PLANNING BALLAST CLEANING USING BALLAST FOULING LEVELS DETERMINED WITH GROUND-PENETRATING RADAR

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SUMMARY

To maintain adequate track top and line, ballast needs to perform all required functions, including spreading loads from rail traffic to the formation and providing drainage. If ballast voids become contaminated (fouled), the performance of these functions can be reduced.

An effective method of removing fouling material is ballast cleaning, however the cost to purchase and operate ballast cleaning machines is high, and they require track possessions that occupy train paths. Optimising ballast cleaning locations and timing is critical for maximising long term performance and availability of rail networks.

QR National has used Percentage Voids Contamination (PVC) values from laboratory testing for several years. However, PVC sampling and testing is time consuming and also requires train possessions, and QR National have recently developed a new method of developing detailed ballast cleaning plans for rail systems, using ballast fouling levels determined from ground-penetrating radar (GPR) testing. This paper describes this new method, including calibration of laboratory PVC values to GPR ballast fouling levels.

INTRODUCTION

QR National owns and operates a heavy haul rail network in Central Queensland for transport of coal, consisting of four systems as follows:

- Moura System: ports at Gladstone
- Blackwater System: ports at Gladstone,
- Goonyella System: ports: Hay Point and Dalrymple Bay,
- Newlands System (including GAP project): port: Abbot Point.

The total track length of this network is approximately 2500km, and the total net tonnage of coal transported on these four systems is currently approximately 150Mnt/a.

In order to maximise availability of this rail network, the performance of all track components needs to be optimised. Along with rail and sleepers, ballast is an integral track component, and poor ballast performance can reduce network availability.

BALLAST FOULING

Ballast performs several functions, including adequately distributing rail traffic loads from the base of sleepers to the formation, and providing drainage from the track structure. New ballast includes approximately 40% voids, however if these voids become filled (or fouled), ballast performance can be reduced, resulting in reduction in load-spreading capability and reduction in drainage. Ballast fouling materials on the QR National network include:

- coal fines (predominant type),
- degraded ballast particles,
- formation material pumped into ballast layer by rail traffic.

Some examples of track cross sections at inspection trenches are shown in Figures 1 and 2.

Impacts from ballast fouling can include track top and line irregularities and creation of mudholes. Mudholes are concentrations of fine material from within the ballast layer, with the source of this fine material on the QR National network generally being either (or a mixture of both):

- degraded ballast due to high rail traffic levels and high axle loads,
- coal fines.

An example of a mud-hole is shown in Figure 3.

Figure 1: Ballast highly fouled with coal

Figure 2: Ballast highly fouled mixture of degraded ballast and some coal fines (formation intact)

Figure 3: Mud-hole, with fine material at end of sleeper adjacent to excavator bucket

Speed restrictions may be required to allow for continued operation of rail traffic across track sections with poor top and line or mudholes, until repair works can be performed however speed restrictions result in increased train running times across the network.

BALLAST CLEANING

The most effective method for removing mudholes, and top and line irregularities due to fouled ballast, is with a ballast cleaning machine. A QR National ballast cleaning machine is shown in Figure 4.

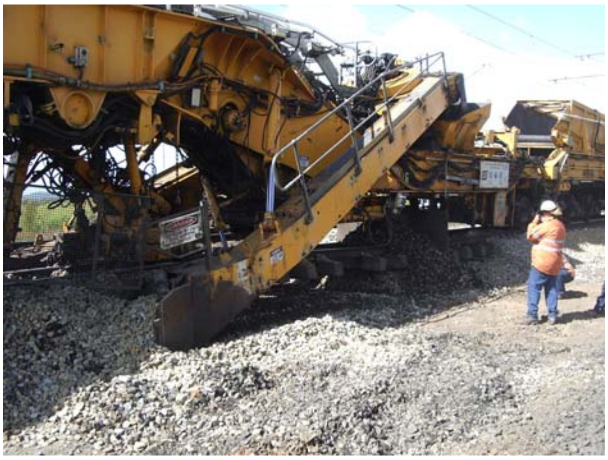


Figure 4: Ballast cleaning machine

Ballast cleaning machines operate by removing fouled ballast from track, screening fouling material from ballast particles, recycling screened ballast back into track and dumping fouling material. If fouled ballast includes wet clay, this ballast is unscreenable and needs to be dumped. New ballast may also be required to supplement screened ballast (or to fully replace unscreenable fouled ballast). Ballast cleaning machines are expensive to purchase and operate, and require full track possessions for operations which reduce network availability, therefore accurate planning of ballast cleaning works is essential.

