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HUNTER WATER

Hunter Water Corporation.

Tillegra Dam Site.
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ABSTRACT

Hunter Water plans to augment its current water supply with the construction of an on-creek storage dam on the Williams River. The proposed Tillegra Dam Site is approximately 3½km upstream from the confluence of the Chichester River.

A concrete-decked rockfill dam is proposed for the site. Embankment length is approximately 800m, with a maximum height of 80m. Diversion will be via a tunnel through the right abutment, with a spillway adjacent to the embankment on the right (southern) side.

A sequence of sedimentary rocks belonging to the **Flagstaff Formation** occur at the site. The formation is Early Carboniferous in age and includes thickly bedded lithic sandstone, with varying proportions of mudstone (shale) and conglomerate with minor limestone.

An option/concept design stage investigation has been completed at the proposed site. The work included geological mapping, test pitting, seismic refraction survey, diamond drilling and laboratory testing. The fieldwork was undertaken during the period September 2007 to March 2008.

This report presents a synopsis of the geology of the dam site and proposed quarry alternatives.

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VOLUME I

1 INTRODUCTION

Hunter Water plans to augment its current water supply scheme with the construction of an on-creek storage dam (Tillegra Dam) on the Williams River. The proposed Tillegra Dam Site is located approximately 3½km upstream from the confluence with the Chichester River. Dungog is the closest township, some 9½km east of the site via Chichester Dam Road (refer to **Figure 1**).

A concrete decked rockfill design has been adopted for the dam. The Department of Commerce has recently completed option/concept phase geotechnical investigations. The main facets of the investigations were:

- Investigations for the dam elements, including embankment, spillway options and diversion.
- Investigation of the rim of the storage, including the various fault systems that may affect the storage area.
- Assessing potential sources of construction materials, in particular identifying quarry areas for the production of rockfill and concrete aggregate.

This report presents a synopsis of the geology of the dam site and proposed quarry alternatives and has been written to provide a general interpretation of the site conditions.

Accepted engineering geological terminology is used in this report. **Appendix A** documents the terminology relating to weathering, rock strength, discontinuity spacing, block size and aperture width of discontinuity spaces. Estimated rock strength refers to rock substance strength as opposed to rock mass strength.

2 PREVIOUS WORK

Two (2) preliminary phases of investigation have been previously undertaken at the dam site. Initial site investigations were undertaken in 1952, followed by more specific work in 1970. Cost studies for the project concept were undertaken in 1985. Details are as follows:

- Hunter Water Board, 1952. Investigation included geological mapping and percussion boreholes, some extended with diamond coring. Drilling was mostly on the left alluvial terrace, upstream of the site, the right bank, extending upstream of the embankment footprint, and the lower left abutment. Drill core from the investigation is stored at Chichester Dam.
- Hall, L.R., 1952. A regional survey of the area was undertaken by the Geological Survey of New South Wales.
- Snowy Mountains Engineering Corporation (SMEC), 1970. Investigation included additional mapping, a seismic traverse in the riverbed and inclined, diamond cored

boreholes across the valley floor. Core from the investigation is currently stored at Chichester Dam.

- Water Resources Commission of New South Wales, 1985. Engineering and cost studies were undertaken for the development of the proposed dam. A concrete faced rockfill dam was adopted for the study.

In addition to the above work, Douglas Partners Pty Ltd (2007A) has recently undertaken an aerial photograph interpretation of the proposed site and surrounding area, together with a follow-up geotechnical inspection (2007B).

3 CONCEPT DESIGN STAGE INVESTIGATIONS

Concept Design Stage investigations at the dam to date include:

- Geological mapping of the dam site and storage perimeter.
- Test pit investigation, including the storage/storage perimeter and dam site. A total of one hundred and fifty one (151) test pits have been excavated. Test pits TP37 to TP109 relate specifically to the proposed dam site and are presented in **Appendix C**.
- Seismic refraction survey of the dam site by Coffey Geotechnics Pty. Ltd. (**Appendix B**).
- Diamond drilling investigation of the dam site, potential Quarry Site B and the Chichester Range. A total of eleven (11) boreholes have been drilled. Boreholes relating to the dam site and Quarry Site B are presented in **Appendix D**. Where appropriate, the boreholes were water pressure tested nominally at 3m stages (**Appendix E**).
- Petrographic analyses of rocktypes encountered at the site by Dr. B.J. Franklin (**Appendix F**).
- Aggregate testing of selected core from the proposed quarry source and river gravels from the Williams River by Boral Resources (NSW) Pty. Ltd. (**Appendix G**).
- Unconfined compressive strength testing by Australian Soil Testing Pty. Ltd. (**Appendix H**).

The locations of the investigations are shown on **Figure 3**.

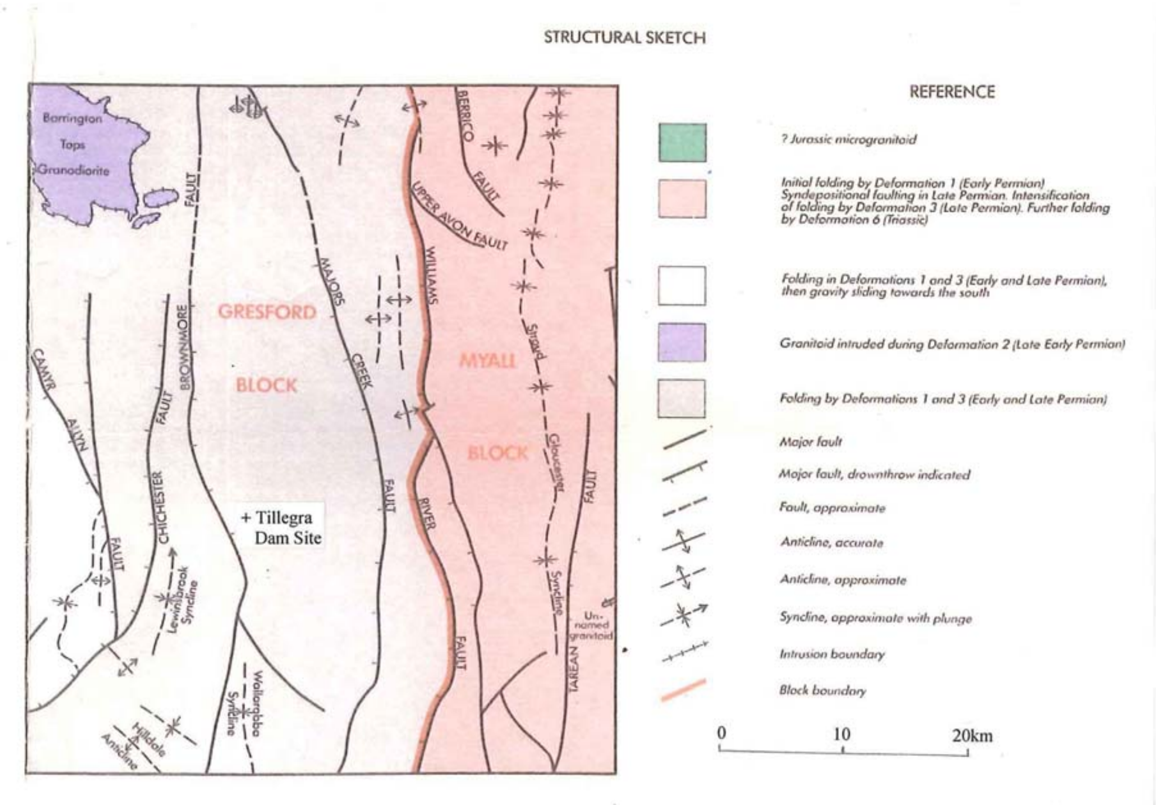
4 CONCEPT DESIGN

A concrete-decked rockfall dam has been adopted as the design for the site. The embankment will have a crest level of RL160m, with a FSL of RL152.3mm. Embankment length is approximately 800m, with a maximum height of 80m.

Diversion will be via a tunnel through the right abutment. The spillway will be located through the ridge above the right abutment of the embankment. The conceptual general arrangement is shown in **Figure 2**.

5 REGIONAL GEOLOGICAL SETTING

The Dungog area falls within the major structural unit known as the Tamworth Synclinorial Zone, which forms part of the New England Fold Belt (Scheibner, 1976). The proposed dam site and storage are within the Gresford Block (Roberts, 1991).



Regional Geology (after Roberts, 1991)

Sedimentary rocks belonging to the **Flagstaff Formation** occur at the dam site and in the immediate environs. The formation is Early Carboniferous in age and includes thickly bedded lithic sandstone, with varying proportions of mudstone (shale) and conglomerate, with minor limestone.

Sandstones at the site comprise a high proportion of intermediate to felsic lithic fragments and have been termed 'tuffaceous sandstone' in the field investigations. It is recognised that the sandstone has been subject to low grade regional metamorphism; however, the term 'tuffaceous sandstone' has been used to maintain consistency with previous investigations. Mudstones (or shales) have also been subjected to low grade regional metamorphism and are termed 'meta-shale'.

Structurally, a series of continuous faults trending north/south occur in the region, including the Brownmore Fault, to the west of the dam site, and the Majors Creek Fault and Williams River Fault well to the east.

