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HUNTER WATER

Hunter Water Corporation

TILLEGRA DAM DESIGN - CONSULTANCY 361802

Storage Rim Stability and Seepage Potential
Engineering Geotechnical Report

VOLUME I

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Executive Summary

Hunter Water plans to augment its current water supply with the construction of a 450,000ML on-river storage, known as Tillegra Dam, on the Williams River.

This report describes the geology and assesses the potential influence of geological features and land sliding on the stability and watertightness of the storage rim. It is based on extensive field investigations and the outcomes of landslide risk assessment studies.

Key issues covered by this report include:

- The potential for a large scale failure of the eastern ridge system and the influence of existing faults.
- Identification and characterisation of pre-existing landslides that could affect the integrity of the reservoir and/or dam safety.
- The potential for re-mobilisation of pre-existing landslides and assessment of their impact on dam safety.
- Consideration of viable first-time (new) slides and their potential impact on reservoir integrity and/ or dam safety.
- The potential for leakage from the storage.

The dam site itself (including the embankment footprint, left and right abutments, spillway, diversion and outlet works etc.), together with the extension of the left abutment, are being investigated in detail as part of the final design stage of investigation and are not covered in this report.

Geology

Figure 1 shows the area of investigation. It extends along the Chichester Range up to 4 km north of the dam site and approximately 2kms west in the Native Dog Creek section of the storage to include two (2) saddles, which represent the lowest points in the storage rim. The areas outside the main study area have been screened out as part of the landslide risk assessment process as geotechnical conditions in those areas are not conducive to large scale instability.

The dam site and immediate environs has been divided into nine geological domains, based on geomorphology, bedding orientation and interpreted faulting. The storage rim geology is described in detail and interpreted in Sections 3 and 4, and in Figures 2A/2B to 13. The relevant investigation data are presented in the appendices at Volumes II and III of the report. A geological field map is presented in Drawings B2A and B2B, Appendix B.

The Tillegra fault has now been accurately mapped. It extends from the Myall Creek area, past the dam site (500m downstream), to 2.6km north of the Williams River. The fault is aligned along the eastern toe of the Chichester Range and dips at shallow to moderate angles to the east, away from the dam site and the Chichester Range. The investigations have shown that it is located on the eastern side of the

Chichester Range. It projects above the ridge crest and cannot provide a failure surface for large scale instability affecting the storage rim.

Several faults have been identified in the valley floor, including the Native Dog Creek arm of the storage. The Brownmore Fault passes through the storage rim at Saddle B in a direction normal to the axis of the saddle. Given its orientation and steeply dipping attitude, it does not present a potential stability problem.

The faults identified are not features that affect either storage rim stability or dam safety.

A report on the geotechnical characterisation and assessment of pre-existing landslides and potential first-time slides has been prepared (PSM 2009) and this is provided as Volume IV.

A report describing the methodology, results and conclusions of the landslide risk assessment has been prepared (URS 2009) and this is provided as Volume V.

Landslides are relatively uncommon in the Tillegra Dam storage area. However, several areas of local instability have been identified in the study area along the Chichester Range. These include:

- Small slides in soil/ weathered rock on the inside of the storage rim in Domain 1A.
- A medium scale landslide in Domain 2 designated “Landslide 2A”.
- A small area of shallow soil creep in Domain 8A.
- Small surficial slides on the eastern side of the Chichester Range; i.e. on the outside of the storage rim.

Mobilisation of Existing Landslides

Slide 2A is a medium size landslide associated with bedding, 360m long by 160m wide by 6.5m average depth. It was included in the quantitative risk assessment given its relatively large size and proximity to the reservoir rim. The smaller slides were screened from the risk assessment study as being too small to affect reservoir rim stability or dam safety.

The results of stability analyses indicate that that with a fully saturated slope, the factor of safety for the existing Slide 2A approaches 1.0. This indicates that the slide is likely to re-activate when it becomes saturated by heavy rainfall as appears to happen at present. Re-activation of the slide is likely to be slow and intermittent in nature and can occur whether or not the slide is inundated by the reservoir. For the purposes of the risk assessment, allowance was made for the possibility that the slide could mobilise en-mass and that the failure would be rapid.

Potential for a Large Scale Failure of Storage Rim

The Eastern Ridge comprises a “tight” (low permeability) rock mass, with shallow depths of weathering and shallow groundwater levels. No credible mechanisms were identified that could result in large scale landslides of the eastern ridge system and loss of storage. Stability analyses for hypothetical large outer rim slides through Domain 1 indicated stable conditions.

Potential for Other First-time Sliding (Area 5A)

The only area identified with potential for first time sliding into the reservoir is Area 5A, situated on the western slopes of the Chichester Range about 600m upstream of the dam, where the dip of bedding is parallel to the natural slope. Area 5A is currently stable with no indication of past failure. A mechanism for toe breakout across bedding is required to cause a slope failure. Field mapping of the area indicates massive sandstone beds with no evidence of meta-shale layers. The area is limited in size and restrained by side ridges to the north and south controlling the gully complex below the feature.

Stability analyses of potential Slide 5A indicate that sliding is very unlikely, even in the event of a large earthquake.

Risk Analysis

A quantitative risk analysis method was used to assess the risk of landslide events causing failure of the dam or storage rim. The analysis considered all existing slides and the potential for first time slides. The following scenarios were selected for evaluating risks:

- Large scale first time landsliding of the Chichester Range leading to uncontrolled release of the storage.
- Rapid failure of Slide 2A leading to the formation of a wave in the storage and overtopping failure of the dam structure.
- Rapid failure of Slide 5A leading to the formation of a wave in the storage and overtopping failure of the dam structure.

In all cases the risk of dam or reservoir rim failure was negligible.

The risks resulting from the landslide hazard are significantly lower than the acceptable levels under the NSW Dams Safety Committee and ANCOLD risk guidelines for new dams for both individual and societal risk. The very low probabilities of dam failure and loss of storage are consistent with the normal design objective of new large dams to safely handle extremely rare loading events such as extreme floods and earthquakes.

Rim Stability – Conclusion

It is concluded that engineering works are not required to stabilise the storage perimeter surrounding the Tillegra Dam site.

Seepage Potential

The geotechnical investigations for the storage rim area along the Chichester Range confirm a typically tight rock mass, with shallow depths of weathering and groundwater levels relatively close to the surface.

Away from the dam site and the saddle areas, the storage rim topography rises significantly to in excess of RL200m. The full supply level lies well below the natural water table in these areas and there is no potential for leakage from the storage to the adjacent valley.

In the extended left and right abutments at the dam site, the full supply level will lie above the natural water table. Grouting to a tight basement using conventional techniques will be required in these areas to form a low permeability barrier to flow through open defects above the water table. Similar conditions remain a possibility in Saddles A and B. The leakage potential in these areas is being investigated as part of the design phase investigations for the dam site.

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VOLUME V

URS Australia (URS 2009), Tillegra Dam – Storage Rim Landslide Risk Assessment, Report 43167549, Final Report V6.0, February 2009.

1 Introduction

1.1 General

Hunter Water plans to augment its current water supply system with the construction of a 450,000ML on-river storage, known as Tillegra Dam, on the Williams River. The proposed Tillegra Dam site is located approximately 12km upstream of the township of Dungog and 3½km upstream from the confluence with the Chichester River.

A concrete faced rockfill design has been adopted for the dam. The embankment will have a parapet crest level of RL160.2m, with a full supply level (FSL) of RL152.3m. 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 Department of Commerce has recently completed option/concept phase geological investigations. The main strands of the investigations were:

- Investigations at the dam site, including the embankment, spillway options and diversion.
- Investigations relating to the rim of the storage, including fault systems and pre-existing landslide features that may affect the storage.
- Assessing potential sources of construction materials, in particular identifying quarry areas for the production of rockfill and concrete aggregate.

1.2 Scope of this Report

This report presents the interpretation of geology and the potential influence of geological features and land sliding on the stability and watertightness of the storage rim. It is based on extensive field investigations and the outcomes of landslide risk assessment studies. It addresses the following specific issues:

- The influence of faulting, bedding surface shears and joint defects on reservoir rim stability and leakage potential.
- The potential for large scale landslides within the eastern ridge system and consequent loss of storage.
- Identification and characterisation of pre-existing landslides that could affect the integrity of the reservoir and/or dam safety.
- The potential for re-mobilisation of pre-existing landslides and assessment of their impact on dam safety.
- Consideration of viable first-time (new) slides and their potential impact on reservoir integrity and/ or dam safety.
- The potential for leakage from the storage.

The study area is shown in **Figure 1**. The investigated area extends along the Chichester Range, up to 4 km north of the dam site.

To the south and west of the dam site, a broad, complex ridge system occurs. In the Native Dog Creek portion of the storage, the area of investigation extends approximately 2km west to include two (2) saddles (designated Saddles A and B, **Figure 2B**), which represent the lowest points in the storage rim.

The project study area has been divided into nine geological domains. A domain in this context is defined to be an area with uniform geological structure and geomorphologic characteristics. The domain boundaries are defined by a significant change in structure, including fault lineaments. The storage rim geology and interpreted geological domains are described in Section 4. Their locations are shown in **Figures 2A and 2B**.

The dam site itself (including the embankment footprint, left and right abutments, spillway, diversion and outlet works etc.), together with the extension of the left abutment, are being investigated in detail as part of the final design stage of investigation and are not covered by this report.

The field data and the interpretations documented in this report have been independently reviewed by a panel of independent experts retained for the project by Hunter Water Corporation.

2 Site Investigations

2.1 Previous Work

Two (2) preliminary phases of investigation that have been previously undertaken were targeted specifically at the dam site. Data from these studies that is relevant to the storage rim stability evaluation has been incorporated in the current assessment.

