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Midland Railway Workshops site, Helena East Precinct: Review of reports relating to hydrogeology of the site and potential impacts of groundwater contaminants on the Helena River.

Report to ATA Environmental for Midland Redevelopment Authority by Crisalis International Pty Ltd

June 2005

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1. Background.
ATA Environmental (ATA) requested Crisalis International Pty Ltd carry out a review of selected previous reports on the former Midland Railway Workshops site and assess the validity of conclusions on groundwater contamination and remediation in the reports. The work was also to address concerns of the Department of Environment identified in previous correspondence. The site is being redeveloped through the Midland Redevelopment Authority for heritage, residential and commercial uses. The following reports were provided and reviewed:

1. ENV Australia, October 2002. Detailed site investigations / Helena Precinct waste fill, Midland Railway Workshops. Report for Midland Redevelopment Authority.

2. ENV Australia, December 2002. Fate and Transport modeling.

3. ENV Australia, May 2003. Hydrogeological investigation, Helena West, Midland Railway Workshops. Report to Midland Redevelopment Authority.

4. ENV Australia, October 2004. Environmental Investigations in support of Referral: Helena East Midland Railway Workshops Site. Report to Midland Redevelopment Authority.

5. ENV Australia, March 2005. Midland Railway Workshops site, Helena East Precinct: Referral and Scoping Document. Report to Midland Redevelopment Authority.

Two additional reports were made available to address specific issues of hydrogeology around the Coal Dam. These were:

5. ENV Australia, August 2002. Coal Dam Hydrogeology and Remediation Options. Report for Midland Redevelopment Authority

7. Dames and Moore Pty Ltd, 1997. Midland Railway Workshops Environmental Consultancy, Midland, Western Australia. Report for the Department of Contract and Management Services.

The above reports are referred to in the text by the above reference numbers. Additional references are given under section 7 below.

2. Geology of the site
The redevelopment site and land between the site and Helena River is underlain by superficial deposits of the Guildford Formation, comprising alluvial clayey soils with some silt, sand and gravel, grading into sandy soils at depths of around 7-10m below surface at the site and lesser depths beneath the river floodplain. The superficial

Guildford Formation soils are underlain by Henley Sandstone (glauconitic sands), which in turn overly clays and shales of the Pinjar Member of the Leederville Formation [3, 5].

There are fill materials on the site, particularly along the escarpment between the site and the river floodplain, extending from the Coal Dam to the west of the main site in a southeast direction. The fill materials are up to 7-8m deep in places and consist of slags, foundry sands, metal rubble and other discarded materials.

3. Hydrogeology

There is a considerable diversity of views regarding groundwater conditions at and around the site, largely because of the complexity of the superficial soils and the hydrogeological characteristics of these.

Earlier reports by ENV Australia [1,2] indicate that shallow groundwater below the site in sand and silt lenses within clayey soil sequences, flows broadly towards the southwest and the Helena River (see Figure 3, ENV 2002[2,6], and Figure 1 here). The latter conclusions would seem to be based on groundwater level data in shallow superficial deposits, although the source and original data is not provided in the above reports.

Later reports, particularly ENV(2003) [3], summarise more detailed drilling, including that carried out to investigate groundwater in sandy soils that occur lower in the sequence of the Guildford Formation. This report provides a different interpretation of the local hydrogeology, with the superficial Guildford Formation being divided into two distinct sequences: namely

- Upper (Shallow) Superficial sediments (referred to hereafter as Shallow Superficials), comprising clay, silt, sand and gravel sediments, being generally of low hydraulic conductivity, and showing what is reported to be irregularly distributed groundwater levels;

- Lower (Deeper) Superficials, referred to here as Deep Superficials, which are sandy sediments with a higher hydraulic conductivity and showing a relatively uniform regional hydraulic gradient and flow direction to the west, not towards the Helena River.

ENV (2005) [5] regards these units as separate systems, and this does seem justified on available evidence. These units and interpretation of their hydraulic behaviour are considered separately below.

3.1 Shallow Superficials

Drilling logs provided in ENV(2003) [3] record quite complex profiles of clayey sand and silty/sandy clays within the Shallow Superficials below the site and the Helena River floodplain (bores B1-B3; HP8-11). Thick clay sequences were recorded in the eastern part of the area (bores HE6; HE9) and immediately to the west of the Coal Dam (HW3).

The geological cross sections shown in ENV(2003) [2] show complex, layered sediments beneath the river and immediate parts of the floodplain which seem consistent with the bore logs in ENV(2003) [3].

In addition, although groundwater levels across the site show considerable variation and no uniform hydraulic gradient[3-5], there is a broad order to the water level pattern when the distribution of the different soil types are taken into account. Thus higher water levels occur within the Coal Dam itself, and in those bores to the southeast of the dam which show the mixed clay, silt, sand and gravel sediments (bores HP1-4 and HW1). Bore HP2 and HW1 when tested showed higher hydraulic conductivities than other tested bores which are in more clay-rich areas [3], which suggests this shallow zone is more permeable than elsewhere in the shallow superficials.

Approximate contouring of groundwater levels from data shown in Figure 8 in ENV(2003) [3], shown in Figure 2 in this report, suggests there is a reasonably uniform flowfield which is dominated by what seems to be a non-symmetric recharge mound towards the southeast of the Coal dam. There is also a broad groundwater movement to the southwest towards the Helena River from the site. These approximate contours, shown here in Figure 2 in this report, are very similar to the interpreted flowfield shown in earlier ENV reports [1,2, 6] and shown here in Figure 1. In particular, these suggest that the Coal dam and groundwater within the more permeable sand/gravel horizon are in hydraulic continuity, and that the Shallow Superficials act as a single (but complex) aquifer system. These would indicate some potential for movement of groundwater within the Upper Superficials towards the Helena River.

Investigation of the hydrogeology of the Coal Dam[6] also concluded that this surface water body and the superficial sediments were hydraulically connected. However, it was suggested on the basis of a water balance for annual evaporation and precipitation, and more detailed consideration of a water balance for summer months that there was a net evaporation from the dam. As there was no external surface recharge of the dam, it was concluded that groundwater must be maintaining levels in the dam, recharging the surface water on the northeastern edge and discharging on the western and southern edges, although the very steep gradients suggested limited outflow.

Earlier detailed investigation of the hydrogeology of the dam by Dames and Moore (1997) [7], suggested groundwater mounding around the dam which indicates that the dam was recharging groundwater. The approximate contours shown in Figure 2 here suggest some mounding to the southeast.

Whatever the hydrogeological mechanisms and hydraulics of the Coal dam and local groundwater system, it is clear that the Shallow Superficials can be represented as a single (but complex) aquifer unit, rather than a series of irregular perched aquifer units, as suggested in later ENV reports [3-5].

Given this, there is a clear potential for migration of contaminants from the site towards the Helena River through the Shallow Superficials, although any localized flowfield maybe be complex given the soil heterogeneity. The presumed very high hydraulic gradients between the Coal Dam and the river indicate very low hydraulic conductivities (compared with those in the more conductive zones). Consequently, transport of contaminants in groundwater towards the river in the vicinity of the Coal Dam would be slow and travel times would be long. Hydraulic gradients to the east of the dam appear to be lower than those immediately to the west and south of the dam, which suggests higher conductivities of sediments in the eastern area. Slug (recovery) tests (3) indicate hydraulic conductivities of ~0.3m/d within the more permeable regions (bore HP2 and HW1), compared to those an order of magnitude lower outside of this zone. It is assumed that these values are reasonably representative of sediment conductivities and not impacted unduly by bore construction

Although the rate of groundwater flow would be more rapid within the more permeable sediments immediately to the east of the dam (in the region of bores HP1-4 and HW1), even here, on the basis of slug tests (3), transport of contaminants in the shallow superficial sediments is still likely to be slower than anticipated in the fate / transport modeling(2), where conductivities an order of magnitude higher than those found in the recovery tests were used. Consequently, travel times assessed from modeling will be even longer, assuming the estimated hydraulic conductivities are representative of actual values.

