OVERVIEW OF USING DETAINMENT BUNDS FOR MITIGATING DIFFUSE–SOURCE PHOSPHORUS AND SOIL LOSSES FROM PASTORAL FARMLAND

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Introduction

Overview

This paper introduces detainment bunds (DBs) which are a new tool that has been trialled in the Lake Rotorua catchment, specifically for mitigating downstream transport of particulate phosphorus (P) in overland flow during intense rainfall and runoff events. The structure of this paper is aligned with the presentation of DBs given at the FLRC workshop in February 2013. Firstly, context is given to justify the need for DBs and secondly, DBs are introduced with the aid of photos and diagrams to explain the design, function and operation of these structures.

Context

Diffuse-source phosphorus (P) loss from pastoral farmland via surface runoff is a challenging issue for land managers across the globe. Surface runoff (overland flow/ephemeral streams) is generated during rainfall when soil is saturated or infiltration capacity has been met (Figures 1 and 2). These ephemeral flows form in paddocks which are usually dry and they usually only flow for short periods of time (e.g. hours) in direct response to high intensity rainfall. They have the potential to transport a disproportionately large amount of sediment and nutrients from farm systems over short periods of time depending on land use in the contributing catchment.

Figure 1: Overland flow in pastoral farmland in the Waiteti Stream catchment (a sub catchment of Lake Rotorua) after an intense rainfall event. This stream is entirely ephemeral as these paddocks are usually dry. Photo: Photo: D. Clarke 2012

Figure 2: A large ephemeral stream in the upper Hauraki Stream catchment (a sub catchment of Lake Rotorua). Photo: D. Clarke 2012.

There is a range of mitigation tools available for attenuating nutrient and sediment loss via overland flow, each with strengths, weaknesses and variable cost effectiveness (McDowell & Nash 2012). Treating the large volume of water leaving a catchment during runoff events presents a challenge and many mitigation approaches struggle to cope with such large discharges over short periods of time. For example, 'break points' in riparian buffer strips can form where ephemeral flow paths intercept perpendicular to the strip and volumes are too great for water velocity to be reduced substantially by the vegetation, resulting in channelized flow through the riparian attenuation area (Cooper et al. 1990; Owens et al. 2007; Verstraeten et al. 2006). Grass filter strips can be effective for treating overland flow as long as water height is below the height of the grass. Once this height is exceeded then attenuation performance is reduced as grass is flattened (Cooper et al. 1990). Constructed wetlands often have a flood water diversion channels to avoid flood water inundation and damage such as at the large constructed wetland upstream of Lake Okaro in the Bay of Plenty (Tanner, 2003). If storm water is temporarily stored in upper catchment areas, then the above mentioned mitigation tools (and others) would potentially have a greater capacity to remove sediment and associated nutrients from water in overland flow.

Detainment Bunds

Introduction to DBs

Detainment bunds (DBs) are a new type of mitigation tool specifically designed to remove sediment and associated P from water leaving pastoral farmland during intense rainfall and runoff events. Several DBs have been constructed in the Lake Rotorua catchment as part of a collaboration between Bay of Plenty Regional Council, DairyNZ and Lake Rotorua catchment farmers in a wider P mitigation programme known as the 'Rotorua P-Project'. The primary aim of the project is to address the large quantity of P entering Lake Rotorua during storm events (Rutherford & Timpany 2008).

Detainment bunds temporarily pond ephemeral water behind an earth bund (c.1.5 m high) (Figure 3) for the purpose of allowing suspended sediment and associated nutrients to settle from suspension onto the pasture and become part of the soil matrix. Figure 4 shows an example of a DB basin after a ponding event. Clear evidence of sediment deposition can be seen where the water has ponded, but no sediment is retained in the ephemeral flow path.

Figure 3: A typical detainment bund in the Lake Rotorua catchment. Water has ponded behind the bund following a heavy rainfall event which produced surface runoff. This ponded water is slowly draining through the bund's outlet control structure while sediment and particulate nutrients settle from suspension. Photo: D. Clarke 2012.

Figure 4: Evidence of sediment retention (visible on grass) after a ponding event at a detainment bund in the Awahou Stream catchment, July 2012. Note the ephemeral stream flow path (depicted by the arrow) in the foreground is completely clean. Photo: D. Clarke 2012.