The investigations included:

- Hall, L.R., 1952. A regional survey of the area was undertaken by the Geological Survey of New South Wales (on behalf of Hunter Water Board).
- 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, upstream of the embankment centreline, and the lower left abutment.
- Snowy Mountains Engineering Authority (SMEC), 1970. Investigation included additional mapping, a seismic traverse along the river bed upstream of the embankment centreline and inclined diamond cored boreholes across the valley floor.

In addition, Douglas Partners (2007) completed an air photograph interpretation of the proposed site and surrounding region, including the storage area and perimeter,

The NSW Department of Commerce was engaged by Hunter Water Corporation in June 2007 to undertake further extensive geotechnical investigations and to design the dam, appurtenant structures and any necessary leakage controls and stabilisation works. Geological, geotechnical and seismological investigations were to supplement previous investigations, identify the need for any seepage controls or stabilisation works and provide the necessary parameters for the design.

2.2 Current Investigations

2.2.1 General

The recently completed concept design stage field investigations were aimed at assessing the geological conditions of the dam site and storage, in particular the stability of the storage rim and the potential for leakage. The investigations relevant to the storage rim include:

- Geological mapping of the dam site and part of the storage perimeter.
- Test pit investigation, including the storage/storage perimeter and dam site. One hundred and thirty seven (137) test pits, TP1 to TP137, were excavated. The investigation has included a concentration of test pits excavated in the dam site area to assess the embankment foundation conditions and spillway options. The specific data from the dam site has been considered during development of the geological model presented in this report.

- Diamond drilling investigation of the dam site and potential Quarry Area B, located in the ridge system immediately upstream of the embankment site (known as Elwari Mountain). A total of nine boreholes were drilled. Where appropriate, the boreholes were water pressure tested nominally at 3m stages. The water pressure test data has been used as background data in the assessment of reservoir leakage potential. Standpipe piezometers were installed in boreholes to allow ongoing monitoring of the water table.
- Investigation trenching to confirm the location and nature of possible faults.

The relevant geological mapping, test pit logs, trench logs and engineering geological borehole logs are presented in Volumes II and III of this report.

2.2.2 Investigations for Landslide Risk Assessment

Several areas of local instability have been identified along the Chichester Range. In particular, a medium size landslide of approximate surface dimensions 350m long by 160m wide has been identified in Domain 2. This feature was designated as "Landslide 2A". Sections 4.3.2 and 6.3 discuss it in more detail.

The following additional site investigations were carried out to confirm the interpreted geotechnical model in the study area and conditions in areas of local instability, and to provide input data to a systematic assessment of the landslide risks:

- Additional mapping of exposure and test pits on the eastern and western flanks of the Chichester range confining ridge, north of the Spotted Gum Trig Station to confirm lithology and structure to the vicinity of grid line 6427500N.
- Integrating the field results carried out by Douglas and Partners (for the Salisbury Road deviation along the Chichester Range) into the geological model.
- Geomorphologic and conventional field mapping of Area 8A (an area of apparent shallow instability) on the eastern side of Elwari Mountain.
- Geomorphologic mapping of Landslide 2A and surrounds to form a basis for assessing the extent of sliding, state of activity and slide mechanics of the feature.
- Test pit investigation in Landslide 2A aimed at defining lithology, bedding dip, the extent of the slide and for assessing the mechanics of the failure and activity. A total of fourteen (14) test pits, TP138 to TP151, were excavated.
- A seismic refraction survey through the slide long section to determine the depth and extent of disturbed material, and the extent of stress relief effects up-slope of the main body of the slide.
- Diamond drilling of the slope above Slide 2A. Two (2) boreholes, DDH29 and DDH30, were drilled. The boreholes were water pressure tested nominally at 3m intervals. Standpipe piezometers were installed to allow ongoing monitoring of the water table.
- Laboratory testing of clay samples retained from test pits in Landslide 2A.

The areas of local instability in the study area were inspected by landslide specialist Mr Tim Sullivan, an Adjunct Professor of the University of NSW and Principal of Pells Sullivan Meynink Pty. Ltd (PSM). Mr Sullivan was also present during the excavation of test pits in Landslide 2A. A report on the geotechnical characterisation of pre-existing landslides and potential first-time slides has been prepared by PSM and this is provided as Volume IV**.**

The above investigations have been used as input to the landslide geotechnical appraisal and risk assessment discussed in more detail in Section 6 and Volumes IV and V of the report.

3 Geological Setting

3.1 Regional Geology

The Dungog area is located 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 is within the Gresford Block (Roberts, 1991).

A sequence of sedimentary rocks belonging to the Flagstaff Formation occurs 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.

Rocks at the site have been subjected to low grade regional metamorphism. Sandstones comprise a high proportion of intermediate to felsic lithic fragments and have been termed ‘tuffaceous sandstone’ in the field investigations. Mudstones (or shales) are argillitic in nature and are termed ‘meta-shale’.

Structurally, a series of continuous north/south faults trend through 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 (refer Plate 3-1). Deformation is interpreted to have occurred during the Permian period, some 250 million years ago.

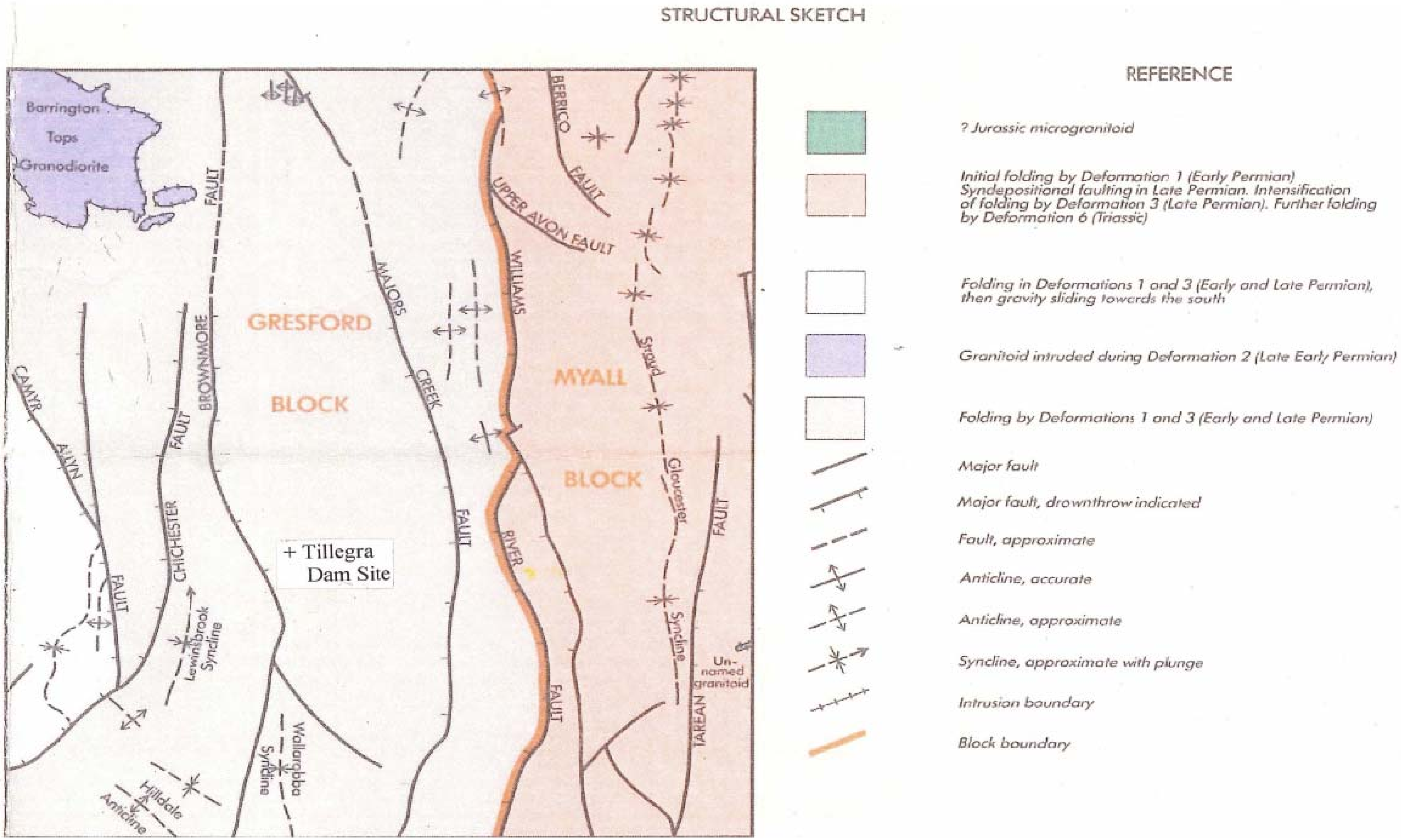

Plate 3-1 - Regional geology (after Roberts, 1991)

3.2 Local Faults

3.2.1 General

In addition to regional-scale faults, less continuous faults occur in the vicinity of the proposed dam site. A number of linear features have been identified, with dominant north/south and east/west trends (Douglas Partners 2007). They are interpreted to be associated with regional folding, strike of bedding and faulting. Those features potentially affecting the storage rim have been considered in the current investigation.

3.2.2 Tillegra Fault

The location of the Tillegra Fault has been the subject of considerable debate leading to speculation about its potential significance as a control on large scale slope instability that could affect the Chichester Range and the integrity of the dam storage. This section of the report examines the evidence for the fault location and characteristics.

Previous Interpretations

In 1952 the Hunter District Water Board requested the Geological Survey of New South Wales to complete a regional survey of the area in the vicinity of the Tillegra Dam Site. Hall (1952) placed the Tillegra fault approximately 600m downstream of the proposed dam site, at the toe of the Chichester Range. His work included mapping and a bulldozer trench in the Myall Creek area, to the south of the dam site. Hall interpreted the fault to be a low angle thrust, dipping to the east. He reported a 2.4m thick clayey zone associated with the fault itself.

