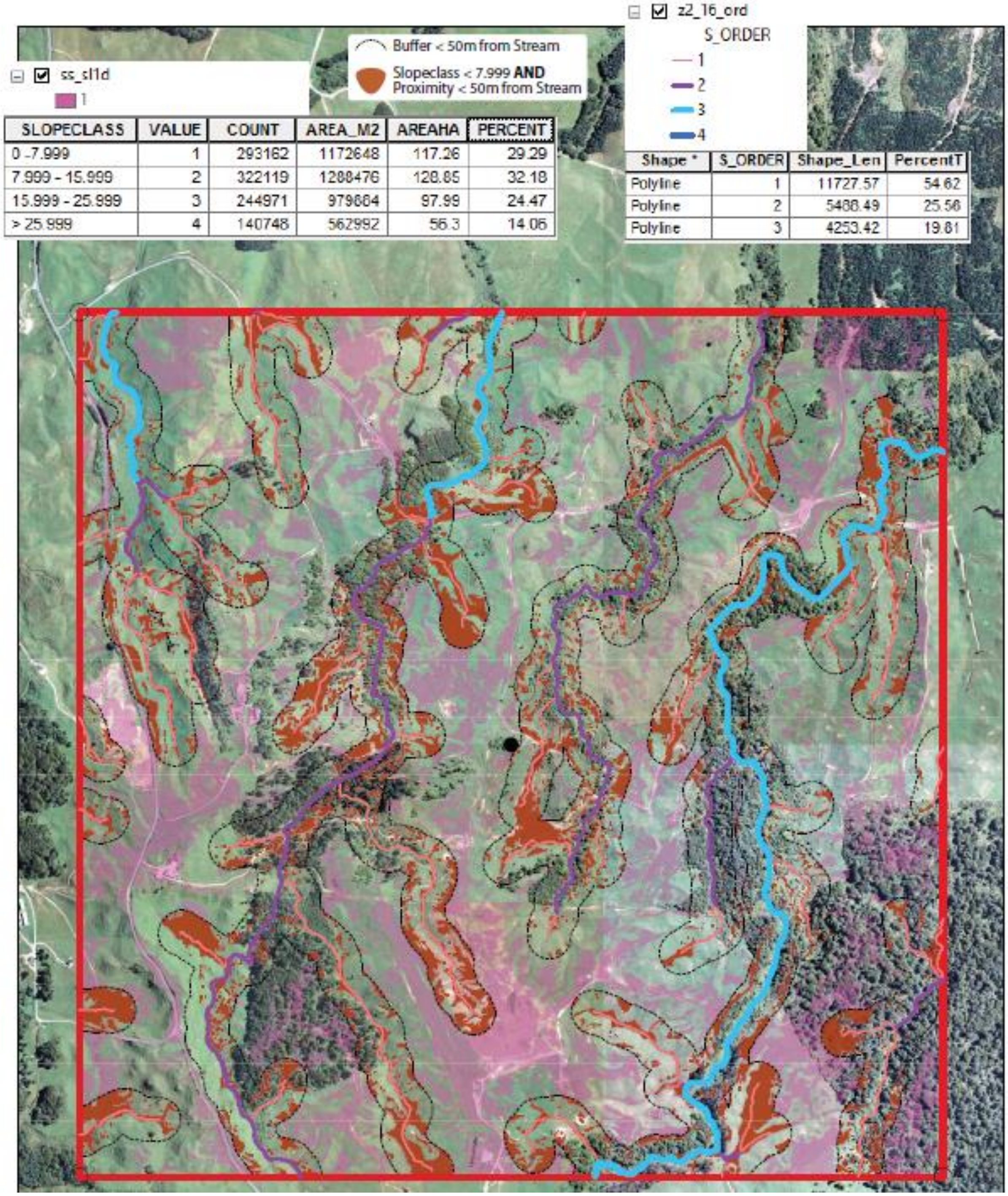
The 'Pongakawa North' plot with GIS attributes displayed in inserted tables providing data ready for input into the DBAM (one of fourteen landscape type plots). See 'control' DB treatment applicability for this same plot in Appendix 3 below.

Appendix 3 – Pongakawa North plot manual assessment

The Pongakawa North plot ‘control’ with outcomes of manual assessment of DB applicability. This example shows 54% of this plot is treatable by Detainment Bunds [PS120].

