Risk-Managed Design and Construction of Flood Exclusion Embankments for the Kogan Creek Mine in the Condamine River Floodplain

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ABSTRACT

Kogan Creek Mine supplies thermal coal to an adjacent power station. The pit footprint lies within the Condamine River floodplain and required flood exclusion embankments founded on cracking self-mulching clays. Design and technical specification were based on utilisation of available construction plant. Strength was almost irrelevant compared with permeability and erosion resistance for a successful design life. Laboratory tests were used to identify compaction conditions that could be achieved with minimal supervision but adequate field testing. The design was adapted to cope with water shortages during a severe drought. This case history demonstrates a cost effective outcome achieved by attention to basic geotechnical principles and careful management of testing.

Keywords: embankments, compaction, density, permeability, specification,

1 INTRODUCTION

The Kogan Creek power station near Chinchilla in South East Queensland commenced operation in 2007. It comprises a single 750 MW generating unit fuelled by bituminous coal from the adjacent Kogan Creek Mine which is located adjacent to the power station but within the floodplain of the Condamine River. To provide the mining operations with an appropriate level of immunity from flooding, a system of flood exclusion embankments were required to link the out-of-pit waste dump and ROM pad with high natural ground to the south.

Hydrological design for the initial flood exclusion system was based on securing the perimeter of the initial mining pit, with a projected operating life of at least 15 years (MWH 2006a,b,c). Design flood levels were calculated for a major flood event involving the Condamine River, a major upper tributary of the Murray-Darling basin, but included the effects of localised storm events in Kogan Creek, a tributary stream at the immediate west of the mining area, and Eastern Branch Creek, an ephemeral tributary of Kogan Creek which required diversion out of the pit area. The elements comprising the flood exclusion system design are outlined in Figure 1.

Required embankment heights were typically in the range of 3 m to 4 m above natural ground level and locally as much as 8m above the Eastern Branch Creek channel floor. The subsurface profile consisted of alluvial floodplain sediments and thin residual soil developed on weathered Jurassic coal measures rocks. The soil and rock materials are typically dispersive and the alluvial floodplain surface comprises cracking self-mulching clays of high plasticity (Golder Associates, 2005).

Regulatory authorities accepted the hydraulic design including two licensed elements corresponding to the closure and diversion of Eastern Branch Creek, and subject to provision of a certified design and construction report for all elements of the flood exclusion system. At the time of approval, pre-stripping of weathered overburden had commenced. The out-of-pit dump (OOPD) was formed by uncontrolled placement of overburden waste while the ROM/MIA earthworks pads were compacted to an engineered specification with testing coordinated to Level 2 of AS3798-1996, Appendix B.

This paper describes the design and construction of the flood exclusion embankments that linked the other system elements to higher ground. Embankment design was deliberately simplified for construction expediency. The compaction testing methodology was deliberately specified to provide practical reliability of permeability control of the embankment profiles.

The flood exclusion system performance in response to the severe flooding events of early 2011 was outstanding, with minimal surface damage apart from superficial and localised surface piping erosion.