6 INTERPRETED GEOLOGICAL CONDITIONS

6.1 Soil

Soil cover associated with the meta-sedimentary rock sequence is generally very thinly developed, often less than 1m thick. Topsoil, comprising pale brown sandy silt, generally ranges from 0.15m to 0.25m in thickness. The underlying residual soils are generally in the order of 0.3m to less than 1m thick and comprise admixtures of gravel, sand, silt and clay. The soils generally classify as SC to CI/CL, ranging from clayey sand to sandy clay. Soils often include a gravel fraction, particularly with depth, comprising angular, weathered meta-sedimentary rock.

6.2 Lithology

An interbedded sequence of tuffaceous sandstone and meta-shale occurs at the dam site. Bedding strikes approximately north-south, across the orientation of the Williams River and dips moderately upstream (west). The ridge system forming the abutments is controlled by strike.

6.3 Weathering

Tuffaceous sandstone outcrops are generally slightly weathered. Finer grained rocktypes are not expressed at the surface. Differential weathering is expected to occur between rocktypes.

The seismic refraction and drilling results have been used to divide the rock mass into three (3) characteristic zones. A shallowly developed upper Zone I comprising soil, grading to highly weathered rock, generally occurs in the upper 2m. The surficial layer grades into a Zone II of differential weathering. This zone is interpreted to represent moderately weathered to slightly weathered rock and generally extends to depths varying from 5m to 15m at the dam site.

Zone III fresh rock is interpreted to occur below Zone II.

6.4 Defects

At the site defects may be grouped into three (3) categories; bedding partings, joints and shears. No dykes have been found in the investigations to date; however, they are a common feature and may occur at the site. The characteristics of these defects are briefly discussed below.

6.4.1 Bedding Partings

The average strike of bedding is 155ºM to 175ºM, dipping upstream, to the west at 40º to 55º. Bedding thickness varies from thinly laminated/laminated in the meta-shale, to medium/thickly bedded in the tuffaceous sandstone. Partings are planar, generally rough, with common Fe/Mn staining in the weathered part of the rock mass. Clay coatings commonly occur in the highly weathered/moderately weathered rock.

6.4.2 Joints

Two (2) major joint sets occur at the site:

- A set striking 175ºM parallel to bedding, dipping 75º to the east, across bedding.
- A set striking 085ºM normal to bedding, dipping at 60º to 90º to the north, into the left abutment.

Joint spacing in the coarse-grained rock types ranges from very close/close to wide. In the finer-grained rocktypes, joint spacing varies from extremely close /very close in weathered outcrop to moderately wide in fresh drill core. The combination of bedding partings and joints results in a prominently fractured rock mass.

6.4.3 Shears

A shear zone interpreted to be in the order of 1.4m wide (horizontally) has been identified in the valley floor (diamond drilling undertaken by SMEC in 1970). The zone comprises altered tuffaceous sandstone with an extremely close/very close defect spacing. Water losses in the order of 60UL were recorded in the water pressure tests across the shear zone. The zone is assumed to be sub parallel to the major joint set striking approximately east/west and is interpreted to be controlling the river orientation at the site. Narrow shears parallel to the joint set have also been observed in the gullies trending approximately north-south, draining off the abutments.

As a result of regional folding, shear zones parallel to bedding are also expected to occur in the finer grained rocktypes. The shears in meta-shale are characterised by extremely close defect spacing and a higher degree of weathering than the surrounding rock mass.

6.5 Faulting

The Tillegra Fault is a major north-south lineament (parallel to the strike of the bedding), located away from the dam, approximately 0.5km downstream of the dam site. The fault dips shallowly to the east at approximately 35º.

No other major faulting was detected in the immediate vicinity of the dam footprint.

6.6 Rock Strength

Rock substance strength varies from very weak/weak in highly weathered rock, to medium strong/strong in fresh meta-shale and very strong in fresh tuffaceous sandstone.

6.7 Permeability

The rock substance at the dam site is considered to be impermeable. However, the rock mass was found to be permeable due to leakage along defects as indicated by water pressure testing in boreholes drilled to investigate the foundation conditions in the dam abutments, upstream portal area and the spillway crest.

A summary of the water pressure test results are presented in **Table 1**. Test results are usually grouped for discussion as follows:

0 to 3 Lugeons	-	low leakage
3 to 20 Lugeons	-	moderate leakage
20 to 100 Lugeons	-	high leakage
>100 Lugeons	-	very high leakage

One (1) Lugeon (UL) is considered roughly equivalent to 1 x 10^{-5} cm/sec in terms of permeability measurement. However, this is only an approximate correlation.

Water losses were generally low to moderate, occasionally ranging to high. Very high losses were recorded in boreholes DDH3, located on the mid right abutment, and DDH8, located in the saddle immediately east of the left embankment.

Losses reduced to low levels at relatively shallow depths (less than half the dam height), which is comparable to typical dam sites and should be readily controllable by normal sealing techniques.

Table 1. Summary of Water Pressure Test Results

Borehole No	Depth (m)		Test Length(m)	Lugeon Value (UL)	Flow Type	Comments
	From	To				
DDH 1 (Right Abutment Spillway)	8.70	11.70	3.00	<1	Laminar	Close to wide defect spacing in test section. Fe-stained.
	11.20	17.70	6.50	1	Laminar	Very close to generally moderately wide defect spacing. Fe and Fe/Mn-stained. Minor clay coating on joint at 13.25 to 13.40m.
	17.20	24.03	6.83	14	Washout	Very close (in meta-shale) to generally moderately wide defect spacing. Fe-stained, occasionally Fe/Mn-stained. Rare (minor) carbonate coatings. Sandy clay fill in partings from 19.85 to 20.05m, minor clay coating on parting at 20.17m
	23.20	26.70	3.50	2.5	Washout	Very close defect spacing (in meta-shale) to wide defect spacing. Fe-stained.
	26.20	32.70	6.50	0	NA	Close to generally moderately wide/wide defect spacing. Fe-stained.
	32.20	38.70	6.50	8	Turbulent	Close to generally moderately wide/wide defect spacing. Fe-stained, heavily in several joints from 33.50 to 33.93m. Several joints/parting carbonate coated (34.15 to 34.40, 35.05, 35.44 36.62 and 36.80 to 37.09m).
	38.20	41.70	3.50	5	Turbulent	Moderately wide to wide defect spacing. Fe-stained to 39.75m (then fresh). Carbonate coated at 39.23, 40.20, 40.60 and 40.92m.
	41.20	44.70	3.50	<1	Laminar	Moderately wide to wide defect spacing. Minor Fe-staining from 42.70m. Carbonate coating on joints at 42.51, 42.70 to 42.88, 43.37, and 44.40m.
	44.20	50.70	6.50	30	Washout	Moderately wide to wide defect spacing. Fe-stained. Carbonate coated joints at 44.40 and 46.28m.
	50.20	53.70	3.50	1	Laminar	Moderately wide to generally wide defect spacing. Fe-stained
	53.50	56.50	3.00	<1	Laminar	Generally wide defect spacing. Fe-stained. Carbonate coated joint at 56.10m
DDH 3 (Mid Right Abutment C/L)	3.83	8.83	5.00	1	Laminar	Very close to wide defect spacing. Fe and Fe/Mn-stained.
	8.33	14.73	6.50	<1	Laminar	Close to wide defect spacing. Fe-stained. Numerous carbonated coated joints.
	14.33	17.73	3.40	15	Washout (Turbulent Flow)	Very close to moderately wide defect spacing. Fe and Fe/Mn-stained.
	17.30	20.80	3.50	10	Washout (Turbulent Flow)	Moderately wide to wide defect spacing. Fe-stained.
	20.30	23.80	3.50	>100	Turbulent	Sheared zone from 21.30 to 22.68m (extremely close/very close defect spacing). Otherwise wide. Fe-stained.
	23.30	26.80	3.50	38	Washout (Turbulent Flow)	Generally close to wide defect spacing. Fe-stained.
	26.30	29.52	3.22	>100	NA	Generally moderately wide to wide defect spacing. Fragmented core recovery from 29.21 to 29.33m. Fe-stained.
	29.83	32.83	3.00	8	Slight Washout	Very close to moderately wide defect spacing. Crushed zone from 31.72 to 31.76m and again at 32.07m (10mm thick). Fe-stained. Clay fill 10mm thick in parting at 30.26m
	32.30	35.83	3.53	7	Turbulent	Very close to moderately wide defect spacing. Fe-stained.
	35.30	38.83	3.53	1.5	Turbulent	Generally moderately wide to Wide defect spacing. Very close defects from 36.02 to 36.42m (partings with joint). Fe-stained to 37m.
	38.30	41.85	3.55	1.5	Turbulent	Very close to very wide defect spacing. Often carbonate coated.