The final version of the model interpreted the data from this same plot (as shown in Appendix 2) to produce a 49.3% DB treatment result, i.e., < 5% error. See result in control plot 1, Table 12.

Appendix 4 – Mamaku plot GIS attribute data

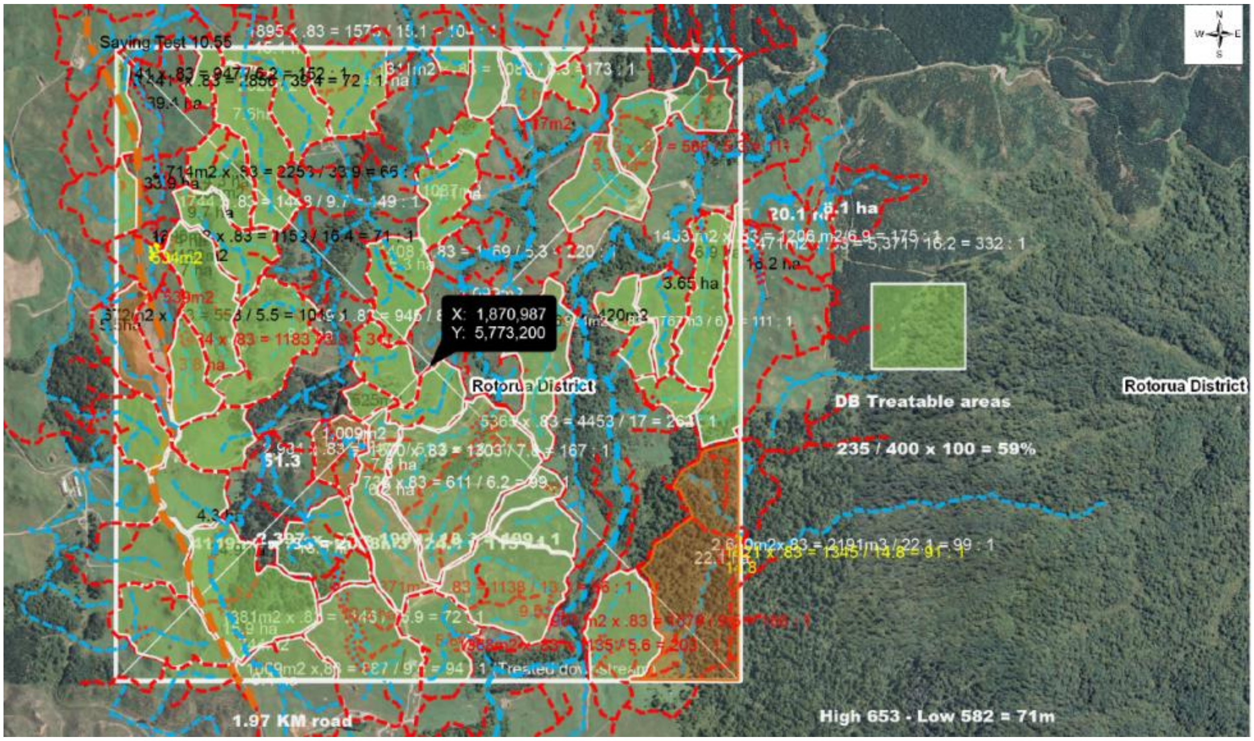


SLOPECLASS	VALUE	COUNT	AREA_M2	AREAHA	PERCENT
0 -7.999	1	293162	1172648	117.26	29.29
7.999 - 15.999	2	322119	1288476	128.85	32.18
15.999 - 25.999	3	244971	979884	97.99	24.47
> 25.999	4	140748	562992	56.3	14.06

Shape *	S_ORDER	Shape_Len	PercentT
Polyline	1	11727.57	54.62
Polyline	2	5488.49	25.56
Polyline	3	4253.42	19.81

The 'Mamaku' 4km² plot (1 of 14 controls used) with GIS attributes displayed in inserted tables providing data ready for input into the DBAM. Note this map shows definition of flat areas (black dashed lines) within 50m of flow paths which was trialled as a contributing attribute and found to be ineffective in the model. See 'control' DB treatment applicability for this same plot in Appendix 5 below.