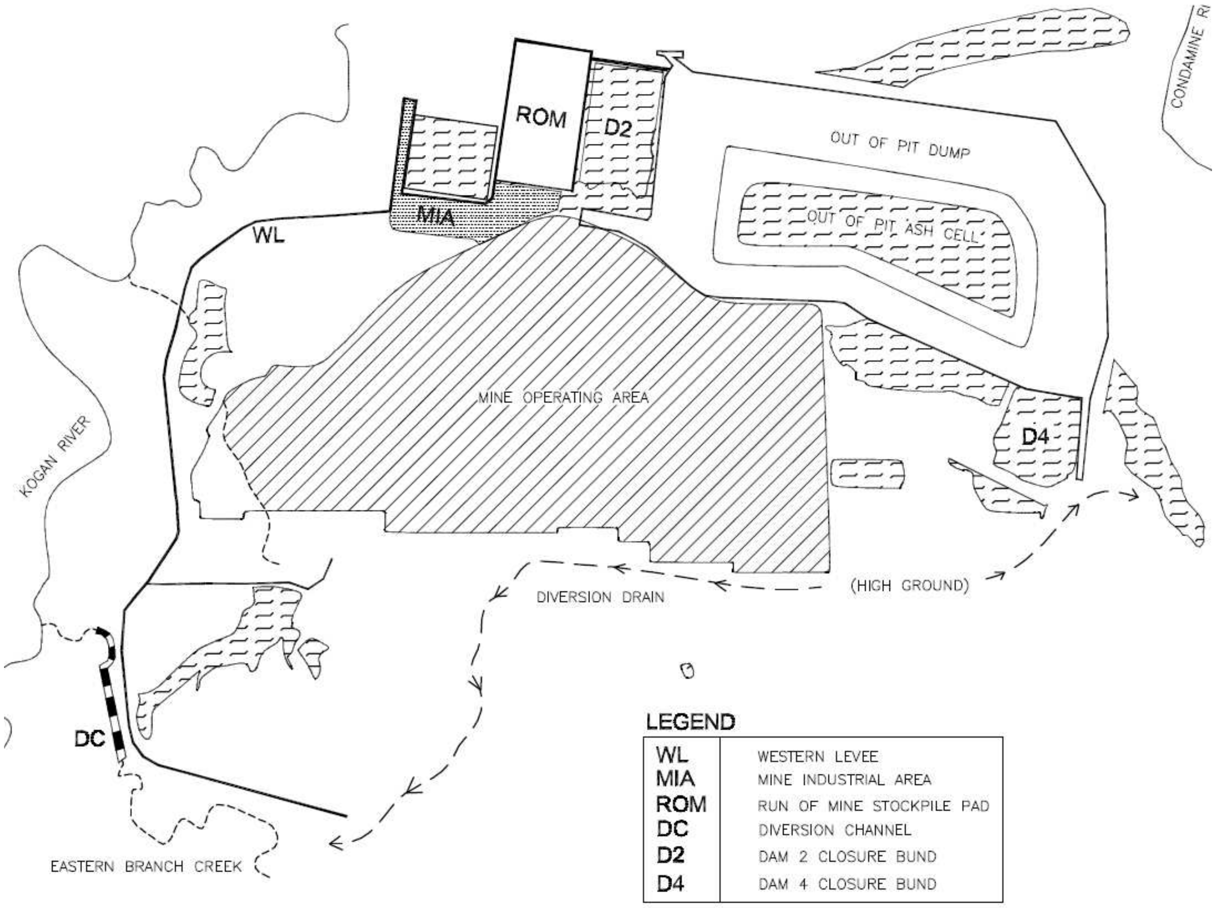

Figure 1. Schematic plan showing elements of Kogan Creek Mine flood exclusion system

2 EMBANKMENT DESIGN

2.1 Construction Resources and Context

The mining contractor planned to construct embankments using the site's available plant and equipment, consisting of a pad-foot compactor, scrapers, mine trucks, dozers, excavators, and water trucks. All embankment fill was to be sourced from the immediate mining path. The region had been in the grip of a severe drought for several years and construction started in late spring with the intention of providing as much flood immunity as possible for the upcoming summer wet season.

Initially all mine overburden waste had to be directed to the out-of-pit dump. Because of the large dimensions of the dump, the relatively flat outer surface slopes, and the moisture condition of the residual soil and extremely weathered rock, compaction trials were undertaken using tracking of large dozers alone. Flood exclusion capability of the out-of-pit dump system component was therefore based on a specified dozer tracking method which was referenced to laboratory permeability tests.

The remaining embankments had to be constructed as rapidly as possible and for this reason were designed as simple sections with minimal details

2.2 Material Sampling and Testing

At the time of construction the floodplain borrow materials were so dry that addition of water for effective compaction was difficult. Visual-tactile assessment and laboratory tests on bulk samples from test pits in potential borrow areas were used to select materials that were considered to be potentially workable. Virtually all near-surface material particle sizes were less than 0.075 mm and all Emerson Class Numbers were 2. Table 1 lists the index properties for the bulk samples.

Laboratory compaction tests were carried out at Standard effort to identify the ranges of density and saturated permeability that were likely to be achieved by the nominated construction techniques. Based on these test outcomes, all borrow areas except for G01 were considered acceptable.