Planning ballast cleaning includes the following two aspects:

- high level: selection of ballast cleaning locations,
- detailed level: assessment of ballast screenability.

MEASUREMENT OF BALLAST FOULING LEVELS

Ballast fouling levels have generally been measured using the mass-based Fouling Index throughout the world:

FI = % passing 4.75mm sieve +
% passing the 0.075mm sieve) [1]

Fouling Index is suitable for measuring ballast fouling levels if fouling materials, such as degraded ballast particles or formation material, have similar densities to ballast particles. However, this method is inaccurate if fouling materials have different densities to ballast particles. The density of coal fines, the predominant QR National fouling material, is ~0.9t/m^3. This is significantly different to the density of ballast particles of ~2.7t/m^3. Based on this density variation, QRN developed the volume-based Percentage Voids Contamination (PVC) method approximately 10 years ago.

Coal fines generally migrate to the base of the ballast layer from washing by rain or vibration from rail traffic. Once the depth of clean ballast is reduced to less than approximately 100mm, track top and line deterioration can occur more rapidly. Based on the voids content of clean ballast of approximately 40%, this clean ballast depth of 100mm below the base of sleepers is equivalent to a PVC value of approximately 30% (ballast cleaning intervention level), based on a total ballast depth of 250mm below the base of sleepers.

An advantage of the PVC method is that ballast fouling rates can be easily determined. For the QR National network, coal fines from rail traffic can be correlated to changes in PVC values, from multiple PVC samples obtained at different times from the same sample locations. For fouling caused only by ballast degradation from rail traffic, the same method can be applied.

QR National have been performing PVC tests on ballast samples obtained from test pits from the track centreline typically at 500m or 1km intervals. An assessment of ballast screenability has also been obtained from a visual assessment of these PVC ballast samples. PVC test results are accurate for ballast samples, however PVC values could vary considerably between PVC sample locations. Also, only approximately 8 PVC samples can be obtained and tested per closure day (closure days only approximately once per month per coal system) with approximately 200 PVC samples tested per annum.

Due to the small number of PVC samples obtained, these PVC results have primarily been used to confirm locations already selected by track maintenance personnel from track inspections.

MEASURING BALLAST FOULING LEVELS WITH GPR

QR National has been measuring ballast fouling levels with GPR on a small scale since approximately 2007. However, these ballast fouling levels have been based on a visual classification system. In 2010, QR National commenced a major GPR testing program over ~700km with ZeticaRail, including measurement of ballast fouling levels. ZeticaRail had previously measured ballast fouling levels from GPR data in terms of Fouling Index, however had not reported this in terms of PVC values. Based on the extensive historical PVC data that QR National had developed, familiarity of the PVC method within QR National and a desire to continue measuring ballast fouling levels in terms of PVC values, a calibration between GPR signals and PVC values was performed.

Initially this calibration involved identifying locations with a range of fouling levels in GPR data from track sections, then performing additional targeted GPR testing followed immediately by PVC sampling. However, after obtaining approximately 30 PVC samples, an adequate distribution of PVC values had not been achieved. In order to achieve this distribution, a track panel incorporating the required distribution of PVC values was constructed. This track panel included 14 x 2m long track sub-sections separated by 0.5m buffer zones of clean ballast (Geotextile was used to on each side of these buffer zones). Details of these sub-sections are as follows:

- 11 sub-sections with mixtures of clean ballast and coal fines, with PVC values of 0% to 100%, increasing in 10% increments, representing typical coal fouling,
- 3 sub-sections with mixtures of unscreenable and clean ballast (25%, 50% and 75% of unscreenable ballast), representing degraded ballast.