Hall mapped the fault along the toe of the Chichester Range to the north of the Williams River for a distance of approximately 2¾ km, where the trace of the fault was lost (Plate 3-2).

On the 1:100,000 Geological Sheet of the area (Roberts, 1991), the Tillegra Fault is shown crossing the top of the ridge forming the Chichester Range, through a saddle in the area of the Spotted Gum Trig Station, 1½ km north of the Williams River. The fault lineament is then interpreted to continue to the north along the ridge, on the western edge of the ridge top, parallel to the contours.

The basis for this interpretation appears to be a break in slope approximately 250m north of the trig station. At this distinct break in slope the top of the ridge broadens and flattens. The lineament interpreted to be the Tillegra Fault is immediately down the slope on the western side of the ridge.

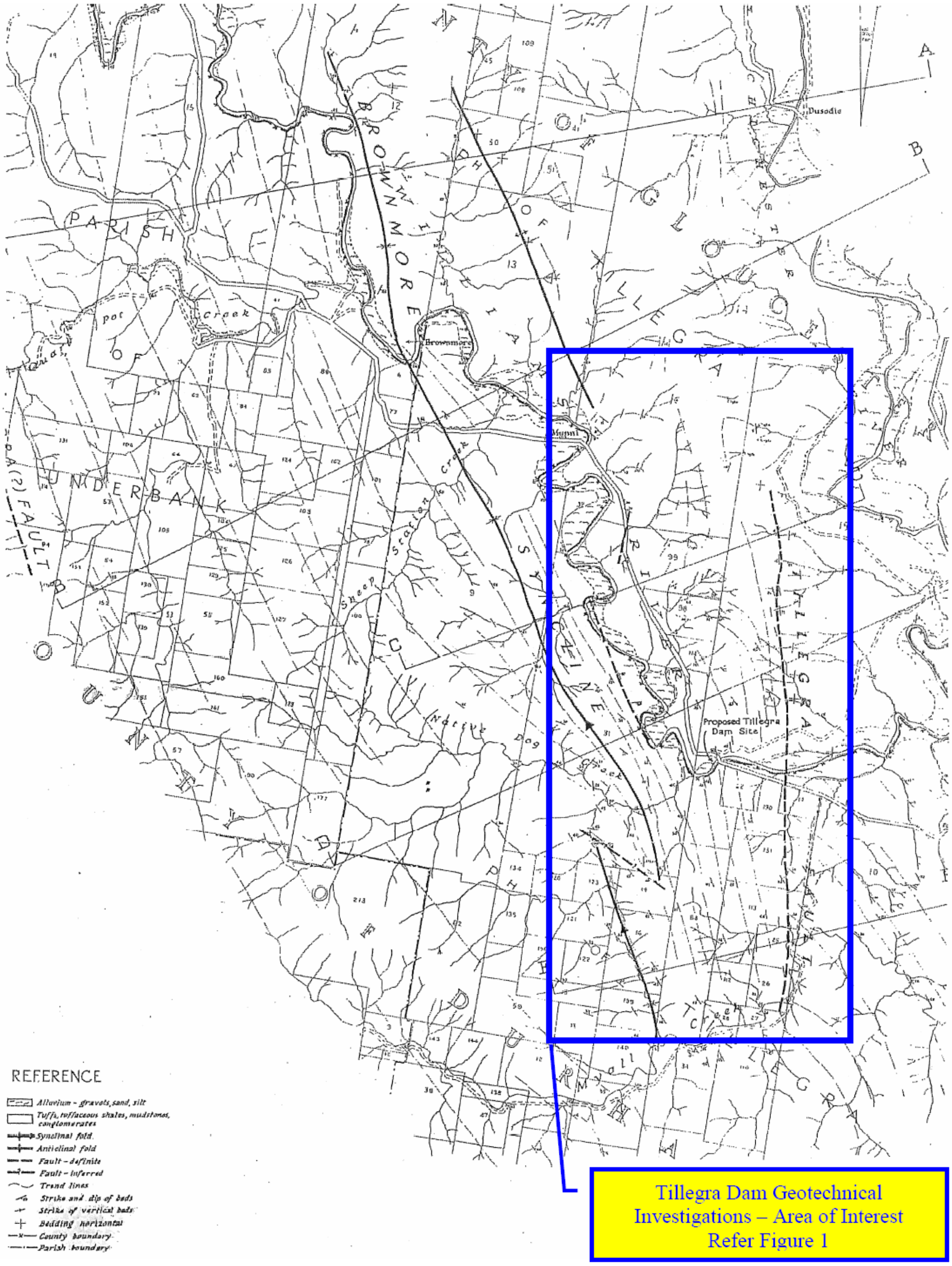

Plate 3-2 - Regional Geology Plan by Hall (1952)

New Investigations

During the current investigations, the location of the fault was initially confirmed by geological mapping and test pits (October 2007) in the following areas:

- Williams River. Variation in the dip of bedding exposed in outcrop on the right bank of the river, approximately 450m downstream of the dam site. Downstream of the fault lineament, the bedding dips shallowly to the southeast at 22º to 25º.
- Lowrey's property. Three test pits were excavated across the fault lineament. Bedding dips moderately (40º to 43º) to the west/southwest on the western (upslope) side of the fault and shallowly at 13º to the southeast on the eastern (downslope) side of the fault.
- Myall Creek. Variation in dip exposed in Myall Creek and adjacent road cuttings. Bedding dips steeply to the west/southwest (62º) on the western (upslope) side of the fault and shallowly to the north at 13º on the eastern (downslope) side of the fault.

In January 2008, a 52m long trench was excavated across the fault trace. The location of the trench (TF) is shown on Drawings B1A and B1B, Appendix B; and a geological log of trench with a photographic record is presented in Appendix C.

The fault plane was exposed midway along the length of the trench. The following features were noted:

- Downstream of the fault, bedding dips moderately at 30º to 33º to the east (in direction 060º to 072ºM), steepening to 44º to 48º close to the fault (refer to Plates TF12 to TF14). Further to the east (downstream), bedding exposed in meta-shales around a small farm dam dip shallowly at 8º to the east.
- It is interpreted that the fault trace has been the focus of erosion, resulting in a V-shaped profile in the trench. The erosion feature has been subsequently in-filled with slope wash, comprising angular meta-sedimentary gravel in a clayey sand matrix. The deposit includes ferruginized sandy gravel lenses (refer to Plate TF11).
- A general view of the fault plane dipping into the floor of the trench from the upstream end is shown in Plates TF3 and TF4. The fault plane dips shallowly to the east (downstream) at 30º to 35º, in direction 073º to 075ºM (refer to Plates TF6 and TF7). A narrow shear zone, up to 300mm wide occurs parallel to the fault plane, on the downstream side (refer to Plates TF9 and TF10). A narrow clayey zone 50mm to 70mm thick immediately overlies the fault plane. A zone of brecciated meta-shale occurs above the fault plane towards the downstream end of the investigation trench (refer to Plate TF5).
- Immediately upstream of the fault trace, bedding exposed below the fault plane varies from vertical (striking east-west), to dipping steeply (53º) to the northwest (in direction 298ºM). Further upstream, the strike of bedding swings slightly to dip consistently very steeply to steeply to the west (70º to 50º progressively away from the fault.

Additional test pits were excavated in July 2008 along the eastern toe of the Chichester Range, to the north of the previous investigations. Logs of the test pits, TP110 to TP137, are presented in Appendix E. Their locations are shown on Drawing B1A, Appendix B.

The location of the fault was confirmed in the following areas:

- Between test pits TP126 and TP127. Bedding variation between the two (2) test pits varies from 30º to the southeast, in direction 058ºM, east or down slope of the fault (TP126), to 45º to the southwest, in direction 245ºM, to the west or up slope of the fault (TP127). Upslope of the fault, exposures along an existing farm track further up the slope (immediately below the Spotted Gum Trig. Station) confirmed bedding consistently dipping to the southwest.
- In the vicinity of test pit TP134. Bedding dips shallowly at 7º to the west, in direction 263ºM. The fault is interpreted to occur down slope, or to the east, of the test pit.
- The fault was exposed in TP137. A photographic record accompanies the log (refer Appendix E). The fault plane dips steeply to the east at approximately 60º and is characterised by a clayey crushed zone 300mm wide. To the west, or up slope of the fault, bedding dips at 30º to the southwest, in direction 240ºM. Down slope of the fault, bedding is indiscernible due to the extremely close defect spacing in the highly weathered meta-shale exposure.

Trenches were also undertaken to investigate the break in slope where Roberts (1991) inferred the fault to cross the Chichester Range. At this location there is a distinct lithologic boundary between meta-shale, in the higher area towards the trig station, and tuffaceous sandstone in the flat, broader area to the north. Two (2) investigation trenches, T1 and T2 were excavated across the interpreted lineament on the western slope of the ridge. The locations of the trenches are shown on Drawing B1A, Appendix B; and geological logs with a photographic record are presented in Appendix D.

In both trenches, the meta-shale was found to be in direct contact with the underlying tuffaceous sandstone (refer to Plates T1B, T1C and T2B, Appendix C). There was no indication of displacement between the two (2) rock types. The bedding orientation observed in the trenches, dipping 23º to 30º, in direction 224ºm to 250ºM, is consistent with bedding to the north and south. The trenches and other test pits in the area do not indicate the presence of a major fault.

Assessment

Based on all available information in the area of the proposed dam and storage area, the Tillegra fault is aligned along the eastern toe of the Chichester Range and dips at shallow to moderate angles to the east, away from the dam site and the Chichester Range. The investigations have shown that it is located on the eastern side of the Chichester Range. It projects above the ridge crest and cannot provide a failure surface for large scale instability affecting the storage rim.