Table 1: Index properties of bulk samples for potential embankment construction

Ref.	Location[a]	w_n[b]	G_s[b]	LL[b]	PL[b]	PI[b]	LS[b]
G01	mine	33.8	2.68	109	40	69	24
G02	mine	17.5	2.70	62	21	41	17
G03	Ch 2360	16.2	2.67	58	19	39	17
G04	Ch 2140	21.8	2.76	81	26	55	22.5
G05	Ch 1550	15.3	2.59	53	19	34	15
G06	Ch 1290	14.1	2.60	52	18	34	16.5
G07	Ch 1130	17.7	2.56	40	20	20	11
G08	Ch 810	11.6	2.62	36	15	21	12
G09	Ch 560	11.0	2.67	29	12	17	10.5
G10	Ch 375	9.2	2.62	29	14	15	8.5
G11	Ch 260	13.9	2.62	49	18	31	14.5

[a] Location: two sources of mine overburden and Western Levee Chainages starting at south end

[b] w_n = natural water content %, Gs = average particle specific density, LL = Liquid Limit %, PL = Plastic Limit %
PI = Plasticity Index, LS = Linear Shrinkage %

2.3 Stability and Seepage Control

The range of embankment heights was so modest that no formal stability analyses were considered to be warranted. From the initial tracking compaction trials it was judged that most material would be placed dry of Standard Optimum Moisture Content (SOMC) and at dry densities less than or equal to Standard Maximum Dry Density (SMDD). Experience from local farm dams in the region was that adequate long-term stability and seepage control could be achieved under these conditions provided that a core zone was adequately compacted to at least 95% of SMDD.

The relatively high dispersivity of the embankment materials was of concern. Local experience indicated that materials compacted to SMDD levels of at least 1.5 t/m^3 were likely to undergo some external rill erosion but develop a self-armoured surface after exposure to rainfall. Similarly, local experience was that internal piping erosion was extremely likely to develop in adequately compacted fill despite external rill erosion and localised shrinkage cracking.

Flooding regimes varied from durations of several hours for rapid local rises of local creeks in response to storm events, to several weeks in the event of a major regional flood event in the Condamine River catchment. Based on consideration of the potential advance rate of a wetting front, a characteristic saturated permeability of at least 10^{-8} m/s was considered adequate to prevent full development of steady-state seepage and thereby limit inflows to negligible levels.

Laboratory saturated permeability testing was carried out on specimens prepared over the range of moisture and dry density ratios that were considered to be adequate, with the emphasis on conditions dry of SOMC. Figure 2 shows the outcomes in terms of moisture ratio, with data points annotated to show dry density ratios.

2.4 Design Profiles

For the Western Levee (Figure 1) the outer or wet-side embankment batter was designed at angle-of-repose which was taken to be 37° or 3v : 4h, except for the licensed sections where a profile of 1v : 2h had previously been approved. The inner or dry-side batter was set to 1v : 3h to enable scrapers to run without impediment and thus minimise temporary ramp construction. The embankment crest width was initially set to 6 m as this corresponded to the blade width of a Cat D11 dozer and also provided adequate running width for inspection and maintenance purposes. A minimum layer thickness of 0.3 m of topsoil was provided to the batters and the crest was sheeted with 0.3 m of compacted mine pavement sub-base material to provide an acceptable running surface.

All material was placed in maximum 0.3 m loose layers to achieve nominal compacted thicknesses of 0.25 m. It was considered unnecessary to compact the full width of the Western Levee embankment profile to achieve the design intent. A fully compacted zone of minimum 6 m was provided to the wet-side of the embankment. Nominal tracking by dozers and/or scrapers or the compactor was specified for the remaining bulk fill.