It is thus clear that there is potential for transport of contaminants within the Shallow Superficials towards the Helena River, from contaminated areas such as the electroplating dump in what is refered to as Area H5 (4) or the “industrial area” (5). Groundwater flow within the Shallow Superficials would be somewhat independent of that in the Deep Superficials, given the disparity in groundwater flow directions.

3.2 Deep Superficials

The more permeable sands in the deeper parts of the Superficial (Guildford) Formation do show a uniform hydraulic gradient and groundwater flow approximately west-north-west(3) and not towards the Helena River, as indicated in the ENV(2003) report (3). Hydraulic conductivities measured from the pumping test (3) showed a mean value of 7m/d , similar to the average for the Guildford Formation of 3m/d (Davidson, 1995). The determined storativity(3) was quite low which indicated confined, or more probably semi-confined groundwater conditions within this part of the aquifer. The lack of response of bore WP1 in the Shallow Superficials which was monitored during the pumping tests, provides additional evidence of a poor hydraulic connection between the Shallow and Deep Superficials, thus supporting the conclusion that these behave as separate aquifer systems, although there may be some vertical connectivity in places. Groundwater in the shallow sediments seems more likely to move and transmit contamination laterally under the imposed hydraulic gradient in the interpretated flow conditions implied in Figures 1 and 2 here.

Given the above, it seems unlikely that the Deep Superficials would be impacted significantly from contaminants from the site, given the semi-confined nature of the deeper sands, and contrasting hydraulic gradients. However, it is recommended below that a further round of monitoring is carried out to assess groundwater quality in both the shallow and deep superficial systems (see 5.3 and 5.4 below).

It is also recommended that a further pumping test is carried out and bores within the shallow superficials are monitored to assess more thoroughly the hydraulic connection between the two systems (see 5.1 below).

3.3 Henley Sandstone and Leederville Formation

The ENV(2003) report (3) states that it seems likely that groundwater in the Deeper Superficials are in hydraulic continuity with that in the Henley Sandstone. It is also stated that groundwater in the Henley Sandstone shows the same flow direction as the regional flow in the Leederville aquifer, although this is unexpected given that groundwater in the latter formation is likely confined by clays and shales of the Pinjar Member of the Leederville Formation and unconnected to the Henley Sandstone.

Dames and Moore (1997) (7) also report artesian conditions in a production bore located adjacent to the Coal Dam and screened within the Leederville Formation. This latter information does suggest little connection between the Leederville Formation and shallower aquifers.

It is recommended that standing water levels be determined in the pumping bore to the east of the site to compare with those in shallower systems (see under 5.2 below). The response of shallower bores to pumping could also be determined to assess any connection between these systems.

4. Contaminants and contaminant attenuation in groundwater

4.1 Distribution / occurrence of groundwater contamination

The ENV reports on investigations at the site indicate varied, multiple-source contamination by inorganics (eg heavy metals) and organic contaminants (BTEX, PAH, VOCs etc) across the site.

Thus in ENV 2002 (2) reference is made to a previous report where an area identified as a “hydrocarbon dump” located near bore MW16 showed groundwater containing benzene (540ug/L) chlorobenzene (1800ug/L), 1,2 dichlorobenzene (760 ug/L), 1,3 dichlorobenzene (54 ug/L) and 1,4 dichlorobenzene (49ug/L). Benzene and chlorobenzene were located in the upper, low permeability superficials, whilst the maximum impacts of dichlorobenzene was “in deeper sands”. The original data on these contaminants was not available for this review, but is assumed to be in ENV (2001). It is understood this site has now been remediated. There would seem to have been no follow-up, post remediation monitoring of groundwater in this area, and no reference has been made to this in subsequent reports.

The ENV(2002) report [1] identified increased concentrations of zinc in groundwater in the vicinity of an electroplating dump (bore HP13, 550ug/L) and in HP4 to the east of the Coal Dam (87ug/L). Free-phase hydrocarbons were noted in bore HP13, and concentrations of polyaromatic hydrocarbons (PAH, expressed as naphthalene at 250ug/L). Moderate concentrations of total petroleum hydrocarbons (TPH) were also understandably found in groundwater at this location., mostly in the heavier C_{14-25} range. Only zinc was found in groundwater downgradient of HP13 at bores HP11 (81ug/L) and B3 (220ug/L). No organic contamination was found downgradient of the contaminated area.

The ENV(2003) report[3] largely summarises contaminant distributions referred to in the earlier report for zinc[1]. Hydrocarbon contamination in groundwater was reported as "minor contamination of heavy-end hydrocarbons have been detected downgradient of the test engine facility "(p10) [3].

In the ENV(2004) report [4] historical contamination in "Area 5" – around the traction motor cleaning area was reported. Area H5 had been previously identified as "moderately high risk" for contamination. Metal concentrations were reported to exceed the Freshwater Guidelines relating to the Helena River in 11 monitoring bores [4], with zinc (8 bores at up to 122ug/L in bore HE2), copper (6 bores at up to 8ug/L), nickel (2 bores up to 68ug/L in H5B), cadmium (2 bores at up to 1ug/L in H5B), and lead (6ug/L in bore HE2). Hydrocarbons were detected in groundwater from 8 bores within Area H5, with short-chain (C6-9) hydrocarbons being found at up to 32000ug/L in bore H5H and lesser amounts in bores HE7 and HE17. The report concluded [4] that "this suggests that a plume of solvent contamination may exist downgradient of the cooling water plant (F) and Power House (K in figure 2, ENV(2004) [4]). Long chain hydrocarbons were detected in bores HE3 and HE15 (up to 3150ug/L) downgradient of the Copper shop (D) and refueling depot (G) and Traction Motor Cleaning Area (H). Concentrations of benzene (to 18ug/L) and xylenes (to 911ug/L) were reported in bores HE17 and H5H. Minor cyanide was also detected.

The most recent reference and referral document [5] summarises some previous data as in ENV(2004) [4] above, as well as noting additional contamination of groundwater by metals from the foundry area. This report identifies "the Industrial Area", which seems to equate to the Area H5 [4] noted above, as being most heavily contaminated with organics. Groundwater around the Traction Motor Cleaning area, extending into the Refuelling Depot and Cooling Water Plant were identified as containing BTEX monoaromatics (benzene etc), and VOCs dichloroethane, dichloroethene, trichloroethene, perchloroethane and trichlorobenzene. The extent of impact of the above organic contaminants is stated to be "localized to the source [zones]" and these contaminants were 'not detected downgradient" of these areas. If the above contaminated area behaves in the same way as the plume from the "hydrocarbon dump" [2] discussed above, then the latter statement requires further investigation to clarify the existence or otherwise of any localize groundwater plumes such as that reported in ENV(2002) [2] (see comments and recommendations under 5.4).

The Referral document [5] identifies the main receptor for contamination as the Helena River, which is some 70m from the waste fill and contaminated areas. The report states [5] that “ it is expected there is some groundwater seepage from the superficial aquifer into the river system during the winter months…. The seepage is believed to be mainly due to localized groundwater [flow] within the floodplain sediments rather than distinct flows from the ‘site aquifer system’ which moves in a westerly direction …”. The latter would seem to refer to groundwater flow within the Deep Superficials rather than the likely more contaminated Shallow Superficials, which could transmit contaminants, albeit very slowly, towards the Helena River.

This review concludes that contaminant transport within the Shallow Superficials is likely of more consequence than that in the underlying Deep Superficials, although steps should be taken to attempt to identify and monitor the distribution of contaminants within both systems to assess interlinkages, and possible flow paths (see 5.2-5.3 below). Further modeling of the groundwater system, if models could be properly calibrated, would assist in assessing appropriate remedial action (see 5.2 below). However, it is doubtful whether the complexity of flows in the Upper Superficial aquifer unit could be modeled in any meaningful sense, and it is not recommended this be contemplated.