It has been traced from the Myall Creek area, past the embankment site (500m downstream), to 2½km north of the Williams River. The current investigations have shown that it does not cross the Chichester Range as interpreted by Roberts (1991).

In the area north of the Williams River, the fault occurs along the eastern toe slopes of the Chichester Range. The fault dips to the east at a shallow angle in the Myall

Creek area and in the vicinity of the embankment site (that is, dipping downstream). To the north, the attitude of the fault is interpreted to steepen but it continues to dip to the east.

3.2.3 Other Faults

The regional geological survey of the area in the vicinity of the proposed dam by Hall (1952) identified several other minor faults within the proposed storage area. Douglas Partners (2007) air photograph interpretation of the proposed site and surrounding environs also identified several lineaments inferred to represent local faults.

Other faults delineated in the current interpretation include:

- The fault mapped by Hall (1952) in the valley floor, along the eastern toe of the Elwari Mountain ridge, designated Interpreted Fault 2. The location of this feature is shown on **Figures 2A, 2B and 13**. In the immediate vicinity of the fault it is characterised by opposing, very steep to near vertical bedding on either side of lineament. The fault is interpreted to be a very steep to near vertical feature (refer **Section EE', Figure 7**). Bedding dips shallowly to the southeast in the valley floor. On the adjacent eastern slopes of Elwari Mountain bedding dips moderately into the ridge (to the southwest).
- A low angle fault, designated Interpreted Fault 1, is located in the Williams River valley floor to the east of the Williams River, forming the boundary between Domains 2/4/5 and 3 (refer **Figures 2A, 2B and 13**). The fault is exposed in a small quarry east of Salisbury Road. Bedding in the floor of the quarry dips steeply at 65º to 68º, in direction 197ºM to 203ºM. The overlying sediments in the southern face of the quarry dip at 35º to 38º to the south. In the western face, the overlying sediments dip at 7º to 20º to the southeast (refer to Section BB', Figure 4). The fault is interpreted to dip shallowly to the west, into the valley, and to remain within the reservoir.
- A prominent linear feature passes through Saddle B, delineated by distinct straight gullies to the north and south (refer **Figures 2A and 2B**). The feature has also been identified by Douglas Partners (2007) and is interpreted to represent the Brownmore Fault (Roberts, 1991). The fault passes through the storage rim, normal to the axis of the saddle and is interpreted to be associated with a very steeply dipping to vertical joint set identified in the saddle area. The leakage potential of the saddle will be assessed at the final design stage of investigation.
- In the Native Dog Creek area (Domain 9), bedding is inconsistent with the adjacent Elwari Mountain ridge system to the north. Two (2) interpreted faults are interpreted to occur in the valley floor. The first, designated Interpreted Fault 3, controls the course of Native Dog Creek at the south-western corner of Elwari Mountain. The fault is interpreted to be associated with a major joint set dipping very steeply to the southwest. The second, designated Interpreted Fault 4, strikes across the toe of the ridge system forming the southern extension of Elwari Mountain. The two (2) features, in conjunction with the Brownmore Fault, form a triangular, fault defined block in the valley floor (refer **Figure 2B**).

The faults identified are not features that affect either storage rim stability or dam safety.

4 Storage Rim Geology

4.1 Extent of Investigations

The area of investigation extends to approximately 4km north of the dam site along the Chichester Range, to where the ridge system broadens. Towards the northern limit of the area of investigation, flow paths from the storage into the adjoining Chichester River valley to the east are in the order of 600m. At the northern limit, the storage ponds on the lower, flatter slopes of the ridge system.

To the south and west of the dam site, there is a broad, complex ridge system. The area of investigation extends approximately 2 km west to include two (2) saddles (designated Saddles A and B, **Figure 2B**) in the Native Dog Creek section of the storage. These saddles represent the lowest points in the storage rim. Further to the west, the storage level lowers onto flatter slopes and the flow paths into the adjoining Myall Creek catchment increase significantly.

4.2 Storage Area Geology

A geological field map is presented in Drawings B2A and B2B, Appendix B. The compilation is based on current mapping, test pits, trenching and borehole information.

4.2.1 Rock types

An interbedded sequence of tuffaceous sandstone, meta-shale and conglomerate occurs at the site. Tuffaceous sandstone varies from fine to coarse-grained and is the dominant rock type. Conglomerate occurs in the northern part of the Chichester Range.

Soils associated with the meta-sedimentary rocks are generally very thinly developed, often less than 1m thick.

Colluvial slope wash deposits commonly occur at the base of steep slopes, in particular at the toe of the ridge forming the right embankment abutment. Deposits up to a known maximum thickness of 15m have been encountered. Alluvium comprising clay/silt/sand/gravel admixtures are associated with the Williams River.

4.2.2 Rock Mass Characteristics

Tuffaceous sandstone outcrops are generally slightly weathered. Finer-grained rock types are not expressed at the surface. The conglomerates are highly weathered in exposures on the western slopes of the Chichester Range.

Three (3) characteristic zones of weathering have been recognised. A shallowly developed upper zone comprising soil, grading to highly weathered rock, generally occurs in the upper 2m. The surficial layer grades into a zone of differential weathering. This zone is interpreted to comprise moderately weathered to slightly weathered rock and generally extends to depths varying from 5m to 15m. Fresh rock is interpreted to occur below that depth.

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.

Two (2) dominant joint sets are present in the rock mass. One set strikes approximately parallel to the strike of bedding and dips normal to bedding. The second set is near vertical and is mutually perpendicular to bedding and the first joint set.

Narrow zones of shearing are occasionally associated with the second joint set, normal to the strike of bedding.

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

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.

4.2.3 Chichester Range - Interpreted Structure

The interpreted bedding orientation along the Chichester Range north from the dam site is shown in **Figure 13**. Bedding strikes approximately normal to the Williams River through the dam site and the southern part of the ridge and dips consistently to the southwest at 35º to 50º.

Approximately 1½km north of the river, the strike swings to the northwest/west, into the gully system above a small quarry off Salisbury Road. Dips steepen to typically 55º to 65º. The strike of the bedding controls the orientation of the gullies.

Further to the north, the dip flattens to 30º and the strike maintains an east-west orientation. Bedding is then essentially horizontal to the north. In the northern part of the area investigated, a slight geomorphic undulation is apparent along the broad ridge crest, indicating the shallow dip angles generally vary from west to east with progression north.

The variation in bedding dip and orientation is interpreted to be the result of folding. No faults are interpreted to cross the ridge system.

4.2.4 Groundwater Conditions

Standpipe piezometers were installed in boreholes to allow monitoring of the water table. Readings taken at the completion of the drilling program are presented in Table 4-1.

Table 4-1 - 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	RA 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) – water entering borehole via gravel layer		
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 (saddle)	165.6	36.92	32.16	133.4
DDH29	Landslide 2A	227.4	13.88	13.88	213.5
DDH30		221.6	5.84	5.84	215.8

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 in depth, respectively.

In the extended right and left abutments, which included the spillway alternatives, the water table is below the storage FSL at 152.3m. Similar conditions are expected in Saddle A and Saddle B, which form low points in the storage perimeter to the southwest of the dam.

The tight rock mass conditions encountered in the ridge system above Landslip 2A is reflected in the high water table. The water table has stabilised in the boreholes at depths ranging from 5.84m (RL215.6m) to 13.88m (RL213.5m), well above the FSL. A number of small farm dams have excavated into rock along the ridge crest in the area. The dams maintain a high water level, despite their negligible catchment, reflecting impermeable nature of the rock mass. Springs have also been noted high on the eastern slopes of the ridge, around approximate RL200m.

A summary of borehole water pressure test results is presented in Appendix G. Water pressure test results conducted in boreholes drilled to investigate the foundation conditions on the dam abutments, upstream portal area and the spillway crest, were generally low to moderate, occasionally ranging to high. Very high water losses were recorded in boreholes DDH3, located on the mid right abutment, and DDH8, located in the saddle immediately east of the left embankment.

Tight rock mass zones were encountered at depth in all the boreholes completed in the area of the proposed embankment.

Low water takes were recorded in water pressure tests in boreholes DDH29 and DDH30, located in the ridge system above Landslip 2A.

Away from the dam site and the saddle areas, the storage rim topography rises rapidly to in excess of RL200m. Considering the observed water table conditions, it is interpreted that the FSL is below the water table level in the more elevated parts of the ridge system.

Monitoring of the standpipe piezometers installed in all diamond boreholes will be ongoing.

4.3 Interpreted Geological Domains

In order to facilitate the assessment of storage rim stability, the dam site and immediate environs has been divided into geological domains, based on geomorphology, bedding orientation and interpreted faulting. The interpreted geological characteristics defining the domains are based on historical data, current geological mapping, test pit and diamond drilling investigations.

The extent of the domains defined in this report has been influenced by the diminishing storage height away from the dam site and the length of the potential flow paths through the containing ridge systems. The area of interest is shown in **Figure 1**.

Nine geological domains and four sub-domains have been identified and assessed. The locations of the domains are shown on **Figures 2A and 2B**. Typical sections are presented in **Figures 3 to 9** and the interpreted bedding strike orientation in **Figure 13**. A geological field map is presented in Appendix B (refer **Drawing B2A/B2B**).

It should be noted that the area immediately north of Domain 1, along the Chichester Range, has been designated Domain “0”. It is not included in the interpretative assessment below due to the broadening ridge system, associated extended flow paths and the diminishing storage depth. In addition, there are no pre-existing instability issues that could affect the integrity of the reservoir and/ or dam safety. Bedding in Domain “0” is interpreted to dip shallowly to the east.

4.3.1 Domain 1/ 1A

Domain 1 includes the northern extreme of investigation of the Chichester Range (see **Figure 2A**). The ridge system reaches a maximum height of approximately 240m. The FSL (152.3m) infringes only on the toe of the ridge within this Domain.

