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USING GIS ANALYSIS OF LIDAR DATA TO PREDICT BEST SITES FOR CONSTRUCTION OF STORM WATER DETAINMENT BUNDS

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Introduction

Storm water surface runoff can be the primary conduit of pastoral phosphorus losses in New Zealand (McKergow et al., 2007). By targeting storm water, Detainment Bunds (DBs) can mitigate the phosphorus load carried by storm water into receiving waterbodies, detaining runoff responsible for the rising arm of a storm hydrograph and associated with disproportionately higher suspended solid loads (Abell et al., 2013).

DB's are low profile raised earthen berms specifically constructed across valley floors that intercept and detain ephemeral runoff to enable suspended particulates to commence settlement and adsorb or infiltrate dissolved contaminants prior to reaching a waterway. Importantly, DBs can be managed to minimise ponding time to less than three days, preventing pasture damage (e.g., Levine et al, 2017). So, DBs offer the exciting potential to mitigate phosphorus loss without reducing pastoral production, adding to the mitigation toolbox available for land holders to operate sustainably within the limits required by the National Policy Statement on Freshwater Management (NPS-FM).

Background Research on DBs

In 2010, the Bay of Plenty Regional Council initiated a review of practical and efficient P-mitigation methods (McDowell 2010). McDowell determined there was inadequate evidence in literature on the potential for storm water detainment of farm run-off, including conditions governing efficacy as much as potential for adoption across catchments in New Zealand. The Bay of Plenty Regional Council then initiated the Rotorua P-Project (in 2010) with the building of DBs in collaboration with Lake Rotorua catchment farmers who shared the confidence that detaining ephemeral storm water runoff on-farm has multiple benefits and would be beneficial for the Lake Rotorua water quality objectives (Paterson 2013). Subsequent research has demonstrated storm water yields of TP to Lake Rotorua are indeed disproportionate and dominant (Abell et al., 2013). Equivalent behavior is expected from many pastoral catchments in New Zealand where ephemeral pathways exist and act as critical sources for TP loss from the land (e.g., McKergow et al., 2007; Monaghan et al., 2008; McDowell and Nash, 2012).

A range of mitigations already exist for targeting TP-loss from pastoral land with a growing evidence-based for promising efficacy, including sediment traps, natural and constructed wetlands, and riparian corridors of grass filter strips or lower storey native plantings (e.g., McKergow et al., 2017; Rutherford et al., 2018). However, these can be limited by excessive volumes of runoff delivered from the land and the cost of retirement, reducing residence time and area for treatment across the edge-of-field, respectively. DBs differ by periodically capturing storm water runoff in-field and temporarily (≤ 3 days), to ensure ponding areas retain their productive value, to increase their residence time and area of effect relative to other P-mitigations.

Bay of Plenty Regional Council initiated research into DBs in 2011, supported by DairyNZ (e.g., Clarke 2012). Initial research qualitatively showed that DBs capture notable contaminant loads, up to 2.7 tonne of sediment (and 6 kg of TP) after one 3-day storm event (Clarke 2013). Accompanying land management had a notable effect, with that latter event an extreme associated with storm runoff from a recently heavily grazed winter forage crop. Across the three DBs monitored by Clarke (2013), a near order of magnitude of variation was reported for the mass of sediment and TP detained per event. At the time, two questions remained unaddressed: (1) the proportion of input loading or efficacy that DBs could then generate on sediment and TP losses to ephemeral flow paths; and (2) whether DBs were effective at reducing dissolved reactive Phosphorus (DRP) loss. Since, Peryer-Fursdon (2014) has revealed that P may not be as tightly bound to soil particles as first thought and adsorption-desorption of P is common during transit to waterways making it readily bioavailable and more likely to also be attenuated by DBs.

In 2016, pastoral farmers in the Rotorua lakes catchments developed an applied research project dedicated to advancing mitigation knowledge specifically of P, the Phosphorus Mitigation Project (PMP). The PMP aims to build on the earlier semi-quantitative research of Clarke (2013), to fully quantify DB efficacy across farm system, DB design and climatic event, for phosphorus and sediment mitigation (e.g., address relative and absolute loading and concentration change in contaminants across multiple DBs during a three-year PhD applied research study). To fully target both particulate and dissolved forms of phosphorus, PMP will also be experimenting with the placement of non-toxic flocculants in DB storm water ponds in 2019 and intends to investigate the potential effects of DBs on mitigating *E-Coli* in storm water.