Detainment bunds have been specifically designed to be readily adapted to farm systems. In order to maintain pastoral production, DBs have been designed and operated to allow ponding of storm water for no more than three days (Figure 4). This is a compromise between the optimal ponding time to achieve more complete deposition of fine particles and the maximum time that land owners will tolerate ponding before detrimental effects to pasture production occur on what are typically very productive areas of farms.

Detainment bunds are similar to detainment dams (DDs) which have been constructed in the Lake Rotorua catchment for flood control over the past 30 years. Detainment dams have no specific control on water residence time as there is a relatively unrestricted culvert pipe under the bund. Detainment bunds differ from DDs as they have a choked riser outlet which enables the management of the residence time of the ponded storm water for up to a maximum of three days. Clarke (2013) found elevated soil Olsen P concentrations in the ponding area of an old (12 year) DD, indicating that even DDs with relatively unrestricted outflow and minimal ponding time can be a P sink in the long term. This finding suggests that DBs are likely to be even more effective as P sinks due to the increased storm water residence time that they permit.

DB design and operation

Ponded water slowly drains from DBs via a floating decant system (Figure 5) which drains surface water until the ponding area is dry (Figure 6). The pasture in the ponding area is only inundated when sufficient intense rainfall produces runoff in the contributing catchment (c. 10 times per year in the Lake Rotorua catchment; Clarke, 2013).

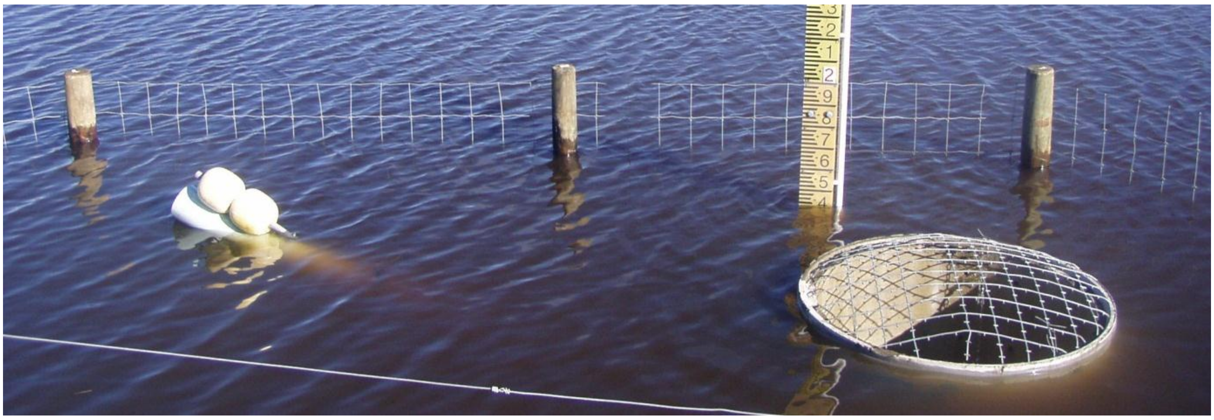

Figure 5: A floating decant structure draining water from a DB in the Waiteti Stream catchment. Photo: D. Clarke 2012.

Figure 6: Residual water following a large ponding event at a detainment bund in the Waiteti Stream catchment, Rotorua. Note that the pasture appears undamaged. Photo: D. Clarke 2012.

Figure 7 depicts the basic structure of a typical DB. Water is ponded behind an earth bund and can leave the basin by three outlets. In theory, the first outflow is via a floating decant structure (1; Figure 7) suspended by a pin which is pulled when water level rises in the basin, allowing the retention of 'first flush' water. The second stage of outflow is via a concrete riser (2; Figure 7). Water flows over the top rim of this when the basin fills to storage capacity. The third stage of outflow is via an emergency spillway (3; Figure 7) which is seldom used if storage capacities are adequate, but is a necessary component to accommodate extreme events. Erosion-proof matting, compact substrate or stable grass cover are necessary to prevent erosion on the spillway. Each bund was 'keyed' and compacted into the ground during construction for stability when retaining water.