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The interpreted geological structure is shown in Sections AA' and DD' (refer **Figures 3 and 6**, respectively).

In this domain, a thin remnant of meta-shale occurs along the top of the Chichester Range; otherwise, the ridge is capped by shallowly dipping tuffaceous sandstone. The attitude of the bedding varies from 10º dip to the south/southeast, to 8º to 10º dip to the east on the eastern side of the ridge system (into the Chichester River valley). The capping tuffaceous sandstone sequence is estimated to be approximately 40m thick, overlying conglomerate and conglomeratic tuffaceous sandstone. Diamond boreholes completed by Douglas Partners as part of the Salisbury Road realignment, intercepted tuffaceous sandstone to the limit of drilling (RL233.6m) along the ridge crest (refer to boreholes 413 and 414, Appendix J). Bedding partings in the drill core dip at approximately 10º.

The conglomerate extends to just below FSL on the western side of the ridge (refer **Figure 3**). The conglomerates exposed on the western slope are highly weathered, with a very weak/weak matrix rock substance strength. The well rounded clasts range from gravel to boulder size.

Along the Chichester Range ridge line, the southern boundary of the domain is arbitrarily defined by consistent shallow dips to the south and southeast.

An interbedded sequence of tuffaceous sandstone, with meta-shale occurs in the western lower slopes of the ridge and the valley floor. Bedding generally dips shallowly, at 10º or less, in varying directions between northeast and southeast. The scatter of bedding measurements is interpreted to be due to bed undulations in the relatively flat lying beds.

In the northern part of the domain, minor landslips are present in the highly weathered conglomerates on the upper steep western slope of the Chichester Range. This area has been designated 1A (see **Figure 2A**). The landslips have shallow failure surfaces and occur at a level above the FSL

In the tuffaceous sandstone on the upper slopes of the ridge a major joint set strikes north-south, across bedding, forming low cliff lines up to 5m in height. Minor block type failures could be expected to occur, defined by bedding partings and the joint set normal to bedding orientation. The frequency of such failures is expected to be very low and failures will be limited in nature.

4.3.2 Domain 2/ 2A

Domain 2 is distinguished by an increase in dip into the gully system and a curve in strike to the northwest-southeast on the western slopes of the ridge system. The interpreted structure is shown in Sections AA', CC' and DD' (refer **Figures 3, 5 and 6**, respectively).

The Interpreted Fault 1, occurring in the valley floor and passing through the area of the quarry off Salisbury Road, forms the western boundary of the domain (see **Figure 2A**). Bedding in the quarry floor dips steeply at 65º to 68º, in direction 192ºM to 203ºM, which is consistent with the gully system in the ridge above (Domain 4). The overlying bedding, to the west of the fault, dips shallowly to the east at 10º to 20º in direction 112ºM to 115ºM, as exposed in the western face of the quarry (refer Section BB'). In the southern quarry face, the bedding dips moderately to the south, at 35º to 38º in direction 170ºM. The fault is interpreted to be a thrust fault, dipping shallowly to the west (towards the Williams River) and is expected to remain within the reservoir.

The Tillegra Fault on the lower eastern slopes of the Chichester Range defines the eastern boundary of the domain (see **Figure 2A**). The fault is interpreted to dip at moderate angles (up to 60º) to the east.

The southern domain boundary is defined by an increase in dip to the south (up to 30º, in direction 176ºM).

A landslide in the southwest corner of the domain has been designated Landslide 2A. A geomorphologic map of the landslide is presented in **Figure 11**. Test pits delineate the extent of the failure. Locations of the investigations are shown on **Figure 11** and test pit logs (TP138 to TP151) are presented in Appendix E. A shallow seismic refraction line (Seismic Line 9) has been shot along the length the failure. Results of the survey are presented in Appendix H.

Two (2) diamond boreholes, DDH29 and DDH30, were drilled above the landslide to assess the potential for propagation of the failure further up the slope towards the ridge crest. Detailed logs of the boreholes are presented in Appendix F. Consistently fresh tuffaceous sandstone was encountered at shallow depths in DDH29 and DDH30 (6.30m and 5.25m, respectively). Rock mass conditions are tight, with the water table recorded at 5.8m (DDH30) and 13.9m (DDH29) depth.

The landslide investigation has reported on separately by Pells Sullivan and Meynink (PSM 2009) and is presented as Volume IV. The landslide is interpreted to be a shallow feature associated with the bedding which dips shallowly at 15º to 20º to the southwest. The bedding orientation is roughly coincident with the natural surface slope, providing a mechanism for planar failure, but requiring a toe breakout mechanism.

It should be noted that the FSL will encroach on, and saturate the toe of the landslide. The slide is likely to reactivate when it becomes saturated by heavy rainfall as appears to happen at present. This can occur whether or not the slide is inundated by the reservoir.

4.3.3 Domain 3

Domain 3 occupies the valley floor area south of Domain 1 and will be completely inundated by the storage (see **Figure 2A**). Domain 3 is bounded to the east by the Interpreted Fault 1, passing through the small quarry off Salisbury Road, and to the west by Fault Lineament 2, along the eastern toe of the Elwari Mountain ridge. The interpreted structure is shown in Sections BB' and EE' (refer **Figures 4 and 7**, respectively). The area is flat to undulating and includes the shallow lower slopes of the Chichester Range ridge.

An interbedded sequence of tuffaceous sandstone and meta-shale occurs in the area. Bedding dips shallowly at 2º to 14º, generally to the southeast.

4.3.4 Domain 4

Domain 4 is located on the Chichester Range, to the south of Domain 2, and is distinguished by a swing in the strike of the bedding from northwest-southeast to east-west and a significant increase in bedding dip into the gully system in the ridge above the existing quarry in the valley floor. The interpreted structure is shown in Sections BB' and DD' (refer **Figures 4 and 6**, respectively).

The dip of the bedding increases towards the south from 30º to typically 55º to 65º in the dissected gully system above the quarry (refer Section DD'). Further to the south, the bedding strike swings to coincide with the orientation of the ridge axis (approximately north-south). This area is taken as the southern boundary of the domain.

Interpreted Fault 1, occurring in the valley floor and passing through the area of the small quarry off Salisbury Road, forms the western boundary of the domain. The Tillegra Fault on the eastern slopes of the Chichester Range forms the eastern boundary (see **Figure 2A**).

Meta-shale occurs on the highest part of the ridge system, in the area of the Spotted Gum Trig Station. The meta-shale overlies tuffaceous sandstone that crops out to the north (Domain 2), in the broader part of the ridge. The contact between the lithologic units has been trenched to investigate the relationship between the rock types (refer to Trenches T1 and T2, Appendix D). Bedding dips to the southwest, into the gully system, at 25º to 30º. The meta-shale conformably overlies the tuffaceous sandstone, with no evidence of movement between the two lithologies.

On the eastern side of the Chichester Range, a number of minor, shallow landslips have occurred at the head of the steep gullies draining off the ridge. Slippage is ongoing, with a new failure located below the area of the Spotted Gum Trig Station. The landslip followed prolonged wet weather in early 2008. The failure is across the strike of bedding and includes the thinly developed soil cover and bouldery tuffaceous sandstone scree. Similar, older small-scale slips occur in the gullies further to the north. These failures are limited to the surficial layer of soil and boulders, creeping over insitu tuffaceous sandstone. They do not affect the integrity of the ridge system.

An interbedded sequence of tuffaceous sandstone and conglomerate occurs on the eastern slopes of the ridge, with meta-shale towards the toe (refer to boreholes 421, 422 and 423, Appendix J).

4.3.5 Domain 5/ 5A

Domain 5 is located on the Chichester Range and includes the left abutment of the proposed dam. The interpreted structure is shown in Sections EE' and FF' (refer **Figures 7 and 8,** respectively). It is bounded to the east by Tillegra Fault, which dips shallowly at 30º to 35º to the east, away from the dam site. The Williams River forms the southern boundary (see **Figures 2A and 2B**). A shear zone approximately 1.5m wide has been identified in the valley floor (diamond drilling undertaken by SMEC, 1970), together with several other minor narrow shears. The zone is interpreted to be associated with the major joint set that strikes approximately east/west and is interpreted to control the river orientation at the dam site.

The strike of bedding is approximately parallel to the crest of the Chichester Range and dip is consistently towards the southwest, typically at 35º to 50º, generally in direction 230ºM to 250ºM. In the western part of the domain the course of the Williams River is controlled by the strike of the bedding. Strike and dip remain constant with progression to the north within the domain. The northern boundary has been arbitrarily placed in the area where the strike of bedding swings to the northwest-southeast (into the adjoining Domain 4).

As a result of regional folding, shear zones parallel to bedding occur in the meta-shales. Borehole DDH8, drilled across the saddle forming the crest area of the left abutment spillway alternative, encountered several narrow bedding plane shear zones in meta-shale that included clayey crushed rock. The strike of the bedding is normal to the saddle; consequently, the shears do not daylight on the surface of the ridge.

High to very high leakage was recorded in water pressure tests in DDH8 to RL126m, 26.3m below the FSL. The lowest point in the saddle is approximate RL165.6m, 13.3m above FSL. A second saddle immediately to the west will be filled by the proposed embankment. The lowest point in the saddle is approximately 147.5m, 4.8m below FSL. Borehole DDH7 was drilled across the saddle. An interbedded sequence of tuffaceous sandstone with meta-shale was encountered. Moderate to high leakage was recorded to RL131.2m.

Interpreted Faults 1 and 2 form the western boundary of the domain, separating it from Domain 3 and Domain 8. The faults are contained within the valley floor area.