PMP launched its project to science observers in February 2017 (Levine 2017) and readers should refer to this work for more detailed background on the project's objectives.

Preparations for DB roll out to NZ farmers

Presently, we remain uncertain if DB's can operate effectively and widely across New Zealand's farming landscapes and various pastoral systems. Despite this, over 20 early adopter farmers in the Central North Island have constructed DBs for varying reasons (e.g., for downstream storm water damage control, sediment capture, phosphorus capture, prevention of erosion or pasture damage). However, more widespread uptake of DB's is hindered by three unknowns: (1) robust DB performance estimates for phosphorus and sediment (2) knowledge of DB suitability across landscapes; and ultimately (3) cost-effectiveness of DB's over other on-farm mitigations.

In 2019 the Phosphorus Mitigation Project will deliver on all three knowledge barriers to fully validate the potential of the Detainment Bund as a new on-farm tool for phosphorus loss management.

DB Suitability across landscapes

From initial construction experience it is already known that 'suitable' DBs, that is those with sufficient mitigation efficacy, will not suit all land use situations. A key user-based constraint for suitable DB sites is that they achieve 'permitted activity' requirements of Council land and water plans, to reduce their cost and risks to land holders. In the Bay of Plenty then, a DB cannot exceed 2.5m height, retain more than 5,000m³ or interfere with a permanent natural waterway, which in turn places requirements for relatively gently sloping land upstream of higher order streams.

Whilst DB efficacy is undergoing refinement by the PMP, Clarke (2013) has already established that a key determinant is the ponded-storage-to-catchment-area, recommending this exceed 120:1 (m^3:Ha). When coupled to latter policy restrictions, this restricts suitable DB sub-catchments to ~42 Ha or less.

Predicting suitable DB sites

In addressing the second of those three constraints to DB adoption above, a flexible modelling and reporting approach has been adopted to incorporate our modest knowledge of causes for variation in sediment and TP mitigation efficacy, and requirement for high-resolution (LIDAR) geospatial data with which to ensure permitted activity status of DBs are met by suitable sites (e.g., ≤2.5 m high, ≤5,000 m^3 volume). Output is intended to represent 'potentially' suitable DB sites. More refined understanding of the drivers behind DB efficacy on sediment and P-mitigation is actively being developed and from this, an optimal design can then be re-run. So, despite predicting actual locations for DBs, reporting will be amalgamated to sub-catchment or whole-of-catchment scale, with output also coarsely reported as percentage area draining to provisionally effective and permitted DBs (i.e., failing to recognise for actual sediment or P-yields varying independent of area; constrained by current requirements).

Three alternative methods will be followed for identifying potentially suitable sites in the Lake Rotorua catchment, with comparisons between methods to determine their consequence on reporting:

1. **Manual identification using LiDAR**. Currently sites are manually scoped at 1m contour. Whilst laborious, this offers greatest confidence that a proposed site will meet conditions of suitability (e.g., catchment size, ponded area and volume for 2.5 m high wall [volume estimated as storage area multiplied by the 1/3rd height of the proposed earth bund]). If ponded-storage-to-catchment area is <120:1 the site is excluded. The method is however, highly user-based and subject to inter-operator variation in recommended sites.