Appendix 5 – Mamaku plot manual assessment



The ‘Mamaku’ plot ‘control’ with outcomes of manual GIS assessment for DB applicability (green zones). This example shows 59% of this plot is treatable by DBs [PS120]. The final version of the model interpreted the data from this plot to produce 56.3%, i.e., < 3% error. See result in ‘control’ plot 12, Table 12.

Appendix 6 – DB Applicability Model, Excel Spreadsheet Calculator excerpts

Displayed below are the three integrated parts of the DBAM Excel Spreadsheet calculator:

- 6.1 DBAM DATA ENTRY tab,
- 6.2 DBAM internal attribute scoring scales,
- 6.3 DBAM Results, the predicted percentage of each catchment plot that is treatable with DB's

DBAM DATA ENTRY
GIS LiDAR data attributes from 2 km x 2 km land plots

Site identification	Location (X and Y coordinates from the midpoint of the plot)		Slope class (as % of total)				Length of each Stream Order (SO)				Elevation change		Length of public roads
Plot name/i	Coordinate	Coordinate	Flat (0-7.99°)	Rolling (8-15	Easy (16-25.9	Steep (≥25.9	SO1 (m)	SO2 (m)	SO3 (m)	SO≥4 (m	Highest point (m)	Lowest point (m)	Length (km)
Example plot	*1906403.2*	*5800524.7*	*45.3*	*26.4*	*18.1*	*10.2*	*10,668*	*6,979*	*4,837*	*2,437*	*142*	*54*	*2.05*
Pongakawa Ntl	1906403.2	5800524.7	45.3	26.4	18.1	10.2	10,668	6,979	4,837	2,437	142	54	2.05
Pongakawa Sth	1898148.2	5790258.56	28.6	19.2	22.4	29.7	11,853	7,844	2,323	331	332	250	2.61
Kaharoa W	1,879,053	5,788,399	62.3	19.5	11.5	6.7	11,612	4,695	4,718	1,166	507	426	0
Jolly Flats	1,927,137	5,739,199	98.3	1.3	0.4	0	19,624	9,012	7,742	6,130	198	178	2.5
Jolly Mtn	1,930,416	5,735,679	2.6	2.5	5.8	89.1	9,029	5,347	1,669	3,819	1000	246	0
Rere South	1,907,048	5,750,314	57.3	12.9	14.1	15.7	10,343	5,082	4,679		526	440	1.91

Run model

6.1 The Data Entry template of DBAM (displayed above) shows GIS attributes entered into DBAM for assessment of DB applicability for six named and located 2km x 2km catchment plots

Detainment Bund Applicability Model (DBAM)
Scoring tables for each GIS attribute (A-H)

A Flat

% of 'Flat' sope class is a primary factor conducive to DB sites. This score transfers directly into the summation row

B Flat

Class (%)	Score	Weighting Logic:
<5	65	
5 - 9.9	40	
10 - 24.9	25	
25 - 39.9	8	
40 - 44.9	5	
45 - 49.9	0	
50 - 59.9	-3	>50% 'Flat' starts to inhibit DBs
60 - 69.9	-5	
70 - 79.9	-10	
80 - 89.9	-20	
90 - 100	-30	

C Rolling

Class (%)	Score	Weighting Logic:
<5	-25	
5 - 9.9	-22	<16% 'Rolling' inhibits DBs
10 - 12.9	-20	
13 - 15.9	-15	
16 - 18.9	7	
19 - 21.9	7	
22 - 24.9	5	
25 - 27.9	10	25-30% 'Rolling' conducive to DBs
28 - 30.9	15	
31 - 32.9	10	
33+	5	

D Easy

Class (%)	Score	Weighting Logic:
<5	0	
5 - 9.9	-10	<20% 'Easy' inhibits DBs
10 - 14.9	-15	
15 - 19.9	-3	
20 - 24.9	0	
25 - 29.9	0	
30 - 34.9	5	>30% 'Easy' conducive to DBs
35 - 39.9	10	
40 +	10	