4.2 Attenuation of contaminants -Groundwater (Fate / Transport) Modeling

Simple one-dimensional modeling has been reported in ENV (2002) [2] to assess transport of chlorinated VOCs (chlorobenzene, dichlorobenzene isomers) from the “hydrocarbon dump” towards monitoring bores at 50m distance and the Helena River beyond. Simulations were carried out assuming sorption (partition) of organics on soil organic matter (SOM), decay (assumed first order, although this was not stated) and advective transport with little dispersion (the latter was a WRC requirement). A hydraulic conductivity (K) of ~3m/d was assumed for the sandy clay, 10m/d for sand and 1m/d for clay. These are all greater (by around an order of magnitiude) than the K values determined from the recovery tests for the Shallow Superficials. An SOM concentration in sediment of 1-2% was used with literature values for carbon normalized partition coefficients to determine sorption/partition coefficients for the VOCs. Literature decay coefficients were also used.

The results of the simple simulations were compared with field data for monitoring bores at 50m distance downgradient of the “dump”. However, as pointed out in the report [2], it is not possible to compare these directly because dispersion is not taken into account in the modeling. The simulations thus can only provide indicative timeframes for the development of any contaminant plume in groundwater within the local flowfield. It was assumed that contamination commenced some 30 years prior to collection of monitoring data. Reported VOC concentrations at monitoring bores 50m downgradient [2] were an order of magnitude lower than those at the source.

The modeling results indicate that the VOC contaminants would take more than 30 years to reach the 50m bores with the assumed K values for sandy clay (3m/d), and an average

SOM content of 2%. The simulation of transport through sands (K = 10m/d) indicated "breakthrough" of contaminants within the 30 year timeframe at much higher concentrations than those observed, so these simulations were unrepresentative of actual conditions. Even here, it would take 35-60 years for contaminants to reach the Helena River. Breakthrough at the river would take greater than 100years for sandy clay soils which showed the closest correspondence between the simple model and actual monitoring data.

The conclusions in the report (2) on the simple modeling and related monitoring data suggest that plumes can develop in a complex way within the less permeable Shallow Superficials, as indicated above. Significant attenuation of the chlorinated VOCs, consistent with sorption (partition) and decay, can take place and other contaminants (TPH, BTEX etc) would seem to be more readily attenuated. The report also suggests that the monitoring data probably only reflects "the toe of the hydrocarbon plume, rather than the centre of mass", and that concentrations would increase in future as the centre of mass migrates past the 50m bores, which seems likely. It is understood that the hydrocarbon dump has now been remdiated, although the extent of any plume has not been investigated.

Recommendations for more detailed numerical modeling at the site is given in ENV(2003) (3) proposing to use the modeling program MT3D, and including dispersion, focusing particularly on the metal zinc, which poses a potential problem to the Helena River. This modeling does not seem to have been carried out, or at least has not been reported in the documents reviewed here. The proposed approach seems sensible, although the utility of any modeling will depend critically on being able to calibrate the model adequately with field monitoring data. The latter seems to be of mixed quality as it is difficult to assign groundwater samples to either Shallow or Deep Superficial aquifers because of the use of long screens in monitoring bores. There may be a need to install further monitoring bores in the Shallow Superficials if the current network is considered inadequate, which seems likely.

ENV(2005) (5) concludes that groundwater beneath the "industrial" site is locally contaminated with metals (particularly zinc) and hydrocarbons (VOCs referred to above and possibly naphthalene would seem to be the most problematic) mainly in the Shallow Superficials. The report (5) concludes that "the plume from the plating dump represents a potential risk to the Helena River in future", presumably from zinc contamination. The statement that "hydrocarbon contamination at the site does not appear to represent a risk to the Helena River" (5) is difficult to reconcile with the previously reported incidence of lateral transport of chlorinated VOC contamination from the hydrocarbon dump (2), which clearly indicates lateral transport of contaminants within the Shallow Superficials which could take place elsewhere on the site. It would thus be prudent to assess the extent of any groundwater plumes from these areas within both Shallow and Deep Superficial systems (see 5.4 below).

It is concluded that monitored natural attenuation (MNA) could be applied at the site, as recommended in ENV(2005) (5) but longer term predictions for development of any contaminant plumes from metal and organic contaminant sources in the region of the electroplating “dump” would be required as a benchmark for MNA (see 5.3 and 5.4 below).

In addition, it is recommended that an attempt be made to collate information on the locations and available monitoring data from various contaminated areas, and adopt a uniform reference system and bore identification scheme from the ENV reports. It is believed that a proper appraisal of an appropriate MNA response, including identification of additional monitoring points can only be accomplished when a consistent set of data from investigation and monitoring is available.

The following comments are intended to identify where it is believed there are deficiencies in the data and interpretation of impacts of contaminants at the Helena Precinct site, particularly in relation to issues directly related to groundwater contamination identified by EPA / DoE (email from Melissa Bromly to David Ross, 4 March 2005).

5. Recommendations for further works in relation to comments by EPA/DoE

5.1 Long Term Pumping Tests

EPA/DoE recommend a long term (7 day minimum) pumping test to investigate the interaction between the aquifer and Helena River. It is agreed that a further pumping test is required as indicated, designed more specifically to investigate further the response of pumping from the Deep Superficials (using the existing pumping well close to HR11) on groundwater levels in the Shallow Superficials nearer the surface. Additional monitoring wells may be required at shallow and deeper levels within, or close to the Helena River to assess impacts on the river and associated groundwater close to the river, as requested by EPA/DoE.
Data from the earlier pumping test suggested that bores in the Shallow Superficials did not respond to pumping, although only one bore was monitored (HP2). Given the complexity of the Shallow Superficial sediments and the likelihood that most contamination lies within this upper zone of sediments, then it would be imperative to monitor as many bores within the Shallow Superficials as possible, as well as those bores located in the Deeper superficials.

5.2 Groundwater Modeling

EPA/DoE recommended that further groundwater modeling is undertaken prior to any remediation at the site. However, it is unclear from the reports reviewed here whether there are sufficient data to allow useful calibration of any model, which would be required to assess the utility of any remediation (particularly MNA, which would seem to be the intention at the Helena Precinct site). It is crucial for proper model calibration, and that the Shallow and Deep Superficials be modeled separately.

Modelling of zinc and “hydrocarbon” contamination in groundwater from the region of the electroplating area of the site– as proposed in the ENV(2003) [(3)] would require appropriate data on the distribution of these contaminants in groundwater at the source and downgradient towards the Helena River for model calibration (as with the simple fate/transport modeling[2]). This data would seem to exist for zinc (ENV, 2005 [5]) where concentrations are reported within the source zone in the vicinity of the electroplating plant, and at lower concentrations in 6 monitoring bores at 50m intervals from this area, although there is no cross referencing provided showing the source data. Again, the reviewed reports do not identify in which aquifer system (Shallow or Deep Superficials) the bores are screened. As with the organic contaminants, it is essential to determine which system the bores are monitoring, or whether both aquifer systems are covered by long screens. In the latter case, monitoring data would be of limited value.

It is thus recommended that prior to any modeling, an assessment be made from all available data as to location of screened sections of all existing monitoring bores to ascertain which system these are monitoring, and assess from available monitoring data the distribution of contaminants in three dimensional space and if possible with time. It seems likely that the Shallow Superficials immediately beneath the site are likely to be most contaminated, and lateral movement from these contaminated areas would need to be assessed to provide long-term predictions of likely impact on the Helena River. Groundwater flow in the Deeper Superficials is parallel to the course of the Helena River, and consequently there would be little or no impact of any contamination within these deeper sediments on the river system, unless natural gradients were disturbed by pumping.

If monitoring wells in the Upper Superficials are inadequate to provide data for assessment of contaminant transport (and this seems likely), then it is recommended that consideration be given to emplacement of additional monitoring bores into the shallow system to provide essential, local monitoring of contaminant behaviour (see below under 5.3 and 5.4). It is believed, however, that flows within this system are likely too complex for any meaningful modeling of contaminant transport to be carried out.

5.3 Leaching of metals from waste materials on site

EPA/DoE do not concur with the conclusion in ENV(2005) [5] that waste materials are relatively benign, and have a low propensity to produce leachate. They cite data on groundwater monitoring from beneath "natural ground area(s)" which contain zinc, copper, nickel and cadmium in excess of Freshwater criteria, which indicate the potential for leaching of metals, albeit at relatively low levels.