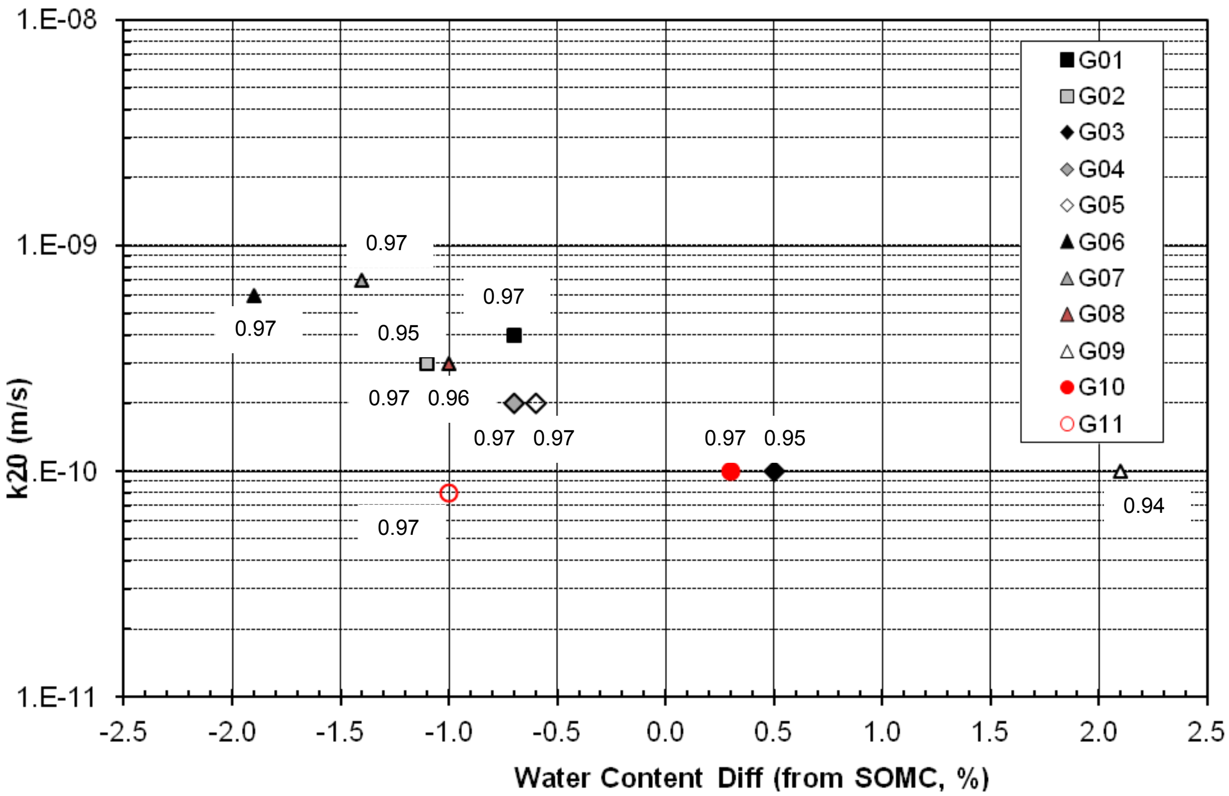

Figure 2. Laboratory saturated permeability results as functions of moisture and dry density condition

The final batter OOPD was 1v : 6h and the wet-side zone was designed as a single method-compacted layer. The two closure bunds D2 and D4 were designed with outer and inner batters at angle-of-repose, crest widths of 6 m, and match lines at the wet-side crest level. Suitable transitions were also detailed from the OOPD batters to the bund sections.

2.5 Technical Specification

The embankment design intent was to place material rapidly, achieve a suitable moisture condition in a reliable and verifiable manner, and compact an adequate width to an acceptable density level. This required full-time earthworks supervision and regular field testing with rapid confirmation of acceptability. Construction in panels was required so that test lots could be identified and compaction works could continue in other lots while waiting for acceptance advice.

From the saturated permeability tests it was judged that acceptable compaction would correspond to dry density ratios of 0.97 of SMDD or greater with moisture ratios within the range of -5.0% to +0.5% of SOMC. All field testing was to be undertaken with a nuclear moisture-density meter and the position and level of every field test location was to be recorded by survey. Based on expected daily production rates, which in practice can be closely related to material source selection, a minimum frequency of two field tests per 0.5m height per 100m of embankment was initially specified. After experiences gained when about 40% of the fill had been placed, the test frequency was reduced to a maximum of six tests per day with no lot exceeding one day of production.

Particle specific density results were more variable than expected and this required careful consideration of reference sampling for compaction acceptance testing in order to make the reporting of compaction outcomes both reliable and meaningful. Based on the known operating characteristics of nuclear moisture-density meters, the specification accepted field bulk density measurements but required moisture contents to be confirmed by laboratory measurement, and also required a laboratory compaction reference test for not greater than every five field moisture-density measurements.

2.6 Treatment of Out-of-Pit Dump and ROM/MIA Pads

The outer surface of the OOPD was dozer-tracked and then trimmed to final line and level before being subjected to a minimum number of passes of the compactor at an acceptable moisture condition and final trimming. Full-time supervision was used to achieve method compliance. The outer surfaces of the ROM/MIA Pads were compacted and trimmed and approved under separate construction supervision. The contact zones for the D2 and D4 Bunds were recessed to provide a key of compacted embankment material and avoid any likelihood of lateral leakage paths.