A major joint set strikes approximately east-west. Dips range from vertical/near vertical to very steep to the north, typically 65º to 85º, in direction 320ºM to 345ºM. A second set is oriented across bedding. Dips generally vary from 30º to 55º, in direction 055ºM to 105ºM. The joint set is often truncated by bedding.

Bedding has the potential to form continuous failure planes on the western side of the Chichester Range. However, the dip of bedding is generally steeper than the slopes and will not be an influence on stability. In the area designated 5A, the dip of bedding is parallel to the slope. The area occurs below the crest of the ridge, at the head of a steep gully complex. The slope above is broadly convex, with a flatter slope than the bedding dip. The head of the gully complex is formed by broad outcrops of tuffaceous sandstone formed by bedding planes. Bedding dips at approximately 32º in direction 240ºM. The bedding related exposures are limited to the north and south by the side ridges controlling the gully complex. No defects are present in continuous outcrop exposures for distances up to 15m. The tuffaceous sandstone is interpreted to be thickly to very thickly bedded. Bedding is estimated to coincide with the slope between approximate RL175m and RL225m. The slope is currently stable, with no indication of past failures. The slope below Domain 5A is flatter than bedding dip.

4.3.6 Domain 6

Domain 6 is the area east of the Tillegra Fault (see **Figures 2A and 2B**). In the southern part of the domain the fault dips to the east at 30º to 35º. Further to the north, adjacent to Domain 2, the attitude of the fault plane increases to 60º (refer to test pit TP137, Appendix E).

Immediately to the east of the fault bedding dips at moderate angles to the east, flattening quickly over short distances away from the fault, further to the east. Bedding typically varies in dip from 20º in the vicinity of the Williams River to 3º to 10º. The strike of the bedding varies over the domain reflecting the flat nature of the bedding and potential undulations in bed surfaces.

Domain 6 is unaffected by the storage and has no slope instability issues.

4.3.7 Domain 7

Domain 7 includes the north-south ridge that forms the right abutment of the proposed dam. The interpreted structure is shown in Section GG' (refer **Figure 9)**. It is bounded to the east by the Tillegra Fault, which is interpreted to dip shallowly to the east, away from the dam site. The Williams River forms the northern boundary (see **Figure 2B**).

Bedding orientation is approximately normal to the river and dips consistently to the southwest, typically at 40º to 55º, generally in direction 240ºM to 250ºM. Along the extension of the Chichester Range strike and dip remain constant with progression towards the south of the domain. The southern boundary is defined by a transitional zone in which the dip of bedding is interpreted to flatten slightly.

A major joint set strikes approximately east-west. Dips range from vertical/near vertical, to around 65º to the north, towards the left abutment, in direction 320ºM to 353ºM. A second set is oriented across the bedding. Dips generally vary from 35º to 65º, in direction 050ºM to 105ºM.

Narrow shear zones associated with the east-west joint set are exposed in gullies on the western side of the ridge forming the southern extension of the Chichester Range. The gully orientation is interpreted to be controlled by the strike of the joints. Shearing associated with bedding in the meta-shales is also expected to occur.

On the western side of Chichester Range extension, slopes are flatter than the dip of bedding which will not be an influence on slope stability. There are no known slope instability issues in this Domain.

4.3.8 Domain 8/8A

Domain 8 includes the area known as Elwari Mountain, immediately west of the proposed dam site (see **Figure 2B**). The interpreted structure is shown in Section FF' **(**refer **Figure 8)**.

The ridge system forming Elwari Mountain is interpreted to be a synclinal fold. On the eastern limb, bedding dips moderately to steeply at 68º to 80º, in direction 240ºM to 253ºM. Bedding orientation is consistent with Domain 5 (left abutment) and Domain 7 (right abutment), immediately to the east.

Bedding flattens through the ridge. In borehole DDH9, bedding is interpreted to dip at 10º to 15º to the southwest. On the western side of the ridge, bedding dips at moderate angles back to the northeast.

Interpreted Fault 2 is interpreted to occur along the eastern margin of the ridge system, forming the eastern boundary of the domain. The fault plane is distinguished by dips steepening to near vertical (in direction 240ºM) immediately to the west of the fault lineament. Dips are moderate (around 50º) towards the southwest on the eastern side of the fault. The eastern margin of Elwari Mountain and the Williams River in part are controlled by the lineament, which is interpreted to be a steeply dipping feature occurring at valley floor level. In exposures along the Williams River, away from the fault to the east, bedding in Domain 3 dips southwest at 15º to 20º.

An area designated 8A was identified as possible landslip from its surface morphology. Geomorphologic mapping is presented in **Figure 12.** In the upper part of the slope bedding dips into the slope at 20º to 32º. The slope has a stepped nature over outcrops, which are continuous along strike, approximately parallel to the topographic contours. Outcrop faces are controlled by the major joint set across bedding, dipping at 52º to 60º down the slope. The slope development is interpreted to have been controlled by shallow joint-controlled failures. Soil cover is thinly developed, being up to 1m maximum thickness. Minor areas of soil creep over the tuffaceous sandstone occur in the upper part of the slope. Rock is exposed in gullies at the toe of the slope. The lack of talus or colluvial soil accumulation at the foot of the slope indicates a lack of past large scale failures.

Bedding dips shallowly to the southeast at the toe of the slope. Interpreted Fault 2, along the eastern margin of Elwari Mountain is interpreted to cross the slope around approximate RL125m (see **Figures 2A and 2B**).

The lower half of area 8A will eventually be inundated by the storage. The areas of minor soil creep in Area 8A occur well above the FSL.

In general, bedding dips into both the eastern and western slopes of the ridge system forming Elwari Mountain, resulting in very steep slopes, controlled by the joint set across bedding.

4.3.9 Domain 9

Domain 9 includes the extension of the Elwari Mountain ridge, to the south of Native Dog Creek (see **Figure 2B**). The ridge axis is slightly offset to the west (by approximately 100m), compared with the ridge axis of Elwari Mountain (Domain 8). The interpreted structure is shown in Section GG' (refer **Figure 9)**.

The ridge system is interpreted to be a continuation of the synclinal structure identified to the north in Elwari Mountain. On the eastern slopes of the ridge, bedding dips to the southwest at approximately 35º to 50º. On the western slope, bedding dips to the east at 45º to 60º.

The dip of the bedding flattens in the valley floor, which is interpreted to be fault bounded. Two (2) interpreted faults occur:

- Interpreted Fault 3, along the south-western edge of Elwari Mountain, coincident with the course of Native Dog Creek. A major joint set parallels the lineament, dipping very steeply at 65º to the southwest in direction 200ºM.
- Interpreted Fault 4, striking northeast-northwest across the toe of the ridge system forming the southern extension of Elwari Mountain.

In addition, a north-south trending feature, known as the Brownmore Fault, extends through the western part of the domain, and persists through the perimeter of the storage to the south, through the area known as Saddle B.

In the area northwest of the domain, a limestone occurrence recorded on the 1:100,000 geological sheet is interpreted to be truncated by the Brownmore Fault. The ridge system immediately to the west was inspected. No limestone outcrop was observed; however, bedding in the area strikes at 120ºM, dipping to the northeast at 40º. Considering the orientation identified, bedding would be truncated by the Brownmore Fault, immediately to the east. The limestone is not interpreted to extend to the south into Domain 9; consequently, having no influence on the perimeter of the storage.

4.4 Storage Rim Saddles

4.4.1 Saddle A

Saddle A, at the south end of the extended Chichester Range, is the lowest point in the storage perimeter (see **Figure 2B**). The interpreted structure through the saddle is shown in Section HH' (refer **Figure 10**). The lowest point in the saddle is at approximately RL165m, 12.7m above the proposed FSL.

No rock crops out in the saddle itself; however, meta-shale crops out extensively in the deeply eroded gullies immediately to the north of the saddle. In the gully outcrops, bedding strikes northwest-southeast through the axis of the saddle, with a moderate dip of 45º to the southwest, typically in direction 235ºM to 245ºM. The meta-shale is laminated to very thinly bedded. Shearing, associated with bedding, is expected to be present within the meta-shale.

A major joint set strikes approximately east-west, dipping steeply at 55º to the north (in direction 340ºM). A second set is oriented across bedding, dipping at 45º in direction 060ºM. The combination of bedding partings and joints results in an extremely close to close defect spacing.

Tuffaceous sandstone occurs away from the saddle axis, as the topography rises to the east and west.

The meta-shale sequence is interpreted to be responsible for the occurrence of the saddle. No bedding or major joint sets daylight in the saddle and the area is regarded as stable. An inclined diamond cored borehole is planned across the saddle in the design phase of the geotechnical investigation. The borehole will be water pressure tested to assess the leakage potential of the saddle into the adjoining catchment. Zones of minor shearing would be expected, associated with bedding within the meta-shale.

4.4.2 Saddle B

Domain 9 includes a second low point in the storage perimeter designated Saddle B (see **Figure 2B**). The lowest point in the saddle is at approximately RL175m, 22.7m above the FSL.

A prominent north-south lineament that passes through the saddle is interpreted to be the Brownmore Fault (Roberts, 1991). No outcrop occurs in the saddle itself; however, tuffaceous sandstone float occurs on the higher ground to the east.

Prominent exposures of meta-shale occur in the north-south trending gully to the south of the saddle. The gully drains directly into Myall Creek. In the gully bed and tributaries to the east and west, bedding dips consistently to the northeast at 15º to 20º. There is no discernible variation in bedding orientation across the fault lineament. Meta-shale occurs in the gully and to the west. Tuffaceous sandstone occurs to the east. The change in lithology across the gully could be the result of vertical movement due to faulting, or the sandstone could simply overlie the meta-shale.

A major joint set is apparent in outcrops, dipping very steeply at 60º to 70º to the west, ranging to near vertical. Joint spacing in highly weathered meta-shale, exposed in a farm track running off the saddle to the south, is extremely close.