It is recommended that if an assessment of impacts can be made from detailed monitoring of more contaminated areas, that this be widened to include other source regions with lower level contamination. The crude mass balance calculations suggested that there is sufficient attenuating capacity within the Shallow Superficials to attenuate zinc which is the most problematic contaminant[3]. Any assessment of such contamination would require consideration of dilution of groundwater discharge by surface water flow in the river.

5.4 Hydrocarbon Contamination

EPA/DoE question the approach to apply MNA at the site without further investigation and modeling. It is apparent that monitoring of hydrocarbon contamination has not been able to establish whether organic contaminants have migrated downgradient from the "electroplating dump" although downgradient bores on the floodplain are not impacted. However, if insufficient attention has been given to monitoring Shallow Superficials, as seems probable, then the extent of any contamination within this system would need to be determined. However, biodegradation is likely to attenuate contamination, as at the hydrocarbon dump. EPA/DoE also have concerns that the extent of hydrocarbon plume(s) have not been assessed, despite localized but quite high concentrations of TPH in groundwater.

It is agreed that the EPA/DoE concerns are justified, as data reported in ENV(2002) (2) clearly show some downgradient transport of chlorinated VOCs (chlorobenzene and dichlorobenzene isomers) within the Shallow Superficials, although there was significant reduction in concentration.

It is recommended that monitoring data for hydrocarbons be reassessed to identify the three dimensional distribution of hydrocarbon contamination within the Shallow and Deep Superficials. Again it seems likely that organic contaminants from light non-aqueous phase liquids (LNAPLs such as diesel) would be present in highest concentration in the Shallow Superficial sediments. However, those associated with dense organic liquids (DNAPLs such as the chlorinated solvents identified in ENV(2002) (2) could be present in higher concentrations in deeper groundwater, as DNAPLs potentially can migrate through water-saturated sand/clay sequences (D Reynolds, UWA, Pers. Comm.). Consideration should be given to providing additional monitoring bores within both aquifer systems to identify hydrocarbon contamination, if existing monitoring bores are considered inadequate for this, which seems likely.

In the latter case it is recommended that short screened bores or multilevel piezometer bundles are used to provide vertical profiles of contaminant distribution within each aquifer system to delineate contaminant plumes in 3-D space. Alternatively, initial profiling could be carried out using direct-push units such as Geoprobe® to provide data on contaminant distribution in key locations. Geoprobe is ideal for monitoring shallow unconsolidated sediments such as sand / clay sequences, and these can be used for *in situ* monitoring of VOCs or for recovering samples of groundwater. However, Dames and Moore (1997) (7) did have some difficulty in using this equipment on the site where heavy brown clay was encountered.

5.5 Leederville Aquifer

Under "Detailed Comments", EPA/DoE requested resampling of the production well for use on the "Police Site", as initial sampling showed no contamination associated with the workshops, but some evidence of residual drilling fluids. It seems opportune to also monitor groundwater levels in this bore during the pump test, if it is not currently in use.

5.6 Groundwater Monitoring

Concerns have been expressed in the US concerning disturbance of sediment in monitoring wells during standard purging and sampling of groundwater, particularly in low permeability sediments (eg Puls and Barcelona, 1996).It has been shown that metals adsorb to colloidal-size particles and these become resuspended during purging and sampling. Samples of groundwater thus contain metal concentrations which are unrepresentative of dissolved-phase metal in groundwater (ie well in excess of the true dissolved phase concentration). Low-flow sampling is thus recommended in this situation (eg pumping at 5-10mls / min. using a peristaltic pump with the intake for the pump being open within the screen of short-screened bores). In such cases, only the pump-line requires purging, as drawdown within the bore is minimal. It is recommended that this type of sampling or multilevel piezometer bundles which require little purging be used for extraction of groundwater samples for metal determination.

EPA/DoE also criticize investigations at the site for lacking any long term monitoring. This review concurs with this view, as there is a lack of any perspective on variation in contamination of groundwater with time, even at sites which have been previously remediated. It is recommended that all groundwater monitoring data be collated to provide this perspective, and that in future regular monitoring from dedicated bores be carried out to assess contaminant variation with space and time.

It is also recommended that consideration be given to monitoring water quality within the Helena River, both upstream and downstream of the Helena Precinct site. Although reference is made in the reports to river water quality being somewhat impaired, this does not seem to have been investigated in any detail. Determination of background surface water quality would seem to be an essential consideration in the assessment of the need for any groundwater remediation.

5. Additional cited references

Davidson A, 1995. Hydrogeology and Groundwater Resources of the Perth Region, Western Australia. GSWA, Bulletin 142.

ENV, 2001. Assessment of the fate and transport of contaminants at the proposed Police Operations Facility Areas B, C and D. Midland Redevelopment Authority.

Puls RW and Barcelona MJ, 1996 Low-flow (minimal drawdown) ground-water sampling procedures. US EPA, Cincinnati, Ohio. Report EPA/540/S-95/504. 12 pp. 1995.

7. Limitations of this report

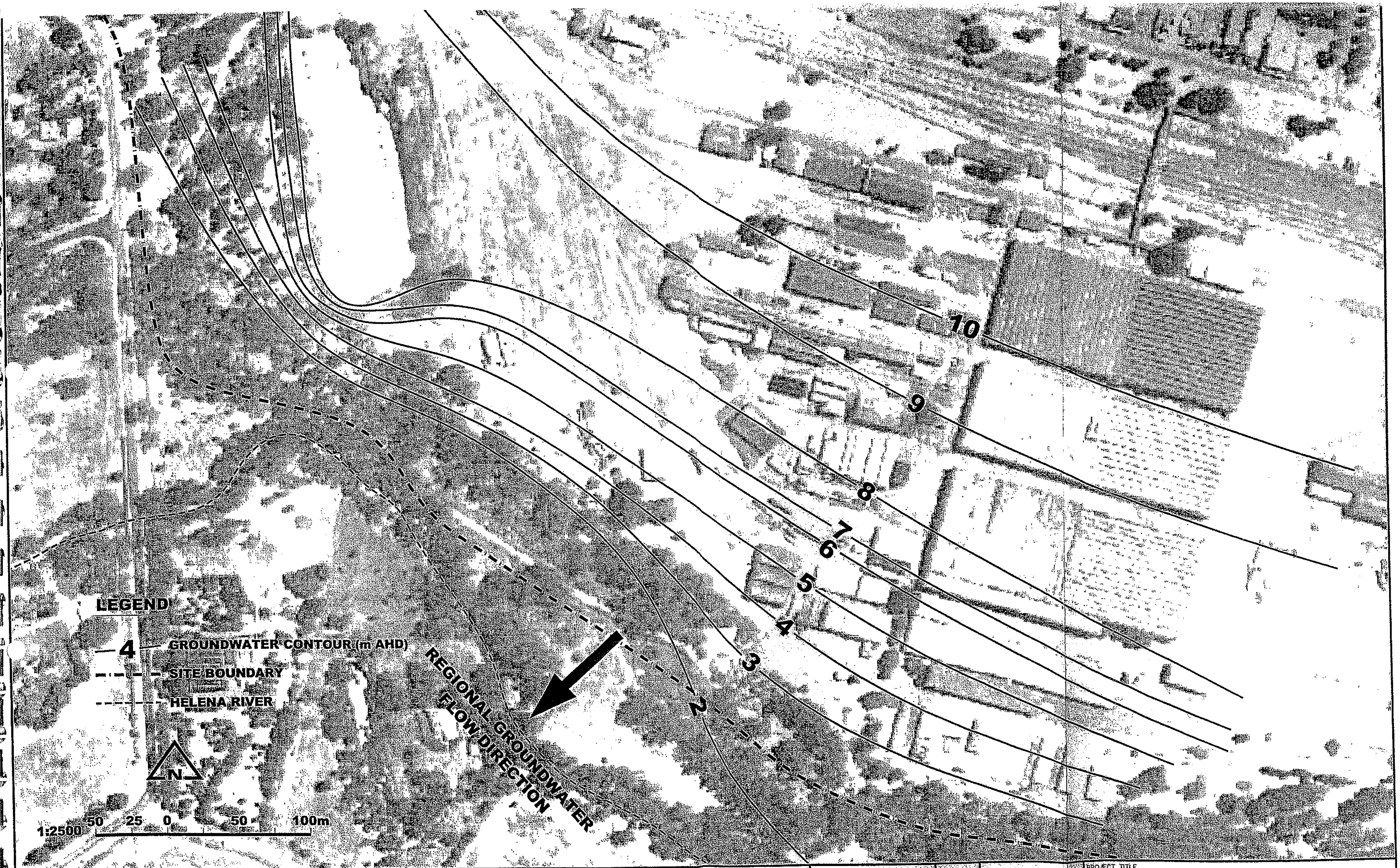
This report was prepared at the request of ATA Environmental for the Midland Redevelopment Authority, as an independent review of available groundwater data relating to the Helena East Precinct at the Midland Railway Workshops site. The report is based on information, consultant's reports and Department of Environment / Environmental Protection Authority comments relating to the site provided by ATA Environmental. In evaluating information, reports and comments, Crisalis International Pty Ltd has relied in good faith on the information provided. We accept no responsibility for any deficiency or inaccuracy contained in this report as a result of our reliance on the aforementioned information.