A photo of this calibration track panel is shown in Figure 5, with clean sub-sections and the GPR equipment at the far end of the track panel, and sub-sections with higher PVC values closer to the photographer.

Figure 5 : GPR PVC calibration track panel

This track panel was tested with GPR equipment before and after being flooded with water (water was used to wash fines to the base of the ballast layer, to represent typical accumulation of fines at the base of the ballast layer in the field. GPR captured data was compared with results of PVC tests from PVC samples obtained from each sub-section, to develop a GPR-PVC calibration curve.

Following these calibration works, GPR PVC values were available at the three GPR testing offsets (track centre, and near both ends of sleepers), at 5m intervals.

GPR data has been captured at speeds of up to 80km/h, with GPR equipment fitted to rail vehicles. At this data capture speed, these rail vehicles can travel at similar speeds to rail traffic, resulting in minimal disruption to rail traffic and no track closures required.

By the end of 2011, QR National had performed GPR testing on all four coal systems (track length of approximately 2000km) resulting in processing of approximately 1.1 million PVC values.

An example of a GPR chart with GPR PVC values in shown in Appendix A. PVC categories on the “1D-BFI” plot on this chart are as follows:

- clean (green): PVC: 0 to <10%,
- moderately clean (yellow): PVC: 10 to <20%,
- moderately fouled (orange): PVC: 20 to <30%,
- fouled (red): PVC: 30 to <50%,
- severely fouled (purple): PVC ≥ 50%.

Note on this GPR chart the distinct change in ballast fouling levels at 45.700km, with generally highly fouled ballast from 45.000km to 45.700km, and generally clean ballast from 45.700km to 46.000km. The information on this chart coincides with recent ballast cleaning on this track section, between 45.700km and 46.000km in July 2010.

BALLAST CLEANING PLANS

The method for developing the ballast plan is as follows:

1. divide each track section in sub-sections with generally similar average PVC values (including individual sections for each track on duplicated track sections. The minimum length of these sub-sections is 1km, which represents generally the minimum desirable length of ballast cleaning works at a particular location from a logistics viewpoint.
2. obtain the most recent ballast cleaning,
3. determine the duration and rail traffic level between the most recent ballast cleaning works and the GPR data capture date,
4. determine the ballast fouling rate per year and per Mnt of rail traffic,
5. determine theoretical rail traffic level (Mnt) until 30% PVC ballast cleaning intervention will be (or was) reached, and corresponding theoretical date,
6. rank sub-sections in order of proposed rail traffic levels until intervention level reached.

Note that:

- average PVC values are assumed to be 5% after ballast cleaning, based on GPR data captured just after ballast cleaning works (or 0% if average PVC value for a sub-section is less than 5%).
- on duplicated track sections, the total rail traffic level for the corridor is considered for calculation of ballast fouling rates for both tracks, as coal fines can settle on either track on duplicated track sections, not just the track carrying loaded trains.

Ballast cleaning plans consist of tables of sub-sections for particular track sections. Information extracted from one of these tables is shown in Appendix B.

As this method is based on rail traffic levels, dates can be easily adjusted if proposed rail traffic levels were to change.

SCHEMATIC PLAN

Though not showing specific ranking of sub-sections, schematic charts with average PVC values within specific ranges have been developed, and an example is included in Appendix B. This type of chart can be used to identify where high fouling levels are located with parts of the rail network.

FURTHER DEVELOPMENTS

Developments planned to be investigated to further improve planning ballast cleaning are as follows:

- calculating ballast volumes, from ballast surface profiles measured with laser equipment and ballast depths measured with GPR,

- considering other track information track geometry data with PVC values,
- using GPR to locate buried objects in ballast that can interrupt ballast cleaning operations, such as rail offcuts,
- assessing ballast screenability with GPR.