Table 1 continued

Borehole No	Depth (m) From	Depth (m) To	Test Length(m)	Lugeon Value (UL)	Flow Type	Comments
DDH 4 (Upstream Diversion Portal)	3.80	7.20	3.40	12	Laminar	Extremely close to moderately wide defect spacing. Fe and Fe/Mn-stained.
	6.80	10.20	3.40	13	Laminar	Very close to moderately wide defect spacing. Fe and Fe/Mn-stained.
	9.80	13.20	3.40	11	Turbulent	Very close to wide defect spacing. Fe and Fe/Mn-stained.
	12.80	16.20	3.40	4	Dilation	Close to wide defect spacing. Fe and Fe/Mn-stained. Partly carbonate coated joint from 15.80 to 16.08m.
	15.80	22.20	6.40	1	Laminar	Generally moderately wide to wide defect spacing. Very closely spaced joint fragments from 19.77 to 20.00m. Fe and Fe/Mn-stained. Partly carbonate coated joint from 15.80 to 16.08m
	21.80	28.20	6.40	0	NA	Wide to very wide defect spacing. Fe-stained.
	27.80	34.20	6.40	<1	Laminar	Very close to moderately wide defect spacing, ranging to wide from 32.56m. Fe-stained, occasionally Fe/Mn-stained, to 32.75m. Carbonate vein 12mm thick at 30.24m.
	33.80	40.20	6.40	<1	Laminar	Wide to generally very wide defect spacing. Unstained.
DDH 5 (Lower Left Abutment U/S Toe)	3.80	6.82	3.02	1.5	Laminar	Very close to moderately wide/wide defect spacing. Fe-stained.
	6.80	10.83	4.03	32	Laminar	Generally close to moderately wide defect spacing. Fe stained, rarely Fe/Mn-stained.
	10.80	14.75	3.95	24	Laminar	Close to moderately wide/wide defect spacing. Fe-stained to 11.55m. Common (minor) carbonate coating, ranging to fill 5mm thick in partings at 13.99 and 14.02m.
	14.35	17.75	3.40	44	Turbulent	Close to moderately wide/wide defect spacing. Defects generally carbonate coated.
	17.35	20.75	3.40	12	Laminar	Very close to close defect spacing. Includes joint parallel to the core axis from 18.66 to 20.10m. Defects carbonate coated.
	20.35	23.75	3.40	25	Turbulent	Very close to moderately wide defect spacing. Includes an interval of very closely spaced joint fragments from 21.70 to 23.46m. Carbonate coated.
	23.75	26.75	3.00	<1	Laminar	Moderately wide to very wide defect spacing. Minor carbonate coatings.
	26.35	31.65	5.30	12	Turbulent	Very close to wide defect spacing. Carbonate coated.
	31.65	35.75	4.10	4	Laminar	Close to wide defect spacing. Carbonate coated, ranging to fill 4mm thick in joint fragments from 35.10 to 35.23m.

Table 1 continued

=Borehole No	Depth (m) From	Depth (m) To	Test Length(m)	Lugeon Value (UL)	Flow Type	Comments
DDH 6 (Middle Left Abutment C/L)	3.80	7.25	3.45	<1	NA	Close to moderately wide defect spacing. Fe and Fe/Mn-stained. Sandy clay coated/fill in defects at 6.10, 6.46 and 7.25m.
	6.80	10.25	3.45	0	NA	Close to moderately wide defect spacing. Fe and Fe/Mn-stained. Clay/sandy clay fill 1 to 5mm thick in joints at 7.25, 8.90 and between 9.15 and 9.35m.
	9.80	13.25	3.45	1	Laminar	Generally very close to moderately wide defect spacing. Includes crushed clayey zone from 11.14 to 11.19m (extremely close defect spacing). Fe and Fe/Mn-stained. Clay fill to 2mm thick in joint/parting fragments between 11.14 and 11.60m.
	12.80	16.25	3.45	<1	Laminar	Extremely close to moderately wide defect spacing. Core loss associated with joint/parting fragments from 15.66 to 15.71m. Fe/Mn-stained.
	15.80	19.25	3.45	3	Laminar	Extremely close to moderately wide defect spacing. Core loss from 18.44 to 18.67m. Narrow crushed zone from 18.08 to 18.11m. Fe and Fe/Mn-stained. Clay coated to sandy clay fill in joint/parting fragments between 16.87 and 17.10m.
	18.80	25.25	6.45	<1	NA	Generally moderately wide to wide defect spacing (very wide from 24.25m). Occasionally Fe and Fe/Mn-stained. Common carbonate coatings.
	24.80	31.25	6.45	<1	Laminar	Generally wide defect spacing. Close to moderately wide from 27.50 to 30.46m. Fe-stained.
	30.80	39.07	8.27	5	Washout	Generally moderately wide to wide defect spacing to 37.94m, then extremely close to moderately wide. Crushed clayey zone associated with parting at 36.28m. Fragmented joint from 38.47 to 38.56m. Fe-stained. Carbonate coated joint at 37.74m.
	38.35	43.25	4.90	<1	Laminar	Extremely close to moderately wide defect spacing to 41.30m, then generally wide. Includes fragmented joint 38.47 to 38.56m. Crushed clayey zone associated with partings from 39.14 to 39.19m. Fe-stained. Minor clay coating with joint fragments and associated partings between 39.95 and 40.53m. Occasional carbonate coatings over the test section.
DDH 7 (Upper Left Abutment)	6.80	10.30	3.50	<1	NA	Extremely close to moderately wide defect spacing. Core loss from 8.43 to 8.53m. Fe and Fe/Mn-stained. Occasional clay coatings.
	9.80	13.30	3.50	0	NA	Generally close to moderately wide/wide defect spacing. Fe and Fe/Mn-stained.
	12.80	16.30	3.50	28	Washout	Generally wide/very wide defect spacing. Fe and Fe/Mn-stained.
	16.30	19.30	3.00	12	Dilation (Turbulent Flow)	Moderately wide to wide defect spacing. Includes an interval of very close to close joint/parting defects between 16.77 and 17.67m. Fe and Fe/Mn-stained.
	18.80	22.30	3.50	<1	Laminar	Very close to moderately wide defect spacing. Fe and Fe/Mn-stained.
	21.80	25.30	3.50	<1	NA	Generally close to wide defect spacing. Includes an interval of very close joint fragments from 22.17 to 22.58m. Fe and Fe/Mn-stained.
	24.80	28.30	3.50	<1	NA	Close to wide defect spacing. Fe and Fe/Mn-stained.
	27.80	31.30	3.50	<1	Laminar	Moderately wide to wide defect spacing. Includes an interval of very close to close joint/parting defects from 28.88 to 29.54m. Fe and Fe/Mn-stained. Carbonate coating on parting at 28.88m and joint at 30.10m.
	30.80	34.30	3.50	0	NA	Close to wide defect spacing. Fe-stained. Carbonate coated joints at 32.46, from 32.66 to 32.87 and at 33.60m.

Table 1 continued

Borehole No	Depth (m)		Test Length(m)	Lugeon Value (UL)	Flow Type	Comments
	From	To				
DDH 8 (Left Abutment Spillway)	3.80	8.18	4.38	5	Washout	Extremely close to moderately wide defect spacing. Shear zone associated with jointing from 7.41 to 8.13m. Core loss from 8.13 to 8.18m. Fe and Fe/Mn-stained. Occasional clay coatings.
	8.10	12.50	4.40	1.8	Laminar	Close to moderately wide defect spacing. Core loss from 8.13 to 8.18m. Fe/Mn-stained. Minor carbonate coating associated with joint between 9.04 and 9.47m.
	12.45	16.23	3.78	2.5	Laminar	Generally very close to moderately wide defect spacing. Fe and Fe/Mn-stained.
	15.75	19.23	3.48	0	NA	Close to wide defect spacing. Fe-Stained.
	18.75	25.23	6.48	0	NA	Generally wide to very wide defect spacing. Fe-stained.
	24.75	28.23	3.48	>100	NA	Generally wide defect spacing. Complete drilling water loss at 27.70m at Fe/Mn-stained joint. Fe and Fe/Mn-stained.
	28.23	31.23	3.00	>100	NA	Very close to moderately wide defect spacing. Fragmented joint from 30.60 to 30.71m. Core loss from 30.71 to 30.76m. Fe-stained.
	31.23	34.23	3.00	<1	Laminar	Generally moderately wide to very wide defect spacing. Fe-stained. Carbonate fill 1mm thick in joint at 34.10m.
	33.75	37.23	3.48	60	Turbulent	Very close to wide defect spacing. Minor shear zone associated with bedding from 37.12 to 37.28m. Fe-stained.
	37.23	40.23	3.00	32	Turbulent	Moderately wide to wide defect spacing. Fe-stained.
	39.75	43.23	3.48	54	Washout (Turbulent Flow)	Extremely close to moderately wide defect spacing. Shear zone associated with bedding from 41.91 to 42.40m, includes clayey crushed zones. Fe-stained.
	42.75	46.23	3.48	50	Washout (Turbulent Flow)	Close to moderately wide defect spacing. Fe-stained to 45.40m. Carbonate coating on defects at 44.45, 45.76 and 45.87m.
	45.75	49.23	3.48	1	Laminar	Very close to wide defect spacing. Common carbonate coatings.

6.8 Water Table

Tight rock mass zones were encountered at depth in all the boreholes in the area of the proposed embankment. Standpipe piezometers were installed in the boreholes to allow monitoring of the water table level. Readings taken at the completion of the drilling program are presented in **Table 2**. On the embankment abutments, the water table depth ranges from approximately 23m to 29m below the natural surface. In the extension of the right abutment (DDH1), the water table occurs at approximately 43m depth. In the extension of the left abutment (DDH7 and DDH8), the water table ranges from approximately 25m to 32m depth.