The findings and conclusions documented in this report have been prepared for specific application to this project, and have been developed in a manner consistent with that level of care normally exercised by environmental professionals currently practicing under similar conditions in this jurisdiction. Crisalis International makes no other warranty, expressed or implied.

Dr Chris Barber
Director / Principal, Crisalis International Pty Ltd
10 June 2005.

Figure 1. Reported groundwater level contours for the Shallow Superficials[1,2,6].

Figure 2. Approximate groundwater level contours around and to the east of the Coal Dam in the Shallow Superficials, based on water levels given in ENV(2003) [3] (shown for each bore within this aquifer unit).



REV.	DATE	DESCRIPTION
A	20/05/02	ISSUED IN REPORT

env Australia

MIDLAND REDEVELOPMENT AUTHORITY

DRAWN	A LEE	DATE 17/05/02
DESIGNED	D ROSS	DATE 17/05/02
CHECKED	D ROSS	DATE 17/05/02
SCALE	1:2500	
FILE NAME	01-068-0003	

PROJECT TITLE
MIDLAND REDEVELOPMENT

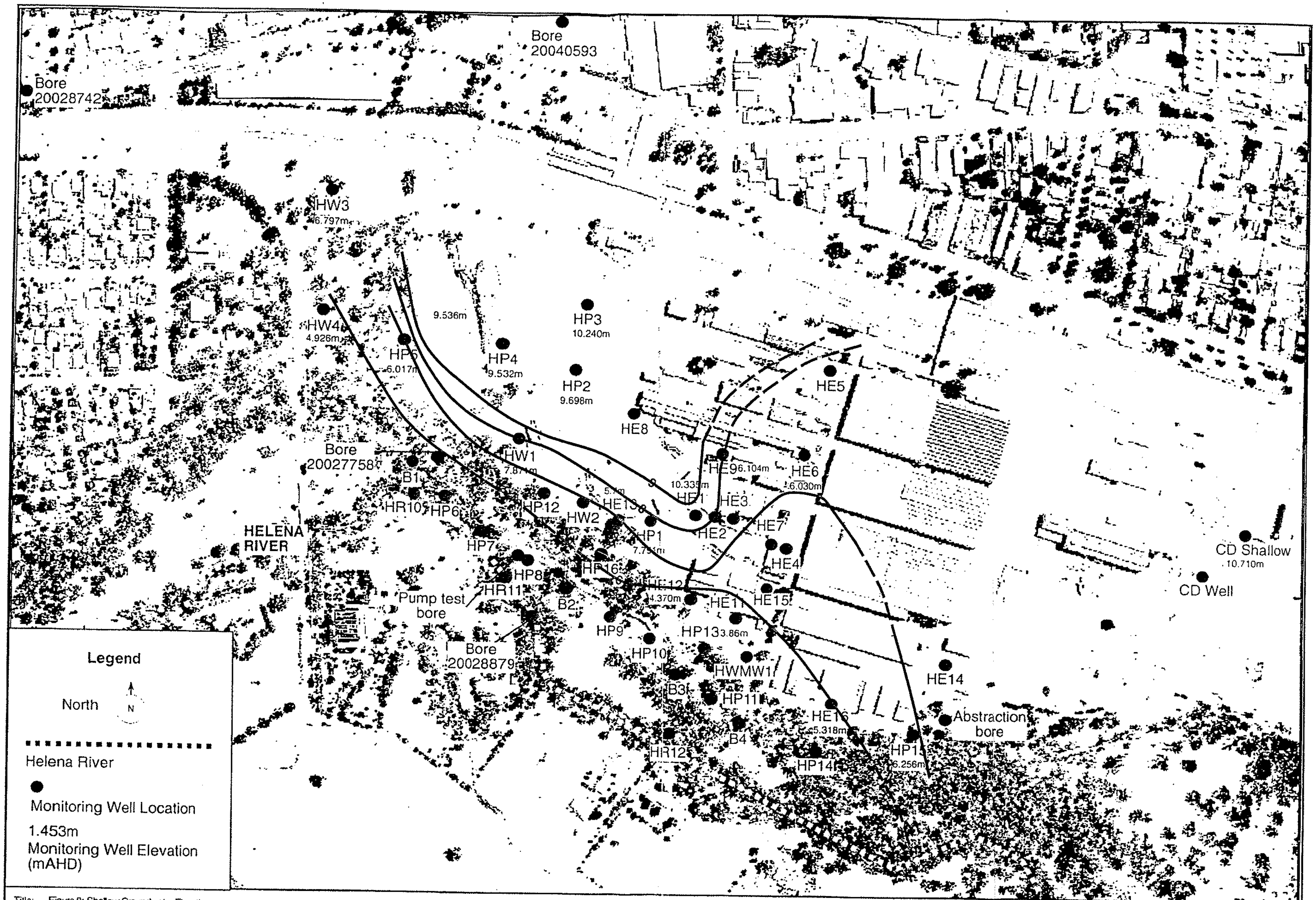
DRAWING TITLE
HELENA PRECINCT
WATER TABLE CONTOURS AND REGIONAL GROUNDWATER FLOW DIRECTION - MARCH 2002

A3

DRAWING/FIGURE No.
FIGURE 3

REV. A

FIGURE 1



Title: Figure 8: Shallow Groundwater Elevations

Client: MRA

Scale: 100m

Job No: 03.003

Date: 24/04/2003

Drawn by: SD

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Review and Recommendation on Groundwater Monitoring at Helena East Precinct, Midland Railway Workshops: Report to ATA Environmental for Midland Redevelopment Authority.

The following comments were requested by ATA Environmental, following an earlier review in June 2005 carried out by Crisalis International and a later monitoring round carried out by ATA in September 2005. The following comments, tables and figures relate specifically to the Helena East Precinct and it is understood that this letter accompanies the Helena East Public Environmental Review (PER) (ATA, 2006) as an appendix. For simplicity, and following terminology used in previous consultants' reports, the complex clay-rich soils in the upper part of the Guildford Formation beneath the MRA site are referred to below as Upper Superficial Soils (USS), which host the Shallow Superficial Aquifer (SSA). The sandier alluvial sediments of the Guildford Formation lower in the profile and above the Henley Sandstone are referred to below as Lower Superficial soils (LSS), which host the Lower Superficial Aquifer (LSA). The locations of bores referred to in the text below are shown in the attached Figure 1.

Hydrogeology

The geology and hydrogeology of the Helena East area has been re-evaluated in detail by ATA on the basis of previous and recent drilling results in 2005 (reported in ATA, 2006), provided for this study. The soils show similar complexity as noted previously, with a thin (0.5m thick) veneer of inert and waste fill generally, but much thicker (to around 7m bgl) in the southwestern part of the area. Sediments below the thin depth of fill are more clay-rich SSA, with sandy clays and sands of the LSA lower in the profile.