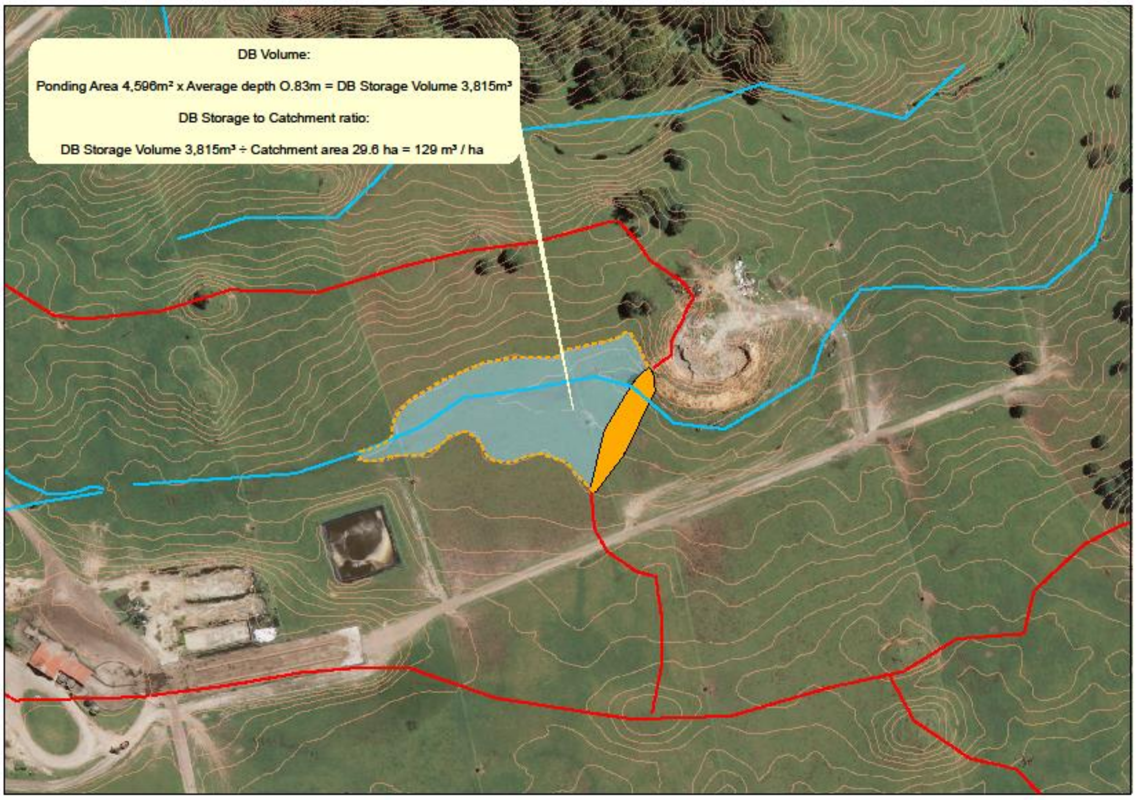
Figure 1 below shows an example of a 'likely' site on a dairy farm. Using the 1m contour lines the manual steps for drawing a proposed DB 'mock up' to test the 'likely' site against DB design requirements include:

- At the 'likely' site, a 2.5m high DB is drawn (yellow polygon) across the flow path
- The ridge lines and catchment extent are marked (red line),
- The ephemeral flow path is drawn in following the valley floor (blue line)
- The catchment area is measured – 29ha in this example
- At the maximum bund height (2.5m) the ponding area has been traced in
- The average depth when full is 1/3rd the height of the bund (e.g., 0.83m)
- The ponding area is measured - 4,500m²
- The ponding volume is calculated – 3,815m³ in this example:

  Ponding area (m² x Average depth of pond) = Pond Volume (m³)
- The DB pond volume to catchment ratio is established

  Pond Volume divided by Catchment Area – 129m³/Ha in this example.

As the test of this likely site 'mock up' has achieved a 129 to 1 ratio, and this exceeds the minimum requirement of 120:1 m^3/Ha, the potential site is passed as suitable subject to on-site checks.



DB Volume:

Ponding Area 4,596m^2 x Average depth O.83m = DB Storage Volume 3,815m^3

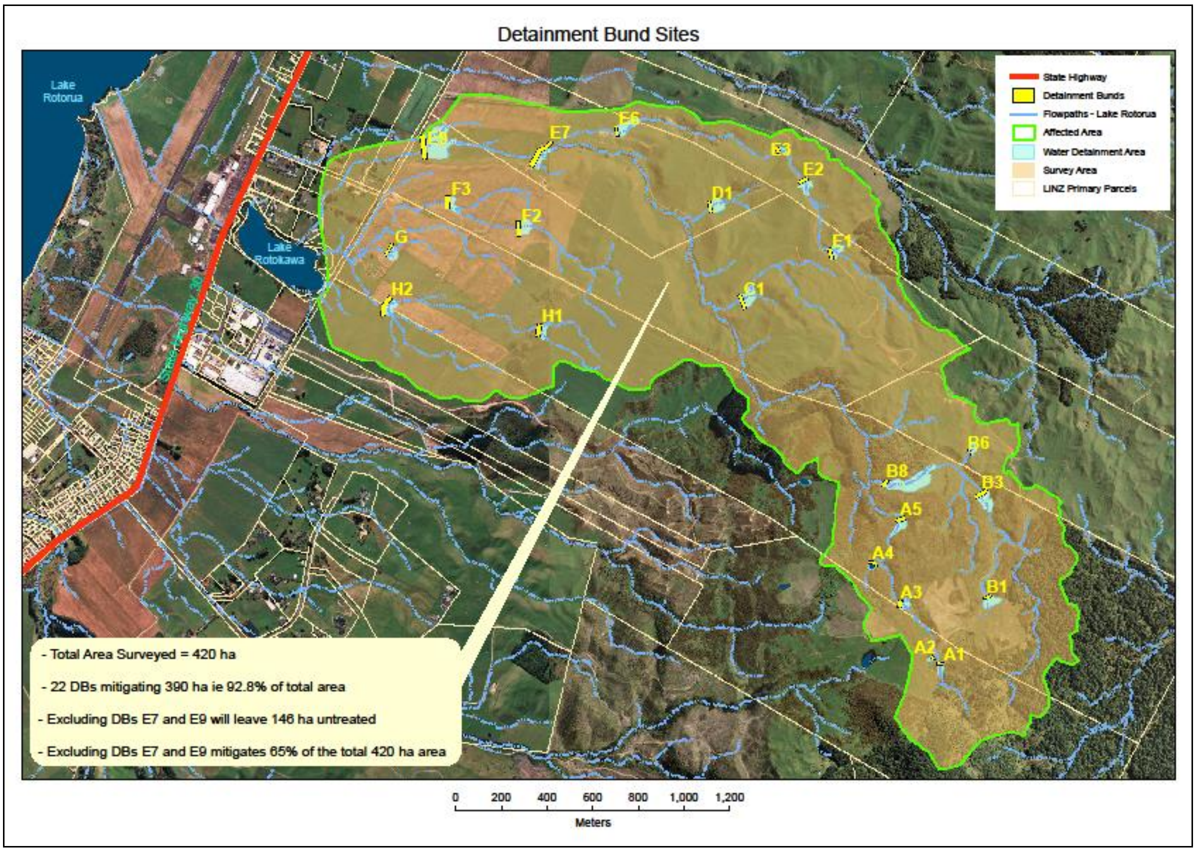
DB Storage to Catchment ratio:

DB Storage Volume 3,815m^3 ÷ Catchment area 29.6 ha = 129 m^3 / ha

Figure 1. Running a GIS LiDAR enabled suitability test for a likely DB site. Its volume to catchment ratio (at 129:1) exceeds the minimum requirement (120:1)

The manual method for selecting suitable DB sites has been carried out across entire sub-catchments. Figure 2 illustrates a 420 ha sub-catchment to Lake Rotorua with 22 'likely' DB sites identified.

Detainment Bund Sites



- Total Area Surveyed = 420 ha
- 22 DBs mitigating 390 ha ie 92.8% of total area
- Excluding DBs E7 and E9 will leave 146 ha untreated
- Excluding DBs E7 and E9 mitigates 65% of the total 420 ha area

Figure 2. Example of an assessment of a 420 ha catchment area to find 'likely' DB sites and confirming pond storage to catchment size ratios for each DB site (as per Figure 1)

2 Automation of GIS searching for DB sites locations using a generalized scoring system based on landscape features.

The second DB suitability method is coarse, resolved to landscape only. Landscapes are grouped according by slope class, drainage class and stream order, with a weighted suitability score generated.

Figure 3 below shows a sub-catchment to Lake Rotorua categorized by slope class and stream order. This approach is more amenable to national scale prioritization where LiDAR resolution is low or absent but might require region-based weightings of contributing topographic, edaphic and hydrologic factors to account for variations in particle size, runoff power and infiltration rate.