In borehole DDH5, located on the lower left abutment, a gravel layer at the base of the soil profile continually introduces water into the borehole, perching the water level.

Table 2. Water Level Readings

Borehole No.	Location	Collar RL (m)	Reading (m)	Vertical Depth (m)	Water Table RL (m)
DDH1	RA spillway crest	173.7	49.09	42.70	131.0
DDH2	RL spillway channel	107.2	17.85	15.53	91.7
DDH3	Mid RA	118.7	27.03	23.51	95.2
DDH4	U/S portal diversion	122.4	26.30	22.88	99.5
DDH5	Lower LA	97.7	NA (perched)		
DDH6	Middle LA	127.6	33.33	28.99	94.3
DDH7	Upper LA (saddle)	147.5	29.11	25.33	122.2
DDH8	LA spillway crest	165.6	36.92	32.16	133.4

7 EMBANKMENT

7.1 Left Abutment - General Stripping

Test pits were excavated to refusal in tuffaceous sandstone, or to a depth of difficult digging or refusal in the meta-shales. Moderately weathered/slightly weathered tuffaceous sandstone outcrop and concentrated surface float occurs along the embankment centreline and to a lesser extent in the upstream half of the embankment footprint. Test pits were located away from these areas, where there was little or no surface expression of rock.

Test pit results indicate a general stripping depth for the embankment foundation in the order of 1m. At that level, generally highly weathered, ranging to highly weathered/moderately weathered rock will be exposed. Rock substance strength is expected to range from weak/medium strong in the tuffaceous sandstone, to generally medium strong in the meta-shale.

In areas of tuffaceous sandstone outcrop/bouldery suboutcrop, minimal foundation stripping is required.

Seismic refraction results interpret a low velocity surficial zone of 400 to 600m/sec, with an average thickness of 1m to 1.5m. The zone is interpreted to represent thin soil cover and highly weathered rock. The results are consistent with the test pits.

Stripping depths are interpreted to increase in the flatter area south of Salisbury Road, in the upstream half of the embankment footprint (lower abutment/valley floor area). Stripping depths up to approximately 10m are expected in the alluvial terrace forming the left bank of the river. Gravel deposits in the river channel are estimated to be up to 1m to 2m in thickness (1.5m average), overlying slightly weathered/fresh rock.

7.2 Left Abutment - Toe Slab Alignment

The toe slab alignment will cross the strike of the bedding at an acute angle. Bedding dips upstream at moderate angles. Tuffaceous sandstone is interpreted to be the predominant rocktype exposed, with interbeds of meta-shale; however, the final distribution of each rocktype will only be known after further investigation.

Test pits excavated in tuffaceous sandstone refused at depths of 0.9m and 1.4m on highly weathered/moderately weathered, medium strong rock. In the meta-shales, difficult digging conditions were experienced at depths of 1.4m to 1.85m in moderately weathered, medium strong rock.

Borehole DDH6, on the middle abutment centreline, encountered highly weathered/moderately weathered, weak/medium strong tuffaceous sandstone at 1.3m (vertical) depth, grading to moderately weathered, medium strong rock at 2.4m. Borehole DDH5, on the lower abutment (upstream toe), encountered moderately weathered/slightly weathered, medium strong meta-shale at 1.45m depth.

Below the low velocity zone identified by seismic refraction, an intermediate seismic velocity zone extends to 5m to 10m depth below the natural surface. Seismic velocities range from 1900m/sec to 2,600m/sec. The zone is interpreted to represent moderately weathered/slightly weathered rock. Highly weathered/moderately weathered rock is expected to occur at the top of the zone, as exposed at the termination depths in the test pits.

Moderately weathered, generally medium strong rock occurring at the top of the intermediate velocity zone is interpreted to be a suitable foundation for the embankment toe slab. It is envisaged that stripping depths will range from approximately 1m in tuffaceous sandstone, to 1.5 to 2m in meta-shale. A slightly irregular foundation will result, due to the differing stripping depths between the tuffaceous sandstone and meta-shale.

In the lower abutment (south of Salisbury Road), up to 10m of stripping will be required under the alluvial terrace adjacent to the river and up to 2m under the gravel in the river channel.

7.3 Right Abutment - General Stripping

On the right abutment conditions are similar to those on the left. Soils are thinly developed, generally being in the order of 0.4m to 0.6m thick, ranging up to 0.8m.

Test pit excavator refusal occurred on highly weathered/moderately weathered tuffaceous sandstone at depths ranging from 0.8m to 1.4m. Rock substance strength was generally medium strong. In meta-shale, difficult digging conditions, ranging to refusal, were experienced at depths ranging from 1.4m to 2.5m in moderately weathered, ranging to moderately weathered/slightly weathered rock.

Seismic refraction results interpret a low velocity surficial zone of 400 to 550m/sec, with a thickness of 1m to approximately 2m. The zone is interpreted to represent thin soil cover underlain by highly weathered rock.

A general stripping depth for the embankment in the order of 1m will provide a generally highly weathered, ranging to highly weathered/moderately weathered rock foundation. Rock substance strength is expected to range from weak/medium strong in the tuffaceous sandstone, to generally medium strong in the meta-shale.

7.4 Right Abutment-Toe Slab Alignment

The toe slab alignment on this abutment is again expected to cross the strike of bedding at an acute angle. Test pit refusal on highly weathered/moderately weathered, ranging to moderately weathered tuffaceous sandstone occurred at depths ranging from 0.8m to 1.35m. Rock substance strength ranges from medium strong to strong.

In meta-shale difficult digging conditions were experienced at depths up to 2.5m in moderately weathered, medium strong rock.

Below the low seismic velocity zone an intermediate seismic velocity zone generally extends to 7m to 15m depth below the natural surface. In the lower abutment, the zone is thinly developed, extending to 2.5m to 3m below the natural surface. The seismic intermediate velocity interpreted was 2,600m/sec. The zone is interpreted to represent moderately weathered/slightly weathered rock. Highly weathered/moderately weathered rock is expected to occur at the top of the zone, as encountered in the bases of the test pits.

It is envisaged that stripping depths will range from approximately 1m in tuffaceous sandstone, to 1.5 to 2m in meta-shale. A slightly irregular foundation will result, due to the differing stripping depths in the tuffaceous sandstone and meta-shale.

On the very steep slope immediately above the river channel, bouldery outcrop occurs. Minimal stripping is anticipated to remove the boulder scree to expose a foundation in sound rock.

8 SPILLWAY OPTIONS

8.1 General

At the initial stage of the option/concept investigation two (2) spillway options were considered. One (1) above the right abutment, approximately 75m south of the embankment and a second through a saddle immediately east of the embankment on the left abutment. The spillway crest foundation level is anticipated to be approximately 152m.

8.2 Right Abutment Alignment

The anticipated depth of excavation is approximately 20m to crest level. An interbedded sequence of tuffaceous sandstone/meta-shale occurs to a depth of 8m. The zone is generally moderately weathered and includes significant core losses which are interpreted to be highly weathered rock. Fresh (stained) rock occurs below that depth, including the spillway foundation.

In the crest area, a high velocity seismic zone occurs at depths ranging from 5m to approximately 12m depth beneath the natural surface. Interpreted velocities range from 3,300 to 4,000m/sec. This basal zone is interpreted to represent fresh (stained) rock, ranging to fresh rock with depth. Diamond borehole DDH1, located in the spillway crest area, encountered strong/very strong rock substance strength in tuffaceous sandstone within the basal zone.

The following batter slopes are envisaged in the required spillway cut in the crest area:

- Soil/highly weathered rock - 2 horizontal:1 vertical.

- Weathered rock, intermediate velocity zone - 1 horizontal:1 vertical (expected to occur to a depth of approximately 8m below the natural surface). Protection of any highly weathered beds will be required to prevent deterioration in the long-term. The more weathered zones are interpreted to be controlled by rocktype. Thicker tuffaceous sandstone beds adjacent to meta-shale may be less affected by weathering.

- Fresh rock - 1 horizontal:3 vertical.

The excavation through the ridge is normal to the strike of the bedding which is favourable for the stability of the cut. A major joint set strikes approximately east-west and dips steeply to the north. The joint set may have some influence on the right wall of the cut. At this stage, it is interpreted that this joint set should not daylight in the cut with the prescribed batters. A second major joint set occurs across bedding should not influence the stability of the cut.

Immediately downstream of the crest, the spillway channel floor drops down a very steep slope. The high velocity seismic layer ranges from 4m to 10m depth below the natural surface. At this stage, deeper anomalies in the seismic profile (to 10m depth) are interpreted to be sequences of predominantly meta-shale.

Towards the toe of the slope the intermediate seismic velocity layer (1,000m/sec) deepens. The underlying high seismic velocity zone occurs at a depth of 20m. Diamond borehole DDH2 at the toe of the slope, encountered slopewash deposits, overlying alluvial gravels to 16.26m depth. Underlying the slopewash/gravels, moderately weathered/slightly weathered rock extends to 19.35m, overlying fresh (stained) rock. The intermediate zone is interpreted to represent bedrock in an area of abandoned river channel which was covered with slopewash material derived from the adjacent ridge system.