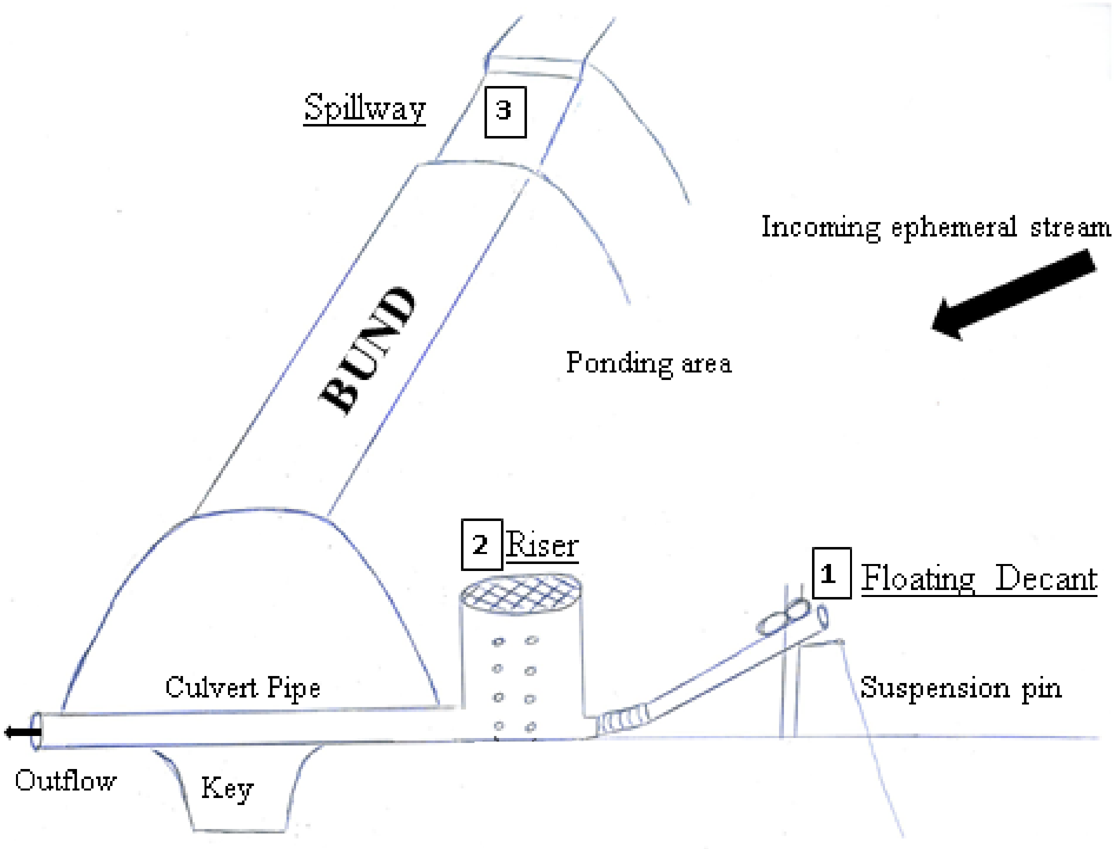

Figure 7: A schematic sketch of a functional detainment bund built for P mitigation (modified from Clarke, 2013).

Adequate storage capacity of DBs is essential to retain incoming water and allowing sufficient residence time behind the bund. Clarke (2013) concluded that a storage ratio of at least 120 m^3:1 ha (water storage per ha of contributing catchment) calculated to the rim of the DB riser should be used as a minimal nominal guideline. In the future, the nominal storage to catchment ratio may increase to be in the order of 150:1 to the rim of the riser. A complete water balance for DBs as part of a more detailed consideration of sizing will provide a better understanding of optimal storage ratios.

The floating decant system used to drain the DBs (as depicted in Figures 5 and 7) requires further development before DBs are 'rolled out' across pastoral landscapes. Each DB has a different optimal decant rate, depending on the volume of water storage. This will be highly dependent on the positioning of the decant float and there are also possible alternative outflow designs.

Best management practices for the use of DBs

There are several best management practices (BMPs) which can be followed when managing DBs. In the long term, DB basins are likely to be a P-sink so there may be no need for application of P fertiliser within the ponding area (Clarke, 2013). However, there may be a need for addition of readily–leached nutrients such as nitrogen and sulphur (A. Roberts, Ravensdown, *Pers. comm*., 2012). Best practice in farming in New Zealand often involves the use of a spatially applied nutrient budgeting model (e.g. OVERSEER®) where a farm's various land management units or blocks are separately assessed for nutrient application, uptake and loss. The DB ponding areas could be treated as separate blocks in such nutrient budgeting models and lead to more efficient fertiliser application strategy in the farm's nutrient management planning. During wet periods it is advised to exclude stock from the ponding area, as shown in Figure 8.

Figure 8: An example of good management of a DB in the Awahou Stream catchment as the ponding area has been temporarily fenced off from stock during wet periods. Photo: D. Clarke 2012.