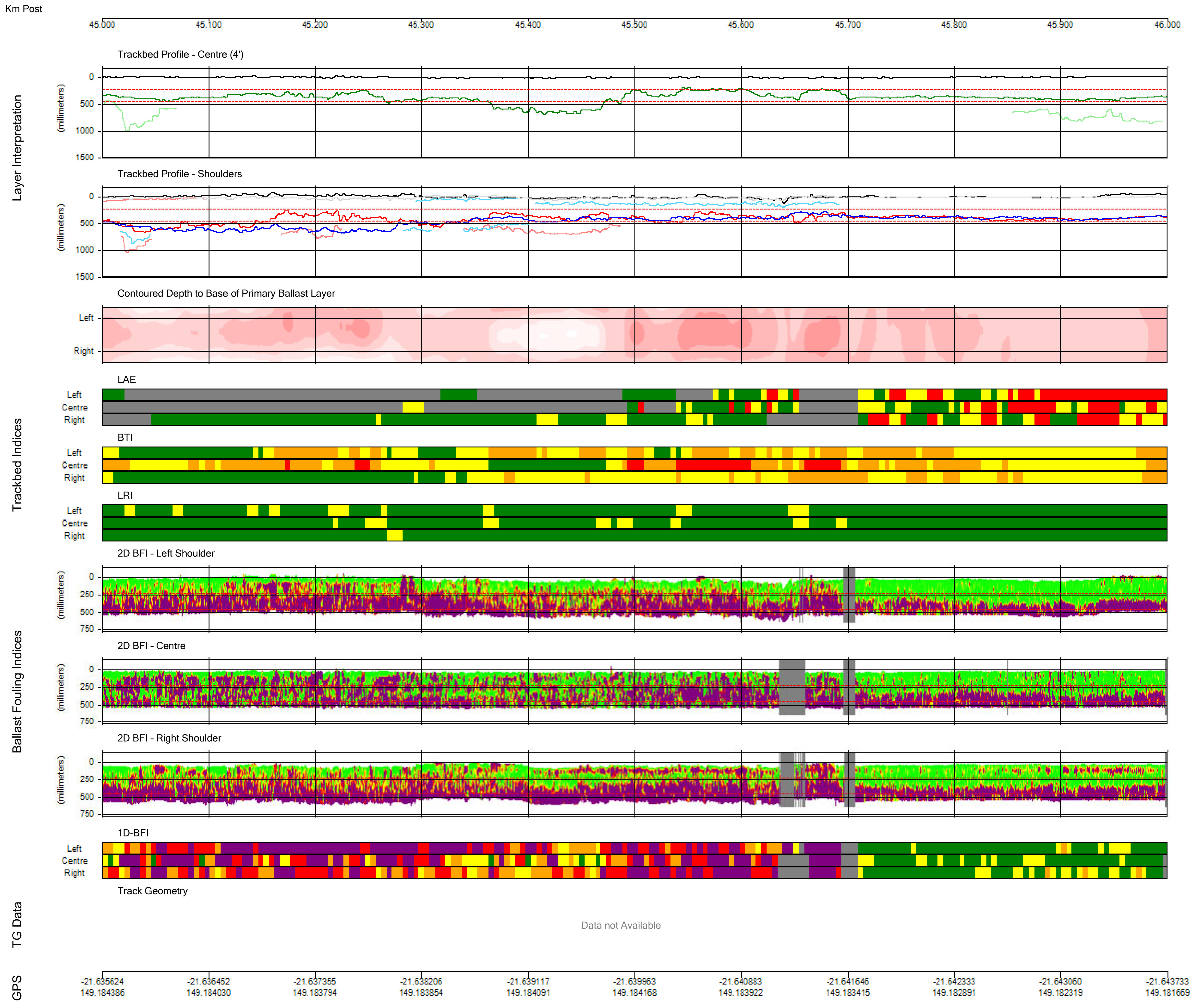
CONCLUSION

Maximising the availability of the rail network by optimising track maintenance activities is a key priority for QR National. One of the most capital intensive and intrusive maintenance activities is cleaning fouled ballast.

This new ballast cleaning planning method can be used to more accurately determine locations and programs for ballast cleaning along the QR National rail corridor, resulting in improved utilisation of ballast cleaning resources, reductions in maintenance costs, and improved network availability for operation of rail traffic.

This method was developed on a railway system with predominantly coal fouling of ballast, however could also be used on railways with other types of ballast fouling material.