The lower 10m to 12m of excavation in the proposed stilling basin will be in the high seismic velocity layer (3,700m/sec), which is interpretd to be fresh (stained) rock. At this stage, the following batter slopes are envisaged:

- Soils/slopewash - 2 horizontal:1 vertical.
- Highly weathered, possibly grading to moderately weathered rock with depth - 1 vertical: 1 horizontal.
- Fresh rock - 1 horizontal:3 vertical.

Along the spillway alignment, the intermediate seismic velocity zone extends downstream for a distance in the order of 100m over the flatter slopes to the east, at depths of approximately 15m. The intermediate zone then thins to depths of 5m to 10m further downstream towards the river. The underlying high velocity zone is at the approximate level of the river channel. Test pits in the eastern (downstream) part of the proposed spillway channel encountered highly weathered, generally weak tuffaceous sandstone at depths ranging from 2.1m to 5.3m. Excavator refusal was reached in the pits.

An alternative spillway alignment, located 80m to the north has been recently investigated (March 2008). A series of test pits were excavated along the downstream portion of the proposed channel alignment. Consolidated slopewash occurs from the toe of the slope for a distance of approximately 120m downstream. The slopewash deposit varies in thickness from 5.1m to in excess of 6m. Alluvial gravels occur further downstream, varying in depth from greater than 6.4m to 1.6m towards the Williams River.

8.3 Left Abutment Alignment

The proposed spillway crest occurs in a saddle immediately northeast of the left abutment of the embankment. The surface of the saddle is approximately 13m above the proposed spillway crest foundation level. Seismic refraction indicates a surficial, low velocity zone approximately 1.5m to 2m thick with a seismic velocity of 400m/sec. Test pit TP59, located in the saddle, encountered highly weathered, very weak/weak tuffaceous sandstone from 0.65m to 1m depth, near excavator refusal. The low velocity seismic zone is interpreted to represent soil and highly weathered rock.

Underlying the low velocity seismic zone, an intermediate zone extends to depths ranging from 4m to 14m. The seismic velocity ranges from 2,100 to 2,800m/sec. The intermediate seismic zone thins (to 4m depth) in the eastern or left half of the saddle. Borehole DDH8 indicates that the zone comprises moderately weathered rock, grading to moderately/slightly weathered rock with depth. Tuffaceous sandstone was the dominant rocktype across the saddle with interbeds of meta-shale. Minor narrow shear zones parallel to bedding occurred in the meta-shales.

Fresh, (stained) rock grading to fresh with depth is interpreted to occur below the intermediate seismic zone. Seismic velocities range from 3,200 to 3,700m/sec. Water pressure tests in borehole DDH8 indicated that the rock mass tightened at a depth of 38m (approximately 25m below the proposed spillway crest level). Iron-staining on the rock mass defects also ceased at that level.

The crest foundation is interpreted to be in fresh, (stained) rock, with some moderately weathered/slightly weathered rock occurring in the western (right) half of the foundation. Rock substance strength is interpreted to be strong/very strong in fresh (stained) tuffaceous sandstone and medium strong/strong in fresh (stained) meta-shale. Moderately weathered/slightly weathered meta-shale is expected to have medium strong rock substance strength.

The strike of the bedding is approximately parallel to the alignment of the spillway channel. The stability of the left wall will be influenced by bedding daylighting into the excavation at dips interpreted to be in the range 40º to 45º. The left wall batter should have a lower slope than bedding dip, or be supported at a steeper slope by an extensive ground anchorage system. On the right wall, the major joint set oriented normal to bedding will dip into the cut, also requiring battering back or ground support. The majority of the right wall is interpreted to be in moderately/slightly weathered rock.

Immediately downstream of the crest, the proposed spillway channel drops down a steep slope. The intermediate seismic zone extends to depths of 10m to 15m in this area and has a seismic velocity of 1,700m/sec. Generally fresh, (stained) rock is expected to occur below that depth.

There is a distinct break in gradient at the toe of the slope. The topography then flattens towards the river. In this area it is understood that the channel floor would be excavated to approximate RL78m to form a stilling basin. In tuffaceous sandstone, the test pits in the area refused on moderately weathered rock at 1.5m to 1.55m. In meta-shale, difficult digging conditions were experienced in moderately weathered rock at 1.6m. The soil and highly weathered rock above refusal is interpreted to represent the surficial low seismic velocity zone. The base of the underlying intermediate seismic velocity layer varies from 10m to approximately 23m depth. The majority of the channel floor in this area will be in fresh rock; however, a limited area of possibly moderately weathered/slightly weathered rock may be exposed where the base of the intermediate seismic zone deepens to 23m depth.

The following batter slopes are envisaged for the spillway channel:

- Soil/highly weathered rock - 2 horizontal:1 vertical.
- Weathered intermediate zone - 1 horizontal:1 vertical.
- Fresh rock - 1 horizontal:3 vertical.

Towards the river, the level of fresh rock is co-incident with the level of the river channel. An alluvial terrace, 130m wide occurs on the left bank of the river. The alluvium is estimated to be in the order of 8m thick adjacent to the river, overlying fresh rock.

9 DIVERSION

River diversion is proposed via a 5.8m diameter tunnel through the right abutment. The invert level of the diversion tunnel is approximately RL89m. At that level, the majority of the tunnel is well within the high seismic velocity zone, with velocities range from 2,800 to 4,500m/sec. The zone is interpreted to represent fresh rock. The alignment is approximately normal to the strike of bedding. The combination of bedding partings and the major joint set normal to bedding may result in overbreak from the tunnel crown.

In the area of the diversion inlet channel and portal, the intermediate seismic velocity zone is thickly developed, with its base extending to depths of 15m to 20m (to approximate RL100m). The seismic velocity of the zone is 2,100m/sec. Borehole DDH4, drilled in the vicinity of the upstream diversion portal, encountered fresh (stained) rock occurred at 5.22m depth. Water pressure test results indicated moderate leakage to 14.1m depth. The intermediate seismic zone zone is interpreted to comprise moderately weathered/slightly weathered rock, grading quickly to fresh (stained) rock with depth. The relatively low intermediate seismic velocity is interpreted to be related to the open defects in the rock mass.

The end face of the proposed cut to establish the tunnel portal is approximately parallel to the strike of bedding, which is interpreted to dip at 45º into the excavation. The bulk of the excavation is expected to be in fresh rock, including the tunnel portal. The batter above the portal should have a slope less than the bedding angle to maintain stability, or be supported by aground anchorage system. Support will be required in the local area around the portal (in fresh rock) to maintain a steeper batter angle.

Similarly, the stability of the left wall at the upstream end of the inlet channel will be controlled by the dip of the bedding. As the alignment of the channel turns to the east, towards the portal area, bedding will have less influence on batter stability.

A borehole planned in the downstream portal area was not drilled as prolonged wet weather prevented access. There is no surface expression of rock in the area of the proposed borehole. Scattered tuffaceous sandstone float and rare bouldery outcrop occurs on the slope immediately upstream. The area will be investigated during the next phase of investigation.

The downstream portal is expected to be excavated in rock beneath a thin soil cover. Bedding is interpreted to dip into the portal batter, with the bedding strike normal to the side batters. The stability of the cut will be influenced by the major joint set normal to bedding, which is interpretd to be dipping very steeply to the southeast, that is, into the excavation. The stability of the right wall will be controlled by a major joint set striking approximately east-west, dipping moderately to the north.

Slopewash to depths of 6m or greater is expected to occur downstream of the portal, on the flatter area to the east. Seismic refraction results in the area indicate fresh rock occurs at approximately 10m depth.

10 COFFER DAM

The upstream coffer dam is located approximately 120m upstream of the main embankment. On the upper left abutment, test pits encountered highly weathered/moderately weathered tuffaceous sandstone at 1m depth. The rock graded to moderately weathered with depth, with very difficult digging conditions at 2.8m depth. Rock substance strength at pit termination was medium strong/strong.

On the lower left abutment, test pits encountered extremely weathered/highly weathered tuffaceous sandstone at 1.4m, grading to moderately weathered, medium strong rock at 2.9m depth.

Well rounded gravel in a clayey sand matrix occurred to a depth of 4.9m on the middle left abutment. The gravels overlie highly weathered/moderately weathered tuffaceous sandstone, with a medium strong/strong rock substance strength. The gravel may represent an abandoned, high level river channel.

A low seismic velocity zone has been identified along the left abutment centreline ranging from approximately 2m thick in the upper abutment, to 5m thick in the middle/lower abutment. Seismic velocity ranges from 400 to 600m/sec. The zone is interpreted to represent soil, including gravels, and highly weathered rock (grading to moderately weathered at the base).

Foundation stripping depths, ranging from 2m in the upper abutment, to 3m to 5m in the lower and middle abutments, respectively, are expected. At that depth, highly weathered/moderately weathered rock, grading to moderately weathered rock, is expected to form the foundationj. Rock substance strength is interpreted to be generally medium strong.

Up to 2m thickness of gravel will have to be excavated from the river channel, to expose slightly weathered fresh rock.

The right abutment has a very steep slope immediately above the river channel. Bouldery outcrop occurs over the slope. Minimal stripping is anticipated to remove the boulder scree.