Detainment bund performance

Clarke (2013) monitored the performance of DBs on three separate dairy farms in three sub catchments (Waiteti, Hauraki and Awahou) of Lake Rotorua in 2012. Clarke (2013) took water samples throughout ponding events and also deployed synthetic turf mats within the ponding areas to quantify sediment deposition during ponding events. He found significant reductions in total suspended sediment concentrations of outflow water throughout ponding events and also reductions in particulate nutrients, although dissolved nutrient concentrations in outflowing water typically did not decrease during the duration of ponding events. Sediment retained in the DBs during this study was enriched with P relative to the benthic sediments of Lake Rotorua and bed sediments of the Waiteti Stream. Correlation analysis also indicated that PP was closely associated with Mn and Fe. Phosphorus which forms associations with these cations is known to be redox–sensitive and therefore potentially bioavailable if exposed to anoxic conditions such as those that prevail in the bottom waters of Lake Rotorua during extended calm periods (Reynolds and Davies, 2001). Furthermore, Peryer-Fursdon (2013) showed that sediment retained in the DB in the Waiteti Stream catchment is likely to be a source of P to the downstream Waiteti Stream as the equilibrium phosphorus concentration (EPC) of the sampled sediment was much higher than the average filterable reactive P concentration of the Waiteti Stream. These results indicate that the sediments retained by DBs in the Lake Rotorua catchment pose a potential risk to downstream water quality and should therefore be the focus of control efforts.

The quantity of sediment and P which is retained by DBs during any event depends on the influent load in the ephemeral stream. Although Clarke (2013) did not quantify the efficiency of DBs (i.e. the quantity of P retained as a proportion of influent load) he did quantify the total sediment and P deposited per storm event. The largest retention observed across all sampled events was 2.7 t of sediment and 6.08 kg of P retained in just one ponding event (Figure 3). This was an extreme example, where a large rainfall event occurred immediately after the complete removal of a winter forage crop upstream by in-situ grazing with dairy cows. The average P retention of a DB in the Hauraki Stream catchment (sited in a more typical dairy farm setting) was 0.2 kg P per ponding event. At this rate, Clarke (2013) calculated that this DB could save $28,000 in lake restoration costs over a 20-year period. Although this value is very specific to the hydrological and catchment characteristics of this specific site, it can be concluded that DBs will have benefits for downstream water quality.

DBs in the P mitigation tool box

A range tools from the 'mitigation toolbox' can be integrated and used collectively, each with their specific function and place in the landscape (McKergow et al. 2007). Strategic placement of mitigation tools in a catchment will increase their cost effectiveness and attenuation performance (McDowell & Nash 2012). Clarke (2013) found that DBs attenuated PP, but were not effective at attenuating dissolved nutrients. Wetlands can be effective at attenuating dissolved P and nitrogen (Tanner et al. 2005; Tanner & Sukias 2011) but are less effective at treating large volumes of water following intense rainfall events (Tanner 2003). Implementing the two mitigation strategies in a catchment together could improve overall attenuation synergistically. Sub-catchment scale models could be a useful tool to examine multiple effects from DBs and constructed wetlands when used together. Flow regulation provided by DBs could also improve the effectiveness of riparian buffer strips and grass filter strips as described in the context section above.

Prioritised implementation of DBs in headwater catchments could retain water on the landscape for longer periods of time and reduce peak flows of floods downstream. There has already been funding for the construction of DBs for flood control to reduce risks to a local State Highway (SH 36). Two sub-catchments of Lake Rotorua have now been completely GIS-scoped by BoPRC in collaboration with NZ Transport Agency to prioritise sites for DBs for nutrient and sediment mitigation as well as providing a co-benefit of flood water control. These sub-catchments are: the Hauraki Stream catchment (three DBs installed) and the Waimihia Stream catchment (39 DBs proposed).

Conclusion

Detainment bunds are a new mitigation tool. They have been trialled in the Lake Rotorua catchment as part of the collaborative Rotorua P-Project to specifically examine their potential to treat P in surface runoff during rainfall events. This paper has introduced DBs with reference to MSc research conducted in 2012–2013 which assessed the performance of 3 DBs in the Lake Rotorua catchment. Detainment bunds can be effective at attenuating sediment and PP from overland flow by temporarily ponding ephemeral storm water. They have been specifically designed to fit into farm systems, with the aim of maintaining pastoral production in the DB ponding areas. In the future, DBs will be an integral part of the wider mitigation tool box for minimising sediment and nutrient loss from pastoral farmland.

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