3 EMBANKMENT CONSTRUCTION

Construction commenced in October 2006 and was completed in April 2007. The construction period was exceptionally dry and difficulties in achieving adequate moisture conditioning of alluvium materials from adjacent borrow pits caused significant delays early in the program when scrapers were used exclusively. Delivery of mining trucks to the site allowed the earthworks schedule to be accelerated by rapid delivery of mine overburden waste which was moister than the shallow alluvium. This required widening of the embankment crest to 7 m and reduction of the outer batter to 1v : 2h to comply with safe operating criteria.

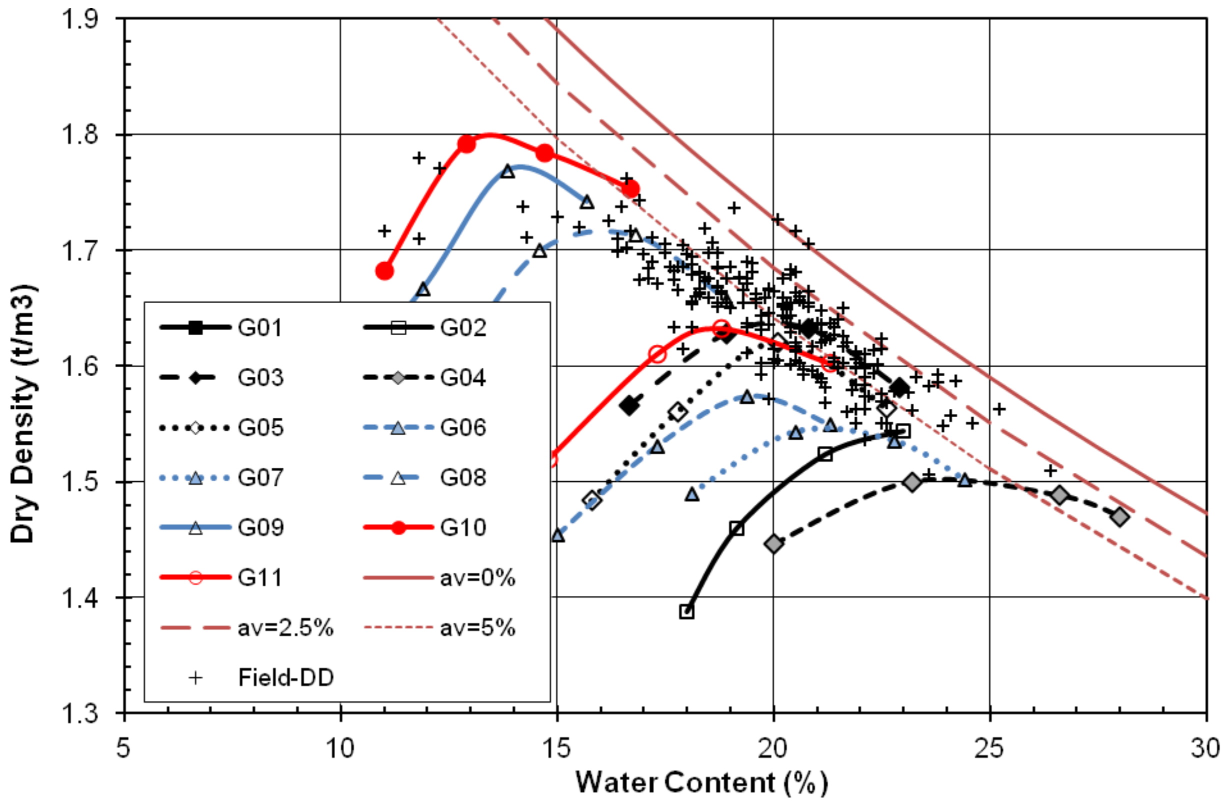

Figure 3. Comparison of field compaction with initial laboratory testing, air voids lines for G_s=2.64

Field compaction results are compared in Figure 3 with the laboratory compaction characteristics for all of the samples listed in Table 1 except for G01. Also shown are the air voids characteristics lines for the site average G_s value of 2.64. From these results it can be seen that the vast majority of the test outcomes had relatively low air voids. Further details are described in Sherwood Geotechnical and Research Services (2007).