11 CONSTRUCTION MATERIALS

Two (2) quarry sites have initially been identified for investigation (refer to **Figure 5**):

- Quarry Site A, comprising the right hand spillway excavation and possible extension along the ridge to the south.

- Quarry Site B, comprising the central ridge to the west of the dam that separates the two (2) arms of the storage (known as Elwari Mountain). Surface mapping indicates that two (2) faces could be worked in this quarry, one (1) in predominantly tuffaceous sandstone and one (1) in an interbedded sequence of tuffaceous sandstone and meta-shale.

Seismic refraction indicates that the spillway may yield only small quantities of rockfill for embankment construction and there is some doubt over the remainder of Quarry Site A. This site is envisaged as an expansion of the (right) spillway crest area. Borehole DDH1, located in the centre of the crest, encountered highly weathered/moderately weathered, interbedded tuffaceous sandstone and meta-shale to 8m depth. Fresh, (stained) rock occurred below that depth. Further drilling investigation of the site will be required to the south, in the area where the ridge rises away from the dam.

Borehole, DDH9 has been drilled in Quarry Site B. Moderately weathered rock was encountered to 4.4m depth. Below that depth, differentially weathered rock (moderately/slightly weathered and fresh, (stained)) was recovered to 25.64m depth. The interval contained approximately 50% fresh (stained) tuffaceous sandstone and may be suitable for use as embankment rockfill. Below 25.64m (to the termination of the borehole at 60m depth) fresh, (stained) tuffaceous sandstone with a strong/very strong rock substance strength was encountered.

Due to access problems with steep topography, the drilling program at Quarry Site B was curtailed. Further work at the site is required, following significant upgrading of the access track.

Petrographic analyses indicate that the tuffaceous sandstone from Chichester Dam and Tillegra are similar. The Chichester sandstone provided good quality concrete aggregate for the construction of Chichester Dam.

Drill core from borehole DDH9 and gravel from the Williams River have been tested for their suitability as concrete aggregate. A summary of results is presented in **Table 3**.

Table 3

Concrete Aggregate Test Results

Test	Core (DDH9)	River Gravels
Aggregate Crushing Value	11.0%	8.7%
Los Angeles Value	15%	10%
Sodium Sulphate Soundness	Nil to 0.2% loss	Nil to 0.2% loss
Unconfined Compressive Strength	66.9MPa to 144.6MPA	NA
Accelerated Mortar Bar Test	0.23% after 21 days	0.07% after 21 days

Aggregate Crushing and Los Angeles Values are well within the recommended test limits of 25% and 30%, respectively. Negligible losses were recorded in the accelerated weathering test (Sodium Sulphate Soundness) In the Accelerated Mortar Bar Test, the drill core sample showed potential for mild/slow aggregate alkali reactivity. The river gravels were non reactive. Rock substance strength ranges from strong to very strong.

Fresh tuffaceous sandstone and the river gravels available from the Williams River are expected to be suitable for use as concrete aggregate.

12 CONCLUSIONS

The concept design stage investigations have found no geological impediment to the proposed construction of the dam. Conditions are considered favourable relative to many other dam sites that have been successfully developed.

Further geological investigation will be undertaken as planned to confirm the geological model of the site and determine the foundation conditions for specific structures.

JF Young,

Senior Geologist.

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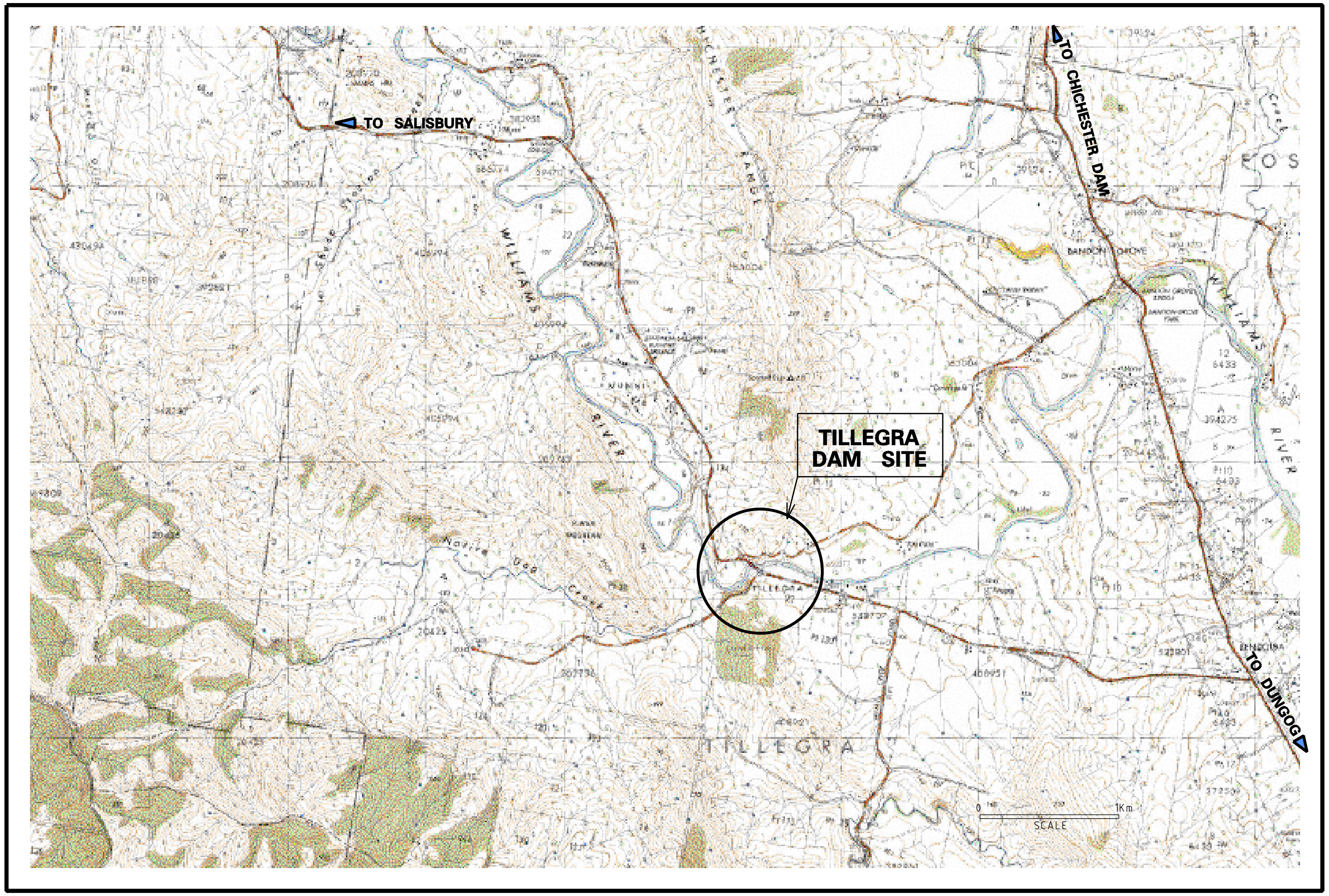
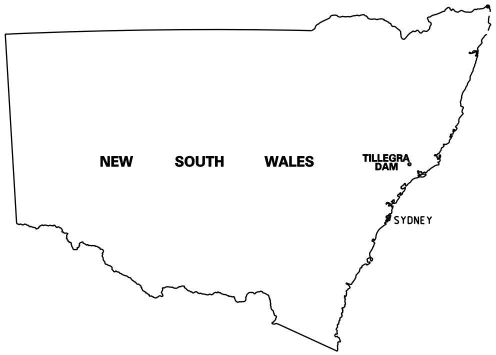
FIGURES





TILLEGRA DAM IS LOCATED APPROXIMATELY 230 Km NORTH OF SYDNEY

DETAILS OF AMENDMENTS	APPROVED	DATE

JOHN LEE
Director General – NSW Department of Commerce

NEW SOUTH WALES WATER SOLUTIONS
WATER TECHNOLOGIES
LEVEL 13, McKELL BUILDING
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PHONE (02) 93727873 FAX (02) 93727877