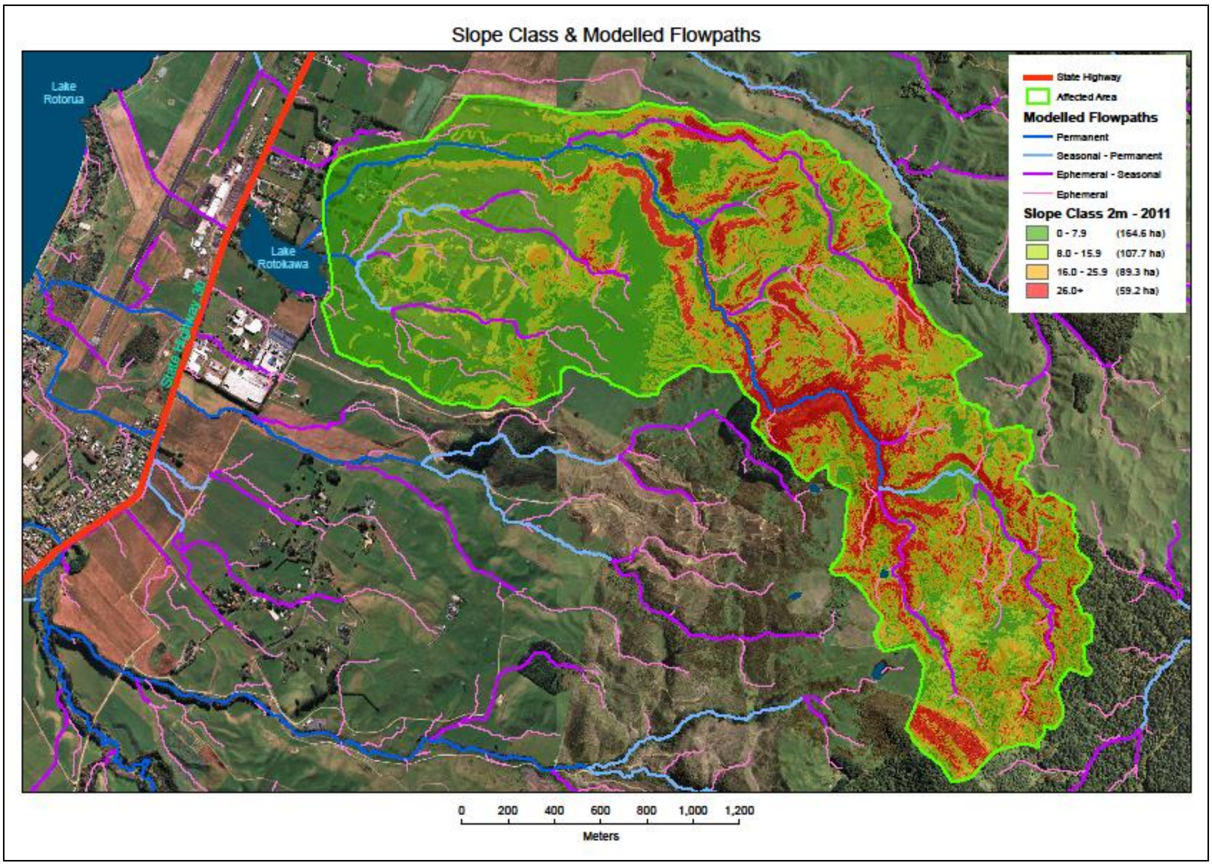


Figure 3. An example of the use of LiDAR for defining slope categories and Stream Orders

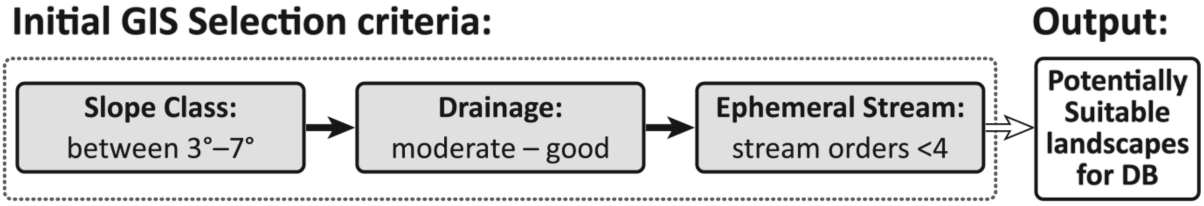


Figure 4. Flow diagram for general characterization of landscape suitability for DBs (Blackant Mapping Solutions)

3 Automation of GIS searching for specific DB sites locations using rules and filters within a GIS LiDAR data search model.

The third method for selecting suitable DB sites is a modification of the second, to automate the process but amending in steps required to determine if a site can actually support an effective and permitted DB. Figure 5 demonstrates the GIS routine that relies on LiDAR geospatial information to apply constraints related to bunding height, volume and ponded-volume-to-catchment-area ratios. Output is more refined spatially, but equally subject to the need for on-the-ground verification as per the first method, before any wider application.