Appendix A – Example of a GPR chart with PVC values



Explanation of Data Labels

NVL — No visible layer interface
MDL — Data masked by Rail(s) in Centre

Trackbed Layer Interpretation

- Surface Profile - Centre / Left Shoulder
- Surface Profile - Right Shoulder
- Base of Dominant Trackbed Layer - Left Shoulder
- Base of Dominant Trackbed Layer - Centre
- Base of Dominant Trackbed Layer - Right Shoulder
- Base of Secondary Trackbed Layer - Left Shoulder
- Base of Secondary Trackbed Layer - Centre
- Base of Secondary Trackbed Layer - Right Shoulder
- Nominal Ballast Depth Design

Ballast Thickness Index (Dominant Layer) (below base of sleeper)

🟦 > 600mm	🟧 50mm - 150mm
🟩 250mm - 600mm	🟥 < 50mm
🟨 150mm - 250mm	⬜ Unavailable

1D Ballast Fouling Index (calibrated against PVC) (5m average)

🟩 Clean (PVC: 0 to <10%)	⬜ Unavailable
🟨 Moderately Clean (PVC: 10 to <20%)	
🟧 Moderately Fouled (PVC: 20 to <30%)	
🟥 Fouled (PVC: 30 to <50%)	
🟪 Severely Fouled (PVC: >=50%)	

Layer Roughness Index (LRI) - 20m wavelength

🟩 Good	⬜ Unavailable
🟨 Poor	
🟥 Very Poor	

Layer Amplitude Exceedence (LAE) - Averaged over 5m

🟩 Low	⬜ Unavailable
🟨 Intermediate	
🟥 High	

Track Geometry

- Top_Up
- Twist_2m
- Top_Down

FINAL

Client
QR National

Route Reference
Hay Point to North Goonyella Line

Site Chainage (km)	Track ID
45.000 - 46.000	Down

Project:
GPR Trackbed Survey

Measurement Vehicle:	Recording Date:
MMC10	29/06/2011

Notes

A Indicated depths are based on an estimated average velocity of 141mm/ns. Actual depth may vary depending on ballast quality and moisture content.

B Depths are relative to top of tie.

C Data location based on dGPS and QR National Roadway Information System

D Verification of layer materials require ABS / Trial Pit Samples

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APPENDIX B – Extract of a ballast cleaning plan, based on GPR information from July 2011

SUB-SECTION NUMBERS		**1**	**2**	**3**	**4**	**5**	**6**
START KILOMETRAGE (km)		8.43	12.97	14.68	16.05	17.42	19.37
END KILOMETRAGE (km)		12.97	14.27	16.05	17.42	18.73	21.68
LENGTH (km)		4.54	1.30	1.37	1.37	1.31	2.31
GENERAL FOULING LEVEL FROM VISUAL ASSESSMENT OF GPR PVC VALUES		Fouled	Moderately Fouled	Moderately clean	Fouled	Moderately clean	Clean
AVERAGE PVC VALUES		36.5	21.4	17.9	38.6	20.0	8.9
DATE OF MOST RECENT PREVIOUS BALLAST CLEANING		30/11/2008	8/01/2008	21/09/2007	19/08/2007	13/09/2007	NA
AVERAGE TONNAGE SINCE MOST RECENT BALLAST CLEANING (000nt)		406303	406303	548576	548576	548576	NA
AVERAGE PVC FOULING RATE	**(per year)**	11.55	11.55	5.12	5.12	5.12	4.80
	(per 100Mnt)	8.72	8.72	4.01	4.01	4.01	4.80
RAIL TRAFFIC REQUIRED TO ACHIEVE PVC VALUE OF 30% (Mnt)		-74.11	98.47	301.65	-213.35	249.14	439.03
AVERAGE ESTIMATED DATE OF NEXT BALLAST CLEANING		2/11/2010	3/11/2011	3/11/2013	2/11/2008	3/11/2012	3/11/2014
SUB-SECTION RANKING VALUE (EARLIEST DATE IS RANKING No.: 1)		15	47	97	5	85	108

Appendix C – Schematic of part of a coal system with different PVC value ranges for 2010/2011