Using the embankment centreline for cross-sectional reference, plots were prepared showing the compaction outcomes in terms of dry density ratio and moisture variation as functions of plan position (chainage and offset) and vertical position with respect to crest and foundation levels. By this means it was possible to rapidly assess whether the spatial distribution of testing conformed to the specification requirements. There were only 5 non-conformances out of a total of 224 field density tests that were carried out. All of the initially non-conforming lots were reworked and retested.

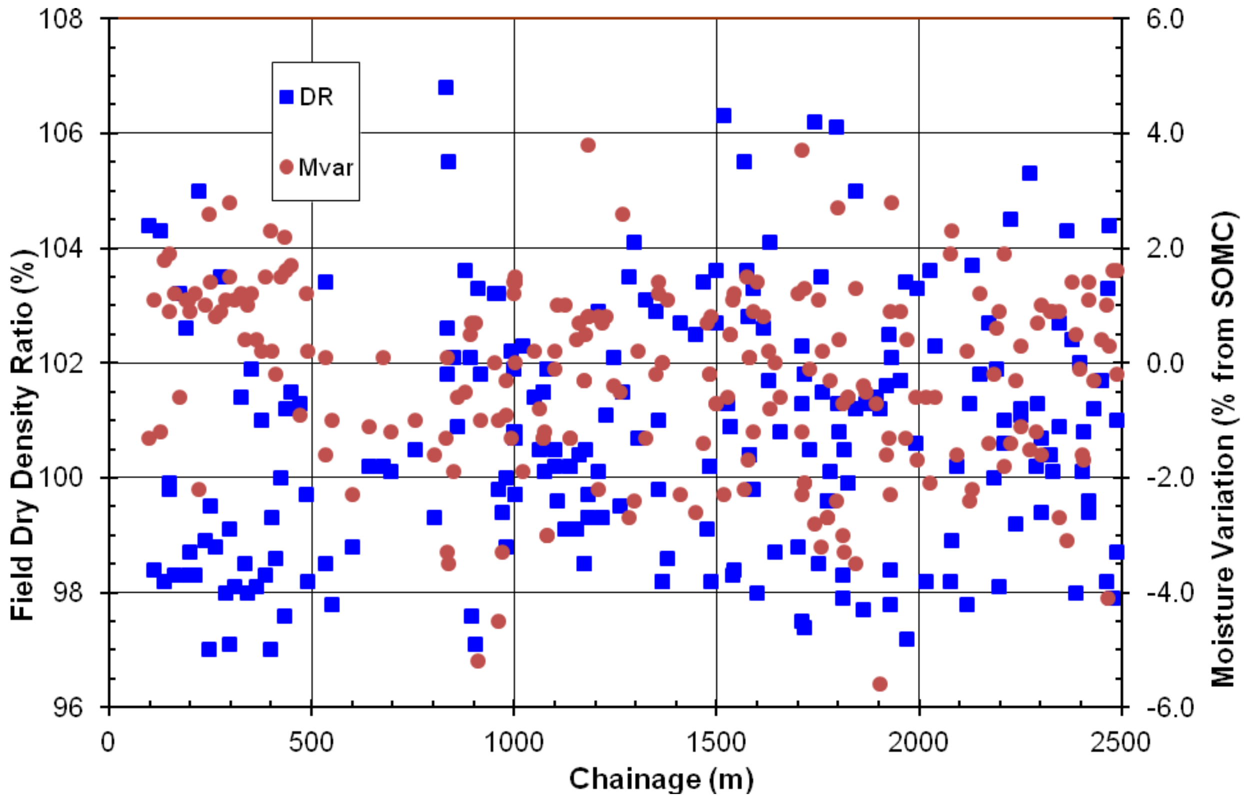

Figure 4. Spatial distribution of density-moisture test results for Western Levee

4 FLOOD EXCLUSION SYSTEM PERFORMANCE

Since construction the system has experienced extremes of drought and flood with only very minor and superficial gully erosion. Despite very poor initial vegetative cover, gully depths were confined to the 0.3 m topsoil layer.

Severe flooding events were experienced over the period from November 2010 to February 2011. The site was isolated by flooding of the Condamine River for a total of about 6 weeks during which the only access was by helicopter or boat. The freeboard for most of the embankment crests was about 1.5 m except for the D2 bund which was raised because of an adjustment to the design flood level. Virtually no erosion of the wet-side was experienced and there were no indications of seepage inflows.

5 ACKNOWLEDGEMENTS

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