GEOTECHNICAL AND ENVIRONMENTAL

PROJECT ENGINEER
SUPERVISOR
DRAFTED J.D.EDWARDS
CHECKED
APRIL 2008

NSW Department of Commerce

TILLEGRA DAM
Site Location Plan

FILE No. GN31A
FIGURE No. 1

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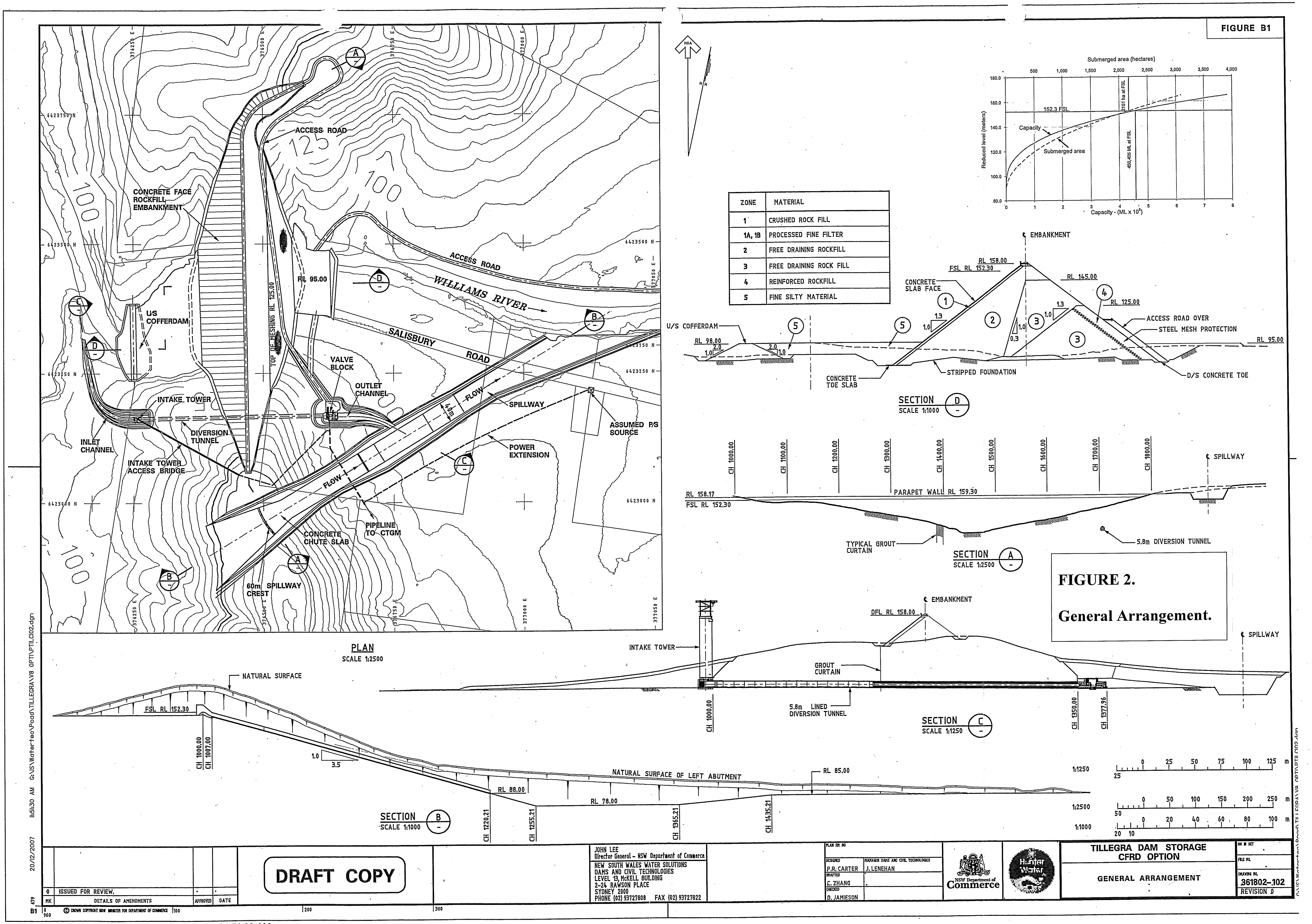
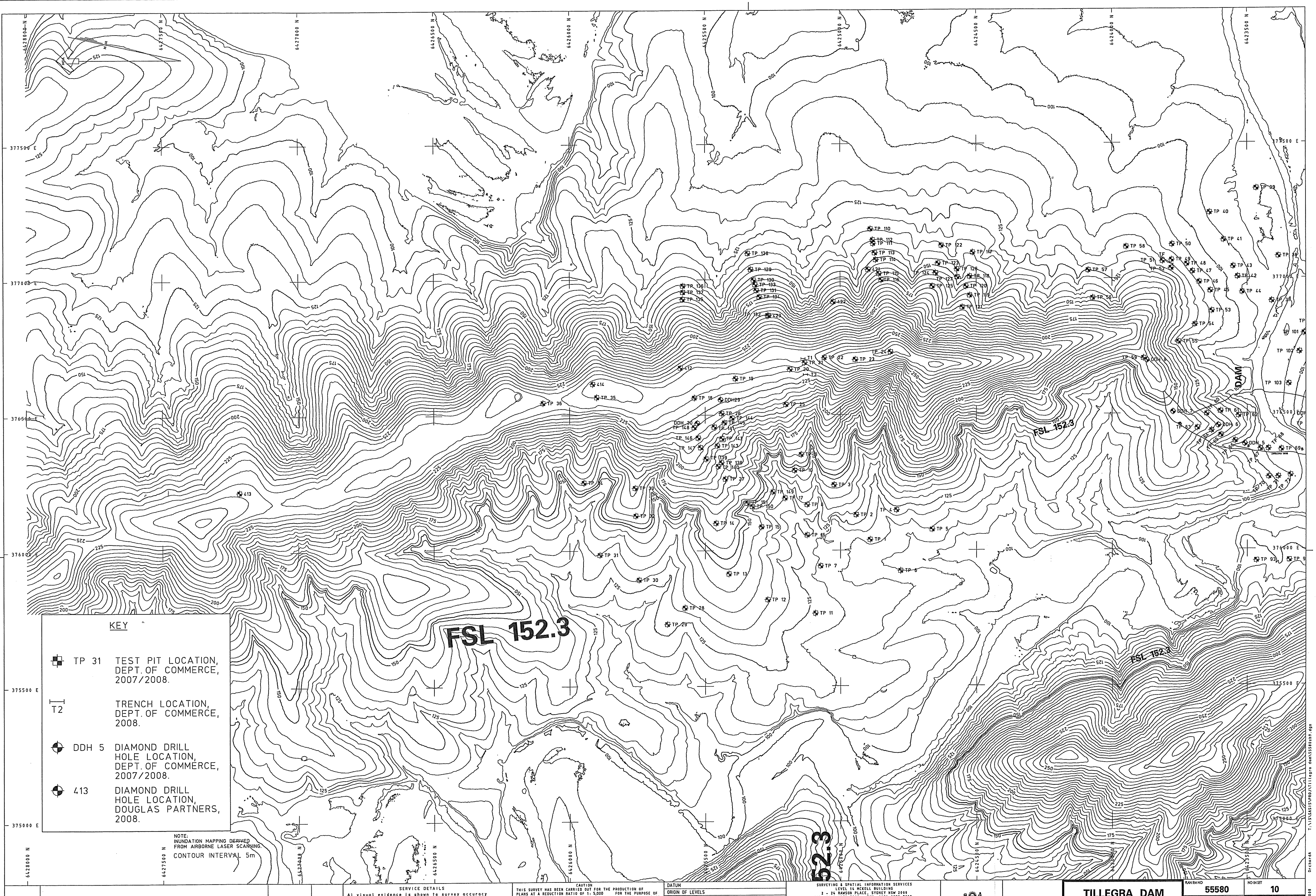


ZONE	MATERIAL
1	CRUSHED ROCK FILL
1A, 1B	PROCESSED FINE FILTER
2	FREE DRAINING ROCKFILL
3	FREE DRAINING ROCK FILL
4	REINFORCED ROCKFILL
5	FINE SILTY MATERIAL

FIGURE 2.

General Arrangement.



KEY

TP 31	TEST PIT LOCATION, DEPT. OF COMMERCE, 2007/2008.
T2	TRENCH LOCATION, DEPT. OF COMMERCE, 2008.
DDH 5	DIAMOND DRILL HOLE LOCATION, DEPT. OF COMMERCE, 2007/2008.
413	DIAMOND DRILL HOLE LOCATION, DOUGLAS PARTNERS, 2008.

NOTE:
INUNDATION MAPPING DERIVED FROM AIRBORNE LASER SCANNING.
CONTOUR INTERVAL 5m

MK	DETAILS OF AMENDMENTS	APPROVED	DATE

SERVICE DETAILS
A) visual evidence is shown to survey accuracy
B) inverts & diameters are shown where reasonable access was obtained
C) direction of services shown have been derived from visual evidence and when in agreement with Service Authority WAE drawings
D) direction of services NOT SHOWN is due to an uncertainty when comparing visual location with service diagrams
E) service details should be confirmed with the relevant Service Authorities during design and prior to construction

CAUTION
THIS SURVEY HAS BEEN CARRIED OUT FOR THE PRODUCTION OF PLANS AT A REDUCTION RATIO OF 1: 5,000 FOR THE PURPOSE OF DESIGN AND SHOULD NOT BE USED FOR ANY OTHER PURPOSE. DISTANCES SCALED MAY BE INACCURATE

0 50 100 200 300 400 500
REDUCTION RATIO 1:5000 METRES

DATUM
ORIGIN OF LEVELS
AZIMUTH
FOLDER LB FB
L.G.A.
SURVEYOR
SURVEY DATE FILE
CADD

SURVEYING & SPATIAL INFORMATION SERVICES
LEVEL 14 MCKELL BUILDING
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TEL: (02) 9372 7903 FAX: (02) 9372 7922