Meta-shale is expected to occur in the saddle, with tuffaceous sandstone immediately to the east. The fault lineament is interpreted to be associated with the very steeply dipping joint set striking north-south, through the saddle.

The fault lineament is normal to the axis of the saddle and does not present a potential stability problem. Trenching and an inclined diamond cored borehole are planned across the saddle in the design phase of the investigation. The borehole will be water pressure tested to assess the leakage potential of the saddle into the adjoining Myall Creek catchment.

5 Seismic Hazard

5.1 General

An earthquake hazard assessment for the Tillegra dam site (ES&S 2008) has been prepared by the Seismology Research Centre, a division of Environmental Systems and Services (ES&S). The aspects of this study relevant to storage rim stability are summarised in the following sub-sections.

5.2 Tectonics and Seismicity of the Tillegra Site

The site is in Carboniferous sediments which were faulted and folded during the Permian age, some 250 million years ago. The faults in the region experienced most of their relative motion at that time. There is no evidence of any geologically recent (within last 1 million years) movement of the faults in the Tillegra region.

The region immediately around Tillegra Dam has a very low level of historical seismicity, much lower than about Newcastle to the south. As at most locations, a large majority of the potential earthquake hazard at Tillegra Dam is from earthquakes occurring within tens of kilometres.

No active faults have been identified in the region surrounding the Tillegra Dam site.

There are a number of small faults within and or nearby the immediate Tillegra area, as described in this report (Section 3.2). Their lengths are typically only up to a few kilometres; limiting the maximum magnitude event that would occur should they reactivate to less than about ML6.0 (Richter scale).

In summary, the faults located within or quite close to the proposed Tillegra dam site and storage area are ancient and there is no evidence they are active. Even if they reactivate they will not produce a large earthquake.

5.3 Estimates of Seismic Hazard

Estimates of seismic hazard have been calculated by ES&S using two assumptions. The first, assuming earthquake activity can occur randomly within the Tamworth Terrane area source zone; and the second, where significant faults in the region were assumed to be active and a proportion of future earthquake activity was assigned to them. The second approach yielded higher estimates of seismic hazard and these estimates are proposed to be adopted for design of dam structures (e.g. intake tower).

The peak ground acceleration for a return period of 475 years (10% probability of exceedance in 50 years) estimated at the Tillegra Dam site is about 0.04g - using the AUS5 model with local faults and area sources, and a minimum considered magnitude of 5.0. The corresponding peak ground acceleration for a return period of 10,000 years is estimated to be 0.24g.

The above seismic loading for the Tillegra Dam site is about average for Australian conditions (ES&S 2008).

5.4 Reservoir Triggered Earthquakes

Reservoir triggered earthquakes have been reported from a small percentage of large reservoirs in many places including Australia. A recent world-wide listing suggested a figure of 2% of large reservoirs experience such events.

Reservoir triggered earthquakes would eventually have occurred naturally, but are triggered prematurely by changes in tectonic stresses arising from the presence of large reservoirs.

The basic parameters of a reservoir that may contribute to triggered earthquakes include the water depth and the volume of water. Worldwide experience is that reservoirs with water depths less than 70 metres and water volumes less than 0.5 km3 (500 gigalitres) rarely trigger earthquakes.

Tillegra Dam, with a water depth of 67m (at full supply level) and 450 gigalitres storage volume is considered a borderline case in terms of reservoir induced earthquake activity. So it is possible that some relatively minor earthquake shaking ranging from micro-earthquakes (not felt) up to about ML 3.0 or 4.0 (resembling vibrations caused by heavy traffic) may be recorded.

Reservoir triggered earthquakes are thus considered marginally possible but would not threaten the integrity of the proposed Tillegra Dam or affect storage rim stability.

6 Storage Rim Stability

6.1 General

This Section of the report addresses the potential influence of geological features and landslides on the long term integrity and safety of the dam storage. The key issues include:

- The influence of faulting, bedding surface shears and joint defects on reservoir rim stability.
- The potential for a large scale failure of the eastern ridge system and consequent loss of storage.
- Identification and characterisation of pre-existing landslides that could affect the integrity of the reservoir and/ or dam safety.
- The potential for remobilisation of pre-existing landslides and assessment of their impact on dam safety.
- Consideration of viable first-time (new) slides and their potential impact on reservoir integrity and/or dam safety.

A summary of the geotechnical engineering assessments is presented. The commentary is based on the extensive geological field investigations carried out, the geotechnical model developed and the following supplementary investigations:

- Geotechnical characterisation and assessment of pre-existing landslides and potential for first-time slides. This work is presented at Volume IV (PSM 2009). Mr Tim Sullivan (PSM), an expert in land sliding including the rock mechanics of slides, was engaged by Commerce to undertake this work.
- Quantitative landslide risk assessment. This work is presented at Volume V (URS 2009). Dr Mark Foster (URS Australia) was engaged by Commerce to facilitate a risk workshop and report the outcomes of the risk assessment.

Figure 1 shows the area of investigation, which has been divided into nine geological domains, based on geomorphology, bedding orientation and interpreted faulting.

An outline of the site (physical) investigations is provided at Section 2. The storage rim geology is described in detail and interpreted in Sections 3 and 4, and in **Figures 2A/2B to 13**. The relevant investigation data is presented in the appendices at Volumes II and III of the report. A geological field map is presented in Drawings B2A and B2B, Appendix B.

The study area extends along the Chichester Range up to 4 km north of the dam site and approximately 2km west in the Native Dog Creek Section of the storage to include two (2) saddles, designated Saddles A and B, which represent the lowest points on the reservoir rim (**Figure 2B**).

The area outside the main study area (shown as light green on **Figure 1**) has been screened and removed as a risk to be considered further as part of the risk assessment process. For this area, it is assessed as inconceivable that the integrity of the reservoir and/or the dam could be threatened by land sliding because:

- The storage pools on the lower, flatter slopes of the ridge system;
- The mountain ranges broaden out providing for very lengthy seepage paths and reduced hydraulic gradients;
- There are no pre-existing large scale landslides capable of affecting the integrity of the reservoir and/ or dam safety.

6.2 Local Areas of Instability

6.2.1 General

For the reasons outlined in Volume IV (PSM 2009), landslides are relatively uncommon in the Tillegra Dam storage area. However, several areas of local instability have been identified in the study area, mostly along the Chichester Range. These include:

- Relatively small slides in soil/ weathered rock in the heads of gullies on the inside of the storage rim in Domain 1, designated Landslide 1A.
- A medium scale retrogressive translational dip-slope landslide in Domain 2, designated Landslide 2A.
- A small area of shallow soil creep in Domain 8A developed on the steeper parts of the slope that cross-cuts bedding.
- Small surficial slides in Domains 4 and 5 on the eastern side of the Chichester Range (north of the “Spotted Gum” Trig Station) developed on the steeper parts of slopes that cross-cut bedding.

The majority of the landslides are very shallow and small, and are located mainly in Domains 4 and 5 but also in localised areas in Domains 1 and 2. Most of these small landslides are located well above FSL and hence will be unaffected by any filling or operation of the reservoir. These features do not pose any threat to dam safety.

Slides 1A and 2A are the only slides of significance in the study area. Area 8A was identified as part of earlier studies as a possible landslide. However, it is no longer considered to be of significance as explained below.

6.2.2 Domain 8 - Area 8A (Elwari Mountain)

Plate 6-1 below shows a small scale pre-existing feature designated Area 8A located on the east facing slope of Elwari Mountain. This feature has been included in the risk assessment.

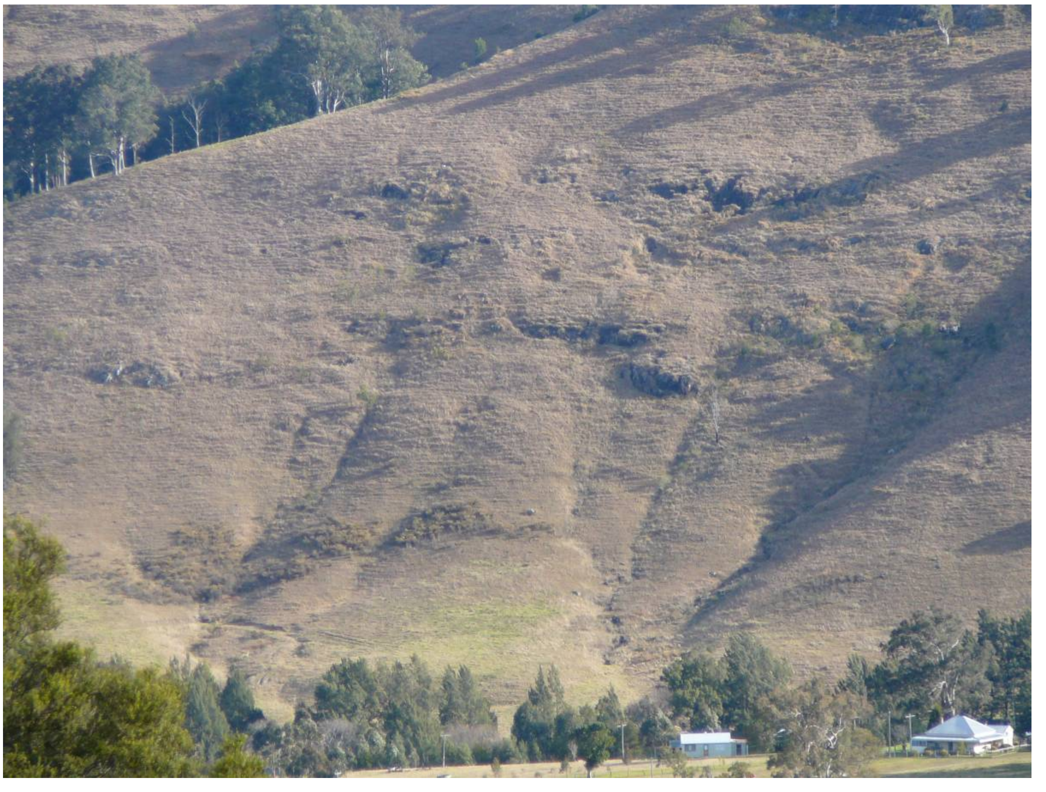

Plate 6-1 - View of Area 8A Feature

Geomorphologic mapping (**Figure 12**) of Area 8A has shown significant rock outcrop with only minor areas of soil creep over tuffaceous sandstone. Soil cover is thinly developed up to 1m thickness. Bedding dips into the slope. A major joint set cross-cutting bedding has formed the steep slope (refer Section 4.3.8).