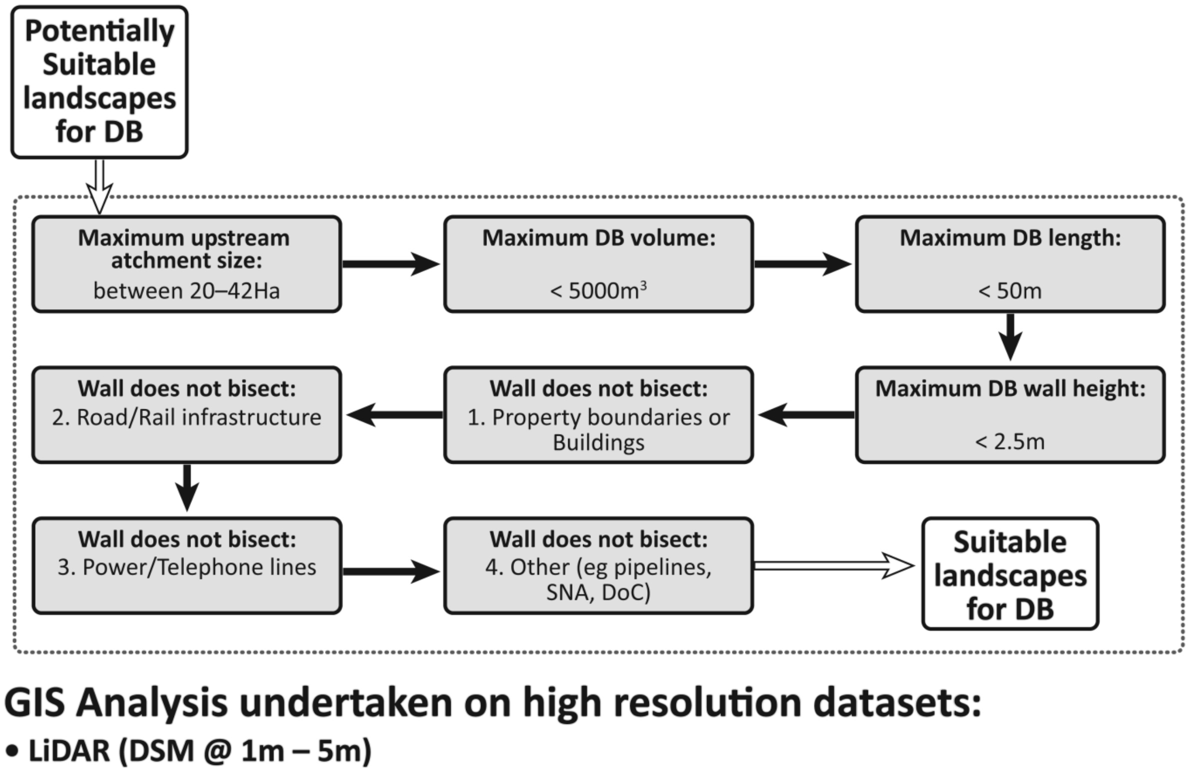


Figure 5. Flow diagram of a proposed GIS model designed to specifically assess for landscape suitability for DBs (Blackant Mapping Solutions)

The PMP will ground-truth output from both methods (1) and (3), to determine rates of positive identification (false-positive, only). Whilst method (3) is less laborious it is contingent on reliably determining landscape topography and the thresholds in slope and stream order likely to relate to appropriate ponding ($\geq 120m^3$:1Ha) and ephemeral flow-paths, respectively. Both appear thus far to be critical constraints to an effective but permitted DB.

Conclusion

Storm water loads of sediment and TP can predominate pastoral contributions to waterways. In conjunction with the wider PMP investigation of DB efficacy for sediment and P-fractions, across varying design and environmental conditions, this study will test if the automation of suitable DB candidate sites can be reasonably achieved in Lake Rotorua through a comparison of three alternate approaches: (1) manual selection; (2) landscape selection; and (3) site-specific selection using LiDAR. Given the ongoing advancement of our knowledge of DB design constraints and effects, considerable risk is attached to incorrectly identifying precise locations. Instead of retaining that scale about reporting, overall sub-catchment suitability will be reported by a simple metric of % area draining to suitable DB sites, noting this is a coarse (and likely inaccurate) assessment of the combined effects those DBs would yield in each sub-catchment.

Combined, the PMP can better inform both the usefulness and constraints facing DB adoption on-farm in the Lake Rotorua catchment as well as hopefully wider afield in New Zealand where DBs might offer a highly effective mitigation for the impacts of excess sedimentation, nuisance algae or bed-habitat on coastal and freshwater quality.

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