VERIFIED
VALIDATED
APPROVED MANAGER

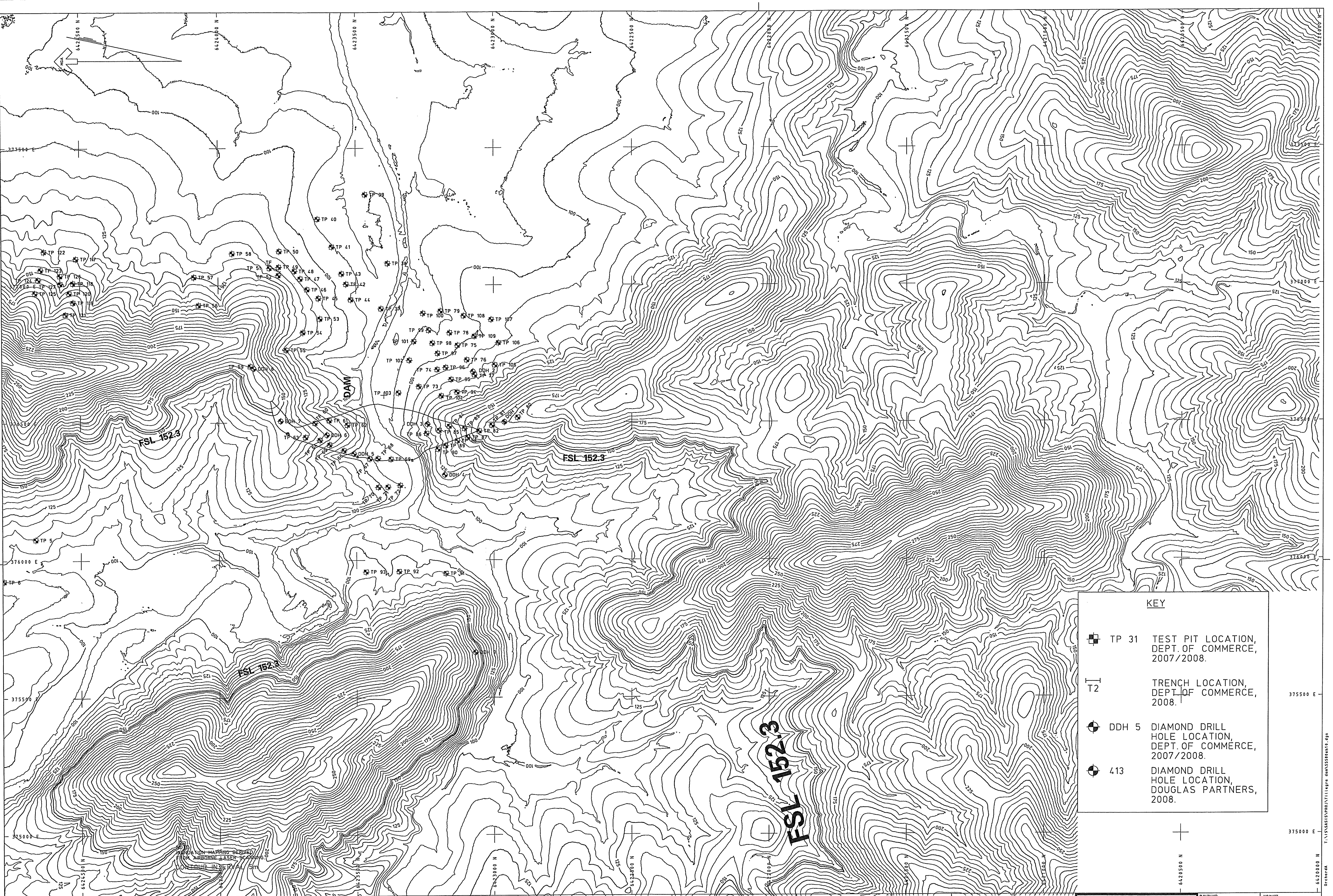
NSW Department of Commerce

TILLEGRA DAM

LOCATIONS OF INVESTIGATIONS

PLAN RM NO	NO IN SET
55580	10
SCALES	SHEET NO
1:5,000	3A
DESIGNED	DATE
DRAFTED	VERIFIED

T:\ISSAS\SSVPROJ\Tillegra dam\55580sh9.dgn 12:23:25 PM6/11/2008 OrchardA



MK	DETAILS OF AMENDMENTS	APPROVED	DATE

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A) visual evidence is shown to survey accuracy
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0 50 100 200 300 400 500

REDUCTION RATIO 1:5000 METRES

DATUM		
ORIGIN OF LEVELS		
AZIMUTH		
FOLDER	LB	FB
L.G.A.		
SURVEYOR		
SURVEY DATE	FILE	
CADD		

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NSW Department of Commerce

TILLEGRA DAM

LOCATIONS OF INVESTIGATIONS

PLAN RM NO	55580	NO IN SET	10
SCALES	1:5,000	SHEET NO	3B
DESIGNED	DATE		
DRAFTED	VERIFIED		

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APPENDIX AI

Definitions of Terms

DEFINITIONS OF ENGINEERING GEOLOGICAL TERMS

This classification system provides a standard terminology for the engineering description of rock.

DEGREE OF WEATHERING

TERM	SYMBOL	DEFINITION
Residual Soil	RS	Rock is converted to soil. The mass structure and material fabric are destroyed. There is a large change in volume, but the soil has not been significantly transported.
Extremely Weathered	EW	Rock substance affected by weathering to the extent that the rock exhibits soil properties - i.e. it can be remoulded and can be classified according to the Unified Classification System, but the texture of the original rock is still evident.
Highly Weathered	HW	Rock substance affected by weathering to the extent that limonite staining or bleaching affects the whole of the rock substance, and other signs of chemical or physical decomposition are evident. Porosity and strength may be increased or decreased compared to the fresh rock, usually as a result of iron bleaching or deposition. The colour and strength of the original substance is no longer recognisable.
Moderately Weathered	MW	Rock substance affected by weathering to the extent that staining extends throughout the whole of the rock substance, and the original colour of the fresh rock is no longer recognisable.
Slightly Weathered	SW	Rock substance affected by weathering to the extent that partial staining or discolouration of the rock substance, usually by limonite has taken place. The colour and texture of the fresh rock is recognisable.
Fresh (stained)	F_S	Rock substance unaffected by weathering. Weathering is limited to the surface of major discontinuities, for example an iron-stained joint.
Fresh	F	Rock substance unaffected by weathering.

ROCK STRENGTH

Rock strength is defined by the Point Load Strength Index (Is (50)), and refers to the strength of the rock substance in the direction normal to the bedding.

TERM	Is (50)	FIELD GUIDE	APPROX. qu MPa *
Extremely Weak (EW)		Easily remoulded by hand to a material with soil properties.	
	0.03		0.7
Very weak (VW)		May be crumbled in the hand. Sandstone is "sugary" and friable.	
	0.1		2.4
Weak (W)		A piece of core 150mm long x 50mm dia. may be broken by hand and easily scored with a knife. Sharp edges of core may be friable and break during handling.	
	0.3		7
Medium Strong (MS)		A piece of core 150mm long x 50mm dia. may be broken by hand with considerable difficulty. Readily scored with a knife.	
	1		24
Strong (S)		A piece of core 150mm long x 50mm dia. cannot be broken by unaided hands, may be slightly scratched or scored with knife.	
	3		70
Very Strong (VS)		A piece of core 150mm long x 50mm dia. may be broken readily with hand held hammer. Cannot be scratched with pen knife.	
	10		240
Extremely Strong (ES)		A piece of core 150mm long x 50mm dia. is difficult to break with hand held hammer. Rings when struck with hammer.	

* The approximate unconfined compressive strength (qu) shown in the table is based on an assumed ratio to the point load index of 24:1. This ratio may vary widely and should be calibrated on site.

STRATIFICATION SPACING

TERM	SEPARATION OF STRATIFICATION PLANES
Thinly laminated	< 6mm
Laminated	6mm - 20mm
Very thinly bedded	20mm - 60mm
Thinly bedded	60mm - 200mm
Medium bedded	200mm - 600mm
Thickly bedded	600mm - 2m
Very thickly bedded	> 2m

DISCONTINUITY SPACING

TERM	SPACING
Very widely spaced	> 2m
Widely spaced	600mm - 2m
Moderately widely spaced	200mm 600mm
Closely spaced	60mm - 200mm
Very closely spaced	20mm - 60mm
Extremely closely spaced	< 20mm

APERTURE OF DISCONTINUITY SPACING

The degree to which a discontinuity is open, or to which the faces of the discontinuity have been separated and the space subsequently infilled (such as in a vein, fault or joint).

TERM	APERTURE THICKNESS (Discontinuities, veins, faults, joints)
Wide	> 200mm
Moderately wide	60mm - 200mm
Moderately narrow	20mm - 60mm
Narrow	6mm - 20mm
Very narrow	2mm - 6mm
Extremely narrow	> 0 - 2 mm
Tight	Zero

BLOCK SIZE AND SHAPE

The following descriptive terms define shape:

Blocky	- approximately equidimensional.
Tabular	- one dimension considerably shorter than the other two.
Columnar	- one dimension considerably larger than the other two.

Block sizes are defined by the following descriptive terms:

TERM	BLOCK SIZE	EQUIVALENT DISCONTINUITY SPACINGS IN BLOCKY ROCK
Very large	> $8m^3$	Extremely wide
Large	> $0.2m^3$ - $8m^3$	Very wide
Medium	> $0.008m^3$ - $0.2m^3$	Wide
Small	> $0.0002m^3$ - $0.008m^3$	Moderately wide
Very small	$\leq 0.0002m^3$	Less than moderately wide

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