Shallow groundwater levels within Helena East and the SSA are in part dominated by water levels in the Coal Dam, with these relatively high levels extending from Helena West (bore HP4) southeast, to the south of bore HE8 to bore HE1. These sediments would seem to be predominantly sandy clays below a few metres of clay soil and fill, and grade into more sandy soils deeper in the profile and on the Helena floodplain to the southwest. Groundwater flows inferred from groundwater levels were to the southwest towards the Helena River. However, the gradient is high (see Appendix 4 in ATA, 2006) which suggests the sediments have a low hydraulic conductivity – consistent with these being clayey sands. In addition, groundwater flows within the LSA, as shown in ENV (2003a), are towards the northwest, approximately parallel to the Helena River. Considering the latter, and the fact that groundwater levels in the LSA are 1-2m lower than the base of the river (ENV, 2003a), this precludes any discharge of groundwater from the LSA into the river, at least in the vicinity of the Railway Workshops site. It is unclear as to the nature of interaction between groundwater within the SSA and that in the LSA, although the absence of springs at the base of the escarpment suggest there is diffuse leakage from the upper to the lower sediments, probably within the sandier soils around the floodplain.

A pumping test of LSA on the southern boundary of Helena East reported in ENV (2003a) comprised some limited monitoring of water levels in bores in the SSA. These showed little response, suggesting a poor hydraulic connection between SSA and LSA. However, given the complexity of the SSA sediments, and strong downward hydraulic gradient between the SSA and LSA, it seems likely that, as suggested above, there is diffuse leakage of groundwater from the SSA into the underlying LSA, and consequently no direct groundwater discharge to the Helena River. It is unlikely that further pump testing would assist in defining the possibility of groundwater flow towards the river, although monitoring of water levels in the LSA and water quality in the river would provide further information which would better define the hydraulics of the groundwater- river system.

Elsewhere in the SSA, thicker clay soils were shown to occur in the region of bores HE6 (central within Helena East) westward and north to bore HE9 and HE8 on the western boundary of Helena East. These clay sediments within the

SSA would be more of a barrier to groundwater flow within the upper part of the profile, and it is possible these extend farther to the east of HE6, possibly towards the location of the CD bores referred to in ENV (2005a). These also occur to the north of the main contamination within Helena East area.

Groundwater Contamination

Heavy Metals

Recent data in Figures 8a – 8d and 10a – 10b in the PER (ATA, 2006) summarise the distribution of contamination of soils and groundwater by heavy metals. Detailed results were also provided on concentrations of heavy metals in groundwater from sampled bores for 2005/2006 sampling for both the SSA and the LSA in Tables representing the same period (ATA, 2006).

Concentrations of metals above the EIL (mainly zinc, occasionally nickel) in soils are mostly located within the southern central region of Helena East, around the locations of the former Copper Shop, Power House, Panel shop, Plating shop and Electrical shop. There are other contaminated regions associated with the former foundry to the north of this area, in Block 3 (machine shop, fitting shop etc) and a "Sand Blast Shed" to the southwest of the area. A small contaminated area to the southeast corner of the site has no obvious source from available data. Contamination deeper in the profile in PER Figure 8b occurs mainly on the southern boundary of Helena East, presumably associated with waste fill materials. Most metal contamination in soils is within the upper metre of the soil profile, except in the latter area where it extends beyond 2m depth.

Groundwater concentrations exceeding freshwater criteria for zinc particularly, and a much lesser extent for nickel, are apparent in Figure 10a in the PER (ATA, 2006) and summarized here in Figure 2. These are mostly associated with the main area of contaminated soil, with multiple sources such as the Copper shop, Plating shop etc within the central southern region of the site. There is some possible contamination associated with the Foundry (bores HE6 and HE8 only) but little apparent contamination with other "source" areas. Bore HE5 in the central northern region of Helena East shows the highest groundwater concentrations of lead and copper.

There is little obvious trend in concentration of zinc in groundwater in bores in Figure 2 associated with the SSA or the LSA. Bores in the SSA within the main contaminated area vary from 0.003 mg/L (ATA-1) to 0.65mg/L (HE6). The only shallow bore on the southern boundary of the area (HP13), closest to the Helena River shows zinc at 0.095mg/L, approximately an order of magnitude above freshwater criteria of 0.008mg/L (8μg/L).

Groundwater in deeper bores in the LSA in Figure 2 show zinc concentrations ranging from 0.093mg/L (ATA15) to 1.2mg/L (bore HE5). Deeper bores on the southern edge of Helena East are generally above the freshwater criteria (up to 0.19mg/L in bore HE11).

Mean concentrations of zinc in groundwater in the SSA (0.2mg/L; 16 bores) are surprisingly less than those in the LSA (0.41mg/L). The highest zinc concentration in 2005 data is also found in the LSA on the northern area of the site (bore HE5) adjacent to the site office and not associated with any obvious contaminant source apart from the roadway.

There is also no obvious background groundwater concentration for either shallow or deep systems for comparison with those in groundwater beneath obviously contaminated soils.

The data for zinc in Helena West and for Areas B, C, D and E (supplied by ATA for September 2005) suggest that background levels for zinc are around or slightly above the fresh water criteria (6-60μg/L), considerably lower than those found in the September 2005 monitoring for Helena East.

Organic contaminants

The following comments are based on summary diagrams in the PER (ATA, 2006) showing locations of organic contamination within Helen East Precinct in Figures 6a-d (cross sections showing soil contaminants), in plan views in Figures 8d and 8e (for soil contaminants) and in Figure 10d for groundwater contamination 10a, 10b and from detailed monitoring results for September 2005 provided in Tables 9 (SSA) and 11 (LSA).

Concentrations of TPH and PAH in shallow soils are distributed across the Helena East area but mostly as isolated, shallow hotspots (PER Figures 8d,e; ATA,2006). More widespread soil contamination by TPH, PAH, VOCs and solvents occurs within the central southern region where there would seem to be multiple sources (Copper shop, Diesel shed and Refuelling area, plating shop etc, identified in Figure 5 of the PER; ATA,2006). Contaminants would seem to have moved vertically to up to 9m bgl in these areas, shown in Figures 8b, 6c and 6d. The location of interpreted cross sections is shown in Figure 5 of the PER (ATA, 2006). Concentrations of TPH, PAH and solvents are also noted in soils to depths of up to 5m on the southern boundary of Helena East, close by bore HWMW1 and H5B.

The above soil contamination corresponds fairly closely with incidence of groundwater contamination (Figure 10b in the PER). Bore HE17 shows the highest concentrations of chlorinated solvents, with dichloroethene isomers present at over 40mg/L, perchloroethene (PCE – referred to as tetrachloroethene in the table) at over 30mg/L, trichloroethene (TCE at over 4mg/L), and vinyl chloride at 0.3mg/L. The presence of this series of chlorinated ethenes (PCE, TCE, DCE and VC) usually indicates a DNAPL (dense non-aqueous phase liquid) source, and that natural bacterial reductive dechlorination is taking place within the soil or groundwater, most usually accumulating vinyl chloride which is not easily degraded. The dominance of DCE isomers suggests only partial bacterial dechlorination; incomplete reductive dechlorination has been described previously during in situ remediation where cis 1,2 DCE accumalted (Graves et al, 2002), as indicated in the data obtained by ATA (2006). Other DNAPL contaminants include carbon tetrachloride, dichloroethanes and dichloromethane. Identified hydrocarbons include BTEX and trimethylbenzenes.

The DNAPL contaminants are shown to have accumulated in clay soils at 1-3m bgl in the region of bore HE17 (Figure 6d, cross section D-D'). Bore HE17 would seem to be screened in the LSA, indicating the DNAPL contaminants have moved vertically to 7-9m or so below ground level, and possibly lower. DNAPLs typically migrate vertically through low permeability soils and vertically in groundwater, given their higher density than water. Bores close to HE17 which show lower concentrations of DNAPL contaminants are ATA-16 and HE7, both immediately to the east of HE17. Figure 6b in the PER suggests these are present in soils at up to 5-7m bgl at this location. Bore H5H, immediately south of HE17, contains BTEX and TPH at low µg/l concentrations in groundwater and indications from soils of presence of hydrocarbons at 1-3m depth (from Figs 8d and 10b in the PER). The absence of detectable DNAPL contaminants or only low µg/L levels in bores within 20-25m of HE17 within both the SSA and LSA (HE1, HE2, HE3, HE-4, ATA 5, ATA 8, ATA9, ATA10, ATA11) indicate little lateral spread of the DNAPL contaminants, at least within the depths sampled. There is some indication that monitoring bores drilled in earlier investigations are screened across both SSA and LSA, which potentially provides a preferred pathway from the more contaminated SSA into the LSA.