E Steep

Class (%)	Score	Weighting Logic:
0 - 1.9	-30	
2 - 4.9	-25	
5 - 9.9	-7	
10 - 14.9	-5	
15 - 19.9	-10	
20 - 24.9	-15	Steep' land inhibits DBs
25 - 29.9	-20	
30 - 49.9	-20	
50 - 69.9	-20	
70 - 84.9	-20	
85 - 100	-20	

F Stream Order

% ≥ SO3	Score	Weighting Logic:
0 - 14	35	
15 - 18	25	SO1 + SO2 conducive to DBs
19 - 22	20	
23 - 26	10	
27 -30	8	
31 - 34	5	≥SO3 inhibit DBs
35+	0	

G Elevation Change

Range (m)	Score	Weighting Logic:
≥ 250	-25	High elevation change inhibits DBs
200 - 249	-20	
150 - 199	-10	
130 - 149	-7	
120 - 129	-5	
105 - 119	-3	
95 - 104	-3	
85 - 94	-3	
75 - 84	-2	
50 - 74	-3	Low elevation change inhibits DBs
25 - 49	-10	
0 - 24	-15	

H Public Road

km of road	Score	Weighting Logic:
0 - 0.4	0	
0.5 - 0.9	-1	
1 - 1.4	-2	
1.5 - 1.9	-3	Public roads inhibit DBs
2 - 2.4	-3	
2.5 - 2.9	-6	
3 - 3.4	-6	
3.5 -3.9	-6	
4 - 4.4	-8	
4.5 - 4.9	-9	

DB applicability ratings based on % of land treatable by DB

Likelihood of DB effectiveness	DB treatable area (%)
High	> 80
Good	60 - 79
Medium	40 - 59
Low	20 - 39
Unviable	0 - 19

6.2 DBAM internal attribute scoring scales (displayed above) for assessing the eight attributes (A-H) entered in the Data entry template (6.1) for each catchment sample plot together with a five-part applicability judgement scale ranging from unviable (<20% DB Treatable area) through to highly viable (>80% DB treatable area).

DBAM: Detainment Bund Applicability Model

A calculator for predicting the percentage of a catchment where stormwater runoff in ephemeral flowpaths can be treated by **Detainment Bunds** [PS120]

Note: The eight GIS data attributes required for this calculator are derived from a selected 2 km^2 sample plot of land from the targeted catchment area.

Show data

Select **'model results'** for printing

Enter plot data into the 'Data Entry' tab, following the format presented in the example.

	DB Fitting Key Model Scores for Attributes A-H														DB Fitting Key Model Results	
	A Flat	B	C Rolling		E Steep		F Stream Order		G Elevation change		H Public Road		Predicted proportion of catchment treated by DB (%)	Likelihood of DB effectiveness
	% 0-7.9°	Score	% 8-15.9°	Score	% ≥26°	Score	% ≥SO3	Score	(m)	Score	(km)	Score		
Example plot	*45.3*	*0*	*26.4*	*10*	*10.2*	*-5*	*29.2*	*8*	*88*	*-3*	*2.05*	*-3*	*49.3*	*Medium*
Pongakawa Nth	45.3	**0**	26.4	**10**	10.2	**-5**	29.2	**8**	88	**-3**	2.05	**-3**	**49.3**	**Medium**
Pongakawa Sth	28.6	**8**	19.2	**7**	29.7	**-20**	11.9	**35**	82	**-2**	2.61	**-6**	**50.6**	**Medium**
Kaharoa W	62.3	**-5**	19.5	**7**	6.7	**-7**	26.5	**10**	81	**-2**	0.00	**0**	**50.3**	**Medium**
Jolly Flats	98.3	**-30**	1.3	**-25**	0	**-30**	32.6	**8**	20	**-15**	2.50	**-6**	**0.3**	**Unviable**
Jolly Mtn	2.6	**65**	2.5	**-25**	89.1	**-20**	27.6	**8**	754	**-25**	0.00	**0**	**-4.4**	**Unviable**
Rere South	57.3	**-3**	12.9	**-20**	15.7	**-10**	23.3	**10**	86	**-3**	1.91	**-3**	**13.3**	**Unviable**

6.3 DBAM Results tab (displayed above) showing results outcomes from input of attribute data from six different 2 km x 2 km plot locations. While just six results are shown here, the model will accept data, calculate and display results from an unlimited number of plots.

For further discussion on the application of DBAM – contact:

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