There is no evidence of accumulated landslide debris at the toe of the slope. The areas of soil creep are located well above FSL.

Area 8A was screened and removed as a risk to be considered further during the risk workshop because the feature is of a minor, surficial nature and too small in size to pose any threat to dam safety.

6.2.3 Domain 1 – Slide 1A

Plate 6-2 below shows Slide 1A, located in Domain 1, where bedding dips at a relatively shallow angle (8 to 10 degrees) to the south-east/ east; i.e. out of the reservoir.

Plate 6-2 - Domain 1 and Slide 1A

Slide 1A is a minor landslip of estimated volume 4,000m^3 that has occurred on the western side of the Chichester Range in the extremely/ highly weathered conglomerates underlying a relatively thick cap of horizontally bedded tuffaceous sandstone. The failure is typically shallow in nature and the toe of the slide is located above the storage full supply level (RL152.3).

The slide is located at the head of a steeply incised creek and has only travelled a short distance down-slope. Plate 6-3 shows a view of the outwash fan, which is assumed to have been formed over a long period from landslide debris and erosion of earlier slides (PSM 2009).

Plate 6-3 - View Looking Down-slope of Slide 1A

Plate 6-4 below shows an indicative geological sectional profile indicating the mechanism causing the localised landslips in Domain 1A.

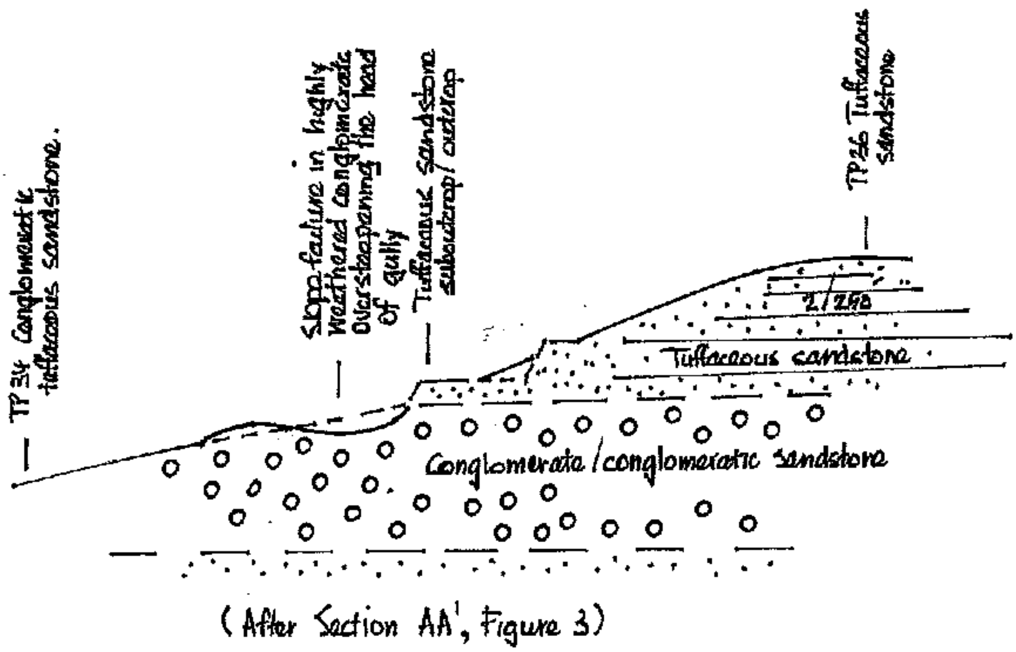

Plate 6-4 - Geological Profile through Slide 1A

Minor block type failures of the tuffaceous sandstone may occur on the upper slopes of the ridge well above the influence of the dam storage (Section 4.3.1). However, the frequency of such failures is expected to be very low.

Assessment of this slide for impulse wave affects (Section 6.6) indicated that the potential affect on the dam safety is negligible.

In summary, Slide 1A is a small scale slump in soil/ weathered rock, only 4000m^3 in volume. The slide was screened and removed as a risk to be considered further during the risk workshop because the feature is considered too small in size and limited in nature to pose any threat to the integrity of the reservoir rim or dam safety.

6.2.4 Domain 2 – Slide 2A

A major focus of the landslide geotechnical assessment is Slide 2A. This feature is a medium scale landslide of approximate dimensions 350m long by 160m wide by 6.5m average depth. PSM formulated a geotechnical model of the landslide based on the site investigation data provided by Commerce. The information used included:

- Topographic orthophoto plan and overlapping aerial photos (for viewing by stereoscope)
- Geomorphologic mapping and conventional geological mapping of the slide and surrounding area,
- Test pit logs (TP 138 to 151)
- Boreholes DDH29 and DDH30 above the slide
- Seismic traverse line 9 taken through the slide long section
- Engineering index tests and clay mineralogy of clay samples retained from slide plane(s)

The locations of the investigations for Slide 2A are shown at **Figure 11**.

The investigations for this slide also contributed to the interpretation of the overall geotechnical model of the study area and understanding the potential for and absence of landslides elsewhere in the storage area (PSM 2009).

Slide 2A was included in the quantitative risk assessment given its size and proximity to the reservoir rim.

A detailed geotechnical assessment of Slide 2A is provided in Volume IV of this report (PSM 2009). A summary of the findings is provided in Section 6.3 following.

6.3 Slide 2A Assessment

6.3.1 Geotechnical Model

Figure 11 shows a geomorphologic plan of the 2A slide feature.

The landslide comprises two components – the active landslide itself and a creep zone up-slope and up-dip, which shows small scale creep movements and inferred long term evidence of creep movements, but no active land sliding. There is an active scarp across the north-eastern edge of the landslide that extends along the northern side.

The main active area has approximate plan dimensions 350m long by 160m wide. The landslide is a relatively shallow feature, 5 to 8m in depth. It has an approximate volume 370,000m^3. The creep zone above the slide is estimated to be in the order of 200,000m^3.

Plate 6-5 shows a view of the upper area of Slide 2A.

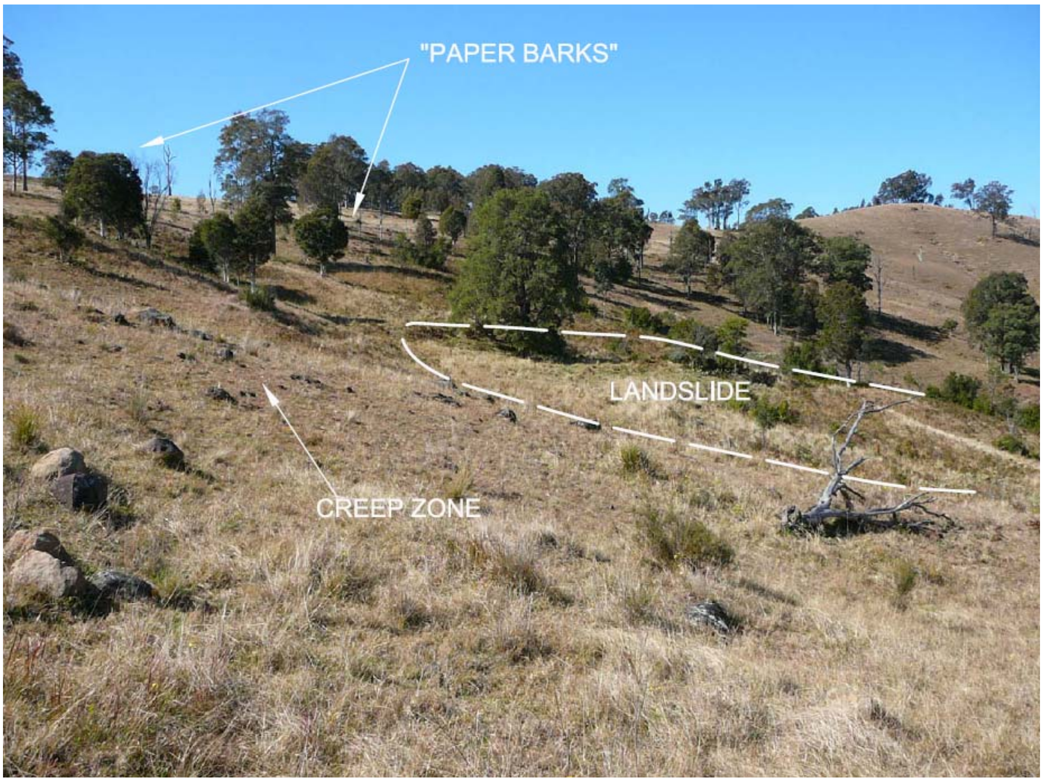

Plate 6-5 - View of Landslide 2A Upper Section

The landslide shows signs of recent re-activation and from the condition of the active scarp this is interpreted to have occurred in June 2007 during a relatively heavy rainfall event (250mm recorded at Dungog from 7th to 9th June). Note that historical records indicate that many larger rainfall events have occurred (refer Volume IV, Figure 20).

A particular feature of the recent scarps is their linearity. Plate 6-6 illustrates this linear control in a number of directions on the recently reactivated landslide scarps.