TPH and "solvents" contamination of soils is also indicated on Figure 8d on the southern boundary of Helena East, around bores HP13 and HWMW1. Bore HP13 showed only low µg/L levels of xylenes and ethylbenzene and some TPH (up to 25mg/L, mainly C_{15-28}) in groundwater. Bore HWMW1 only showed 1.4mg/L C_{15-28} TPH. These concentrations appear relatively minor.

Recommended Groundwater Monitoring

Metals

Given that most groundwater samples obtained from Helena East were above the Freshwater criteria level for zinc of 8 µg/l (0.008 mg/L), and much higher than the possible background concentrations observed in Helena West and in Areas B, C, D and E (18-68µg/l and 6-22µg/l respectively for these sites), it is recommended that the bores sampled in September 2005 continue to be sampled in future. There does not seem to be any compelling reason to increase the level of sampling (at least for metals) through emplacement of additional bores.

However, given the contaminated soils at the site it is also recommended that selected bores continue to be sampled using low-flow techniques, to avoid entrainment of colloidal and other suspended solids which become mobilized during purging and normal sampling, as mentioned previously in Appendix 4 of the PER (ATA, 2006). Puls and Barcelona (1996) have advocated this type of sampling, as suspended solids mobilized during pumping have been shown to significantly increase the total concentration of metals, which inflate the apparent dissolved phase concentration. As the DoE Freshwater criteria relate specifically to dissolved phase metal, then applying this technique potentially would provide a more reliable assessment of the impacts of any discharge of groundwater to sensitive surface water (ie the Helena River). A short description of this technique is given in the attached Attachment 1.

Organic contaminants

Organic contaminants in groundwater within Helena East are mainly restricted to an area around bore HE17, to the south and east of the former copper shop, and to a region around bore HP13 on the southern boundary of the site. The area around HE17 contains a range of DNAPL solvents and BTEX organics, whilst on the southern boundary there are minor amounts of BTEX and TPH compounds. The organics would seem to be present in both shallow groundwater (in the SSA) and deeper groundwater (LSA), but it is unclear whether the total depth of contamination around HE17 has been determined from investigations so far.

Given the above, it is recommended that the bores sampled in September 2005 continue to be sampled for organics, although it seems sensible to consider reducing the range of organic analysis being carried out, with DoE approval. In the latter case, organochlorine pesticides were all non-detects and could be excluded from future analysis. If PAHs continue to show non-detects in samples from specific bores, then it might also be worth considering excluding PAHs from analyses at a later date.

The main issue which has not been adequately addressed in the investigation and monitoring, is the presence and concentrations within the LSA of the DNAPL contaminants (PCE, TCE, DCE etc) in the area around bore HE17, and to a lesser extent of hydrocarbons in the region around bore HP13 on the southern edge of the site. It is recommended that DNAPL contamination be investigated by drilling below the lower level of the existing bore HE17 and emplacing nested piezometers in the LSA and if more extensive contamination is found also in the Henley Sandstone. It is also recommended that similar bores be emplaced in the vicinity of bore HE13 to assess the vertical extent of the LNAPL hydrocarbon contamination which seems to be present in soils to the approximate level of the water table on the southern edge of Helena East.

It is also recommended that steps should be taken to identify those monitoring bores which have been screened across both SSA and LSA sediments, and that those bores be capped at depth and plugged with appropriate sealant such as bentonite to preclude preferential transport of DNAPL contaminants along the casing and gravel pack.

Other considerations

Surface water sampling
It seems that stormwater and water in the Coal Dam is sampled as part of the Management Plan, but there is no provision for sampling of any water in the Helena River, which is a key environment at risk from contaminants at the site. This was mentioned briefly in the earlier review of the site (CIPL, 2005), although it was noted at the time that the river only had water in it in winter, and at the site this might just be in a series of standing water pools (ie the river is not flowing as such). It would seem justified to try and sample even standing water pools, to assess concentrations of zinc, maybe other metals over time. It is likely any VOCs such as BTEX which are the only organics present in groundwater close to the river which might be present in possible groundwater discharge to the stream would readily volatilize and be undetected. However, some screening for hydrocarbons such as TPH and PAH might be justified.

Water level / piezometric surface measurement.

Although no water level data has been provided from the latest monitoring in September 2005, it is recommended that this be carried out (if not already included in the monitoring) to construct maps of the piezometric surface (water table) within the LSA (as in ENV, 2003; Figure 7) for those bores definitely screened within this aquifer, and to determine how this varies throughout the monitoring period. This information would be required for assessment of likelihood of any transport of contaminants towards the Helena River, or within groundwater within the LSA and Henley Sandstone flowing to the northwest parallel to the river (ENV, 2003) which would preclude any contamination in the LSA being discharged to the river from most of the site.

Dr Chris Barber
Principal, Crisalis International Pty Ltd

24 March 2006.

Attachments:

<u>Figures</u>

Tables and Figures referred to in the text which appear in the PER (ATA, 2006):

<u>Tables</u>

<u>Figures</u>

References

ATA Environmental (ATA), 2006. Midland Redevelopment Authority- Helena East Precinct Remediation and Redevelopment: Public Environmental Review (PER), Volumes 1 and 2. Report 2005/142). Prepared for Midland Redevelopment Authority. March 2006.

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Acknowledgements

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Limitations of this report

This report was prepared at the request of ATA Environmental for the Midland Redevelopment Authority, as an independent review of available groundwater data relating to the Midland Railway Workshops site. The report is based on information, consultant's reports relating to the site provided by ATA Environmental. In evaluating information, reports and comments, Crisalis International Pty Ltd has relied in good faith on the information provided. We accept no responsibility for any deficiency or inaccuracy contained in this report as a result of our reliance on the aforementioned information.

The findings and conclusions documented in this report have been prepared for specific application to this project, and have been developed in a manner consistent with that level of care normally exercised by environmental professionals currently practicing under similar conditions in this jurisdiction. Crisalis International makes no other warranty, expressed or implied.

Attachment 1: Short description of low-flow sampling

Puls and Barcelona (1996) describe the technique to avoid entrainment of colloidal particles and solids which become mobilized in groundwater being pumped during purging and sampling. Settled solids at the base of bores can also be mobilized due to turbulent mixing within the borehole casing and screen. These colloids and solids often have high concentrations of metals, which increase the total concentration of metal in the sample of groundwater.

The low-flow technique involves pumping at rates of 5-10 mls/minute or thereabouts which produces little drawdown within the bore, and close to laminar flow within the bore and screen which does not mobilize colloidal material within the aquifer or micron and sub-micron sized solids within the bore and aquifer soils. The pump intake or discharge line intake is located in groundwater within or at the top of the screened section of the bore. Groundwater quality within the screened section is assumed to be representative of groundwater quality outside the bore, and there is little mixing of casing storage water and groundwater in the screened section during low-flow pumping, particularly if pump and / or discharge line is lowered carefully into the bore.

Pumping is often achieved using a peristaltic pump, if depth to groundwater does not exceed 6m or thereabouts. Alternatively there are bladder pumps (eg Well Wizard) which apparently can be used to provide the necessary low flows.

Purging the bore following low-flow pumping can assist with ensuring groundwater quality around the screen is representative of that in the aquifer, and allowing solids to settle out before a new round of sampling using low-flow techniques ensures that metal concentrations are not artificially increased through solids entrainment.

There has been considerable debate as to the usefulness of this technique, although it is becoming more widely accepted and used, particularly for sampling groundwater for metal analysis.

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DATUM: MGA DRAWN BY: EDS/GLM 23-3-06 (ATA) CHECKED BY: KS/BC 23-3-06 (ATA)

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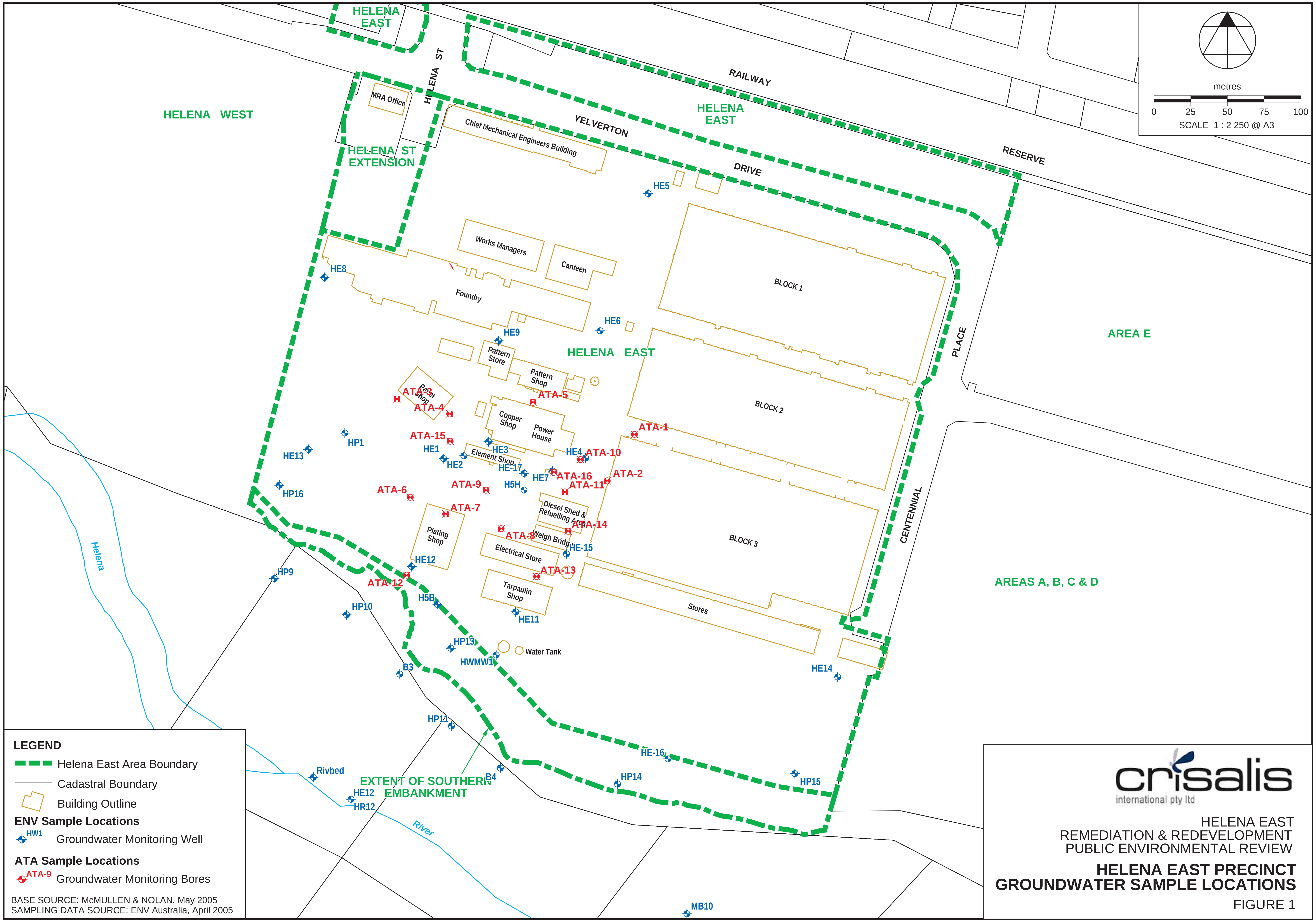

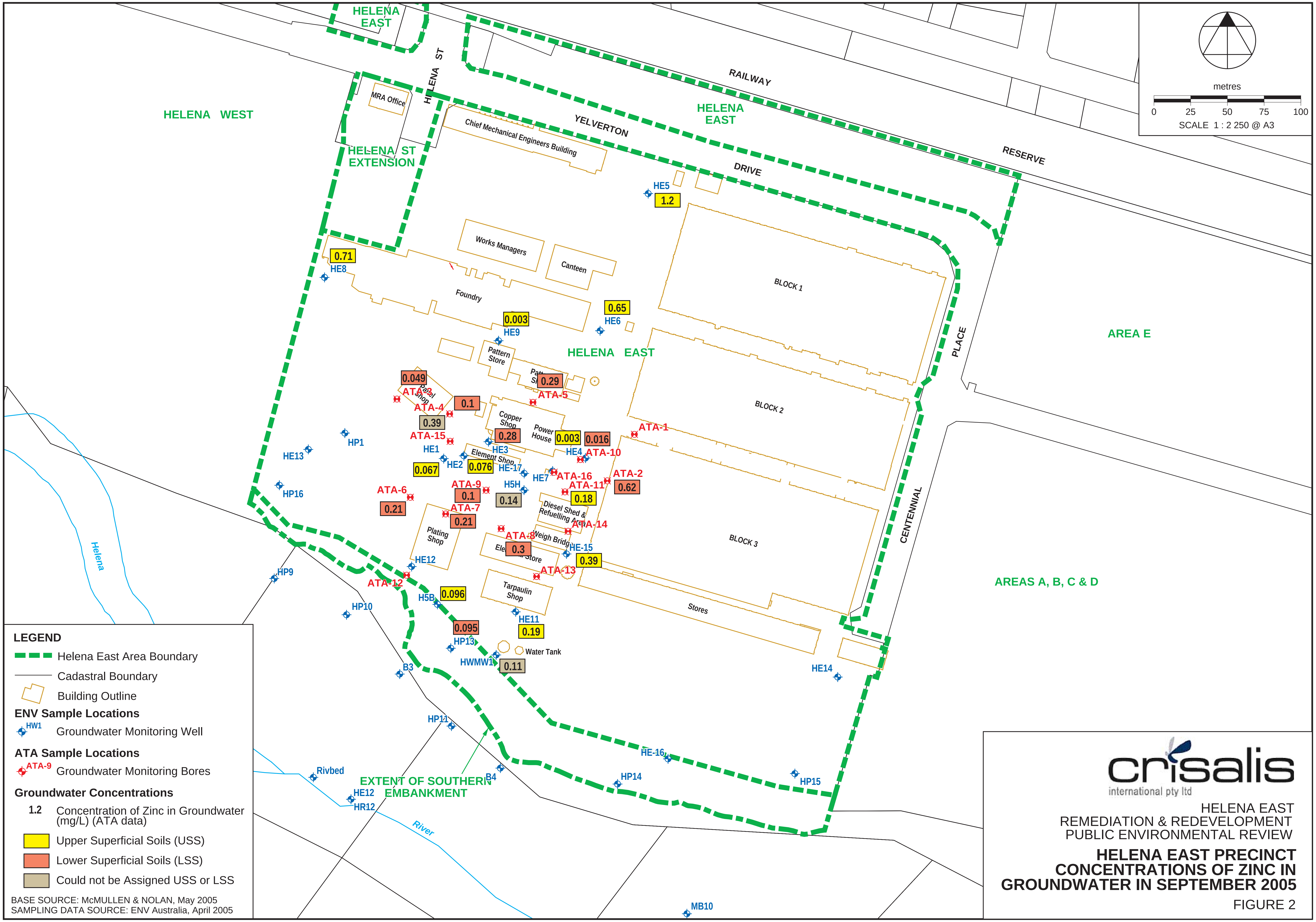

HELENA EAST
REMEDIATION & REDEVELOPMENT
PUBLIC ENVIRONMENTAL REVIEW

HELENA EAST PRECINCT CONCENTRATIONS OF ZINC IN GROUNDWATER IN SEPTEMBER 2005

FIGURE 2

MRA-5-4/BORI/MRA-5-4-BORIf02.dgn DATUM: MGA DRAWN BY: EDS/GLM 23-3-06 (ATA) CHECKED BY: KS/BC 23-3-06 (ATA) PRINTED: Mon 03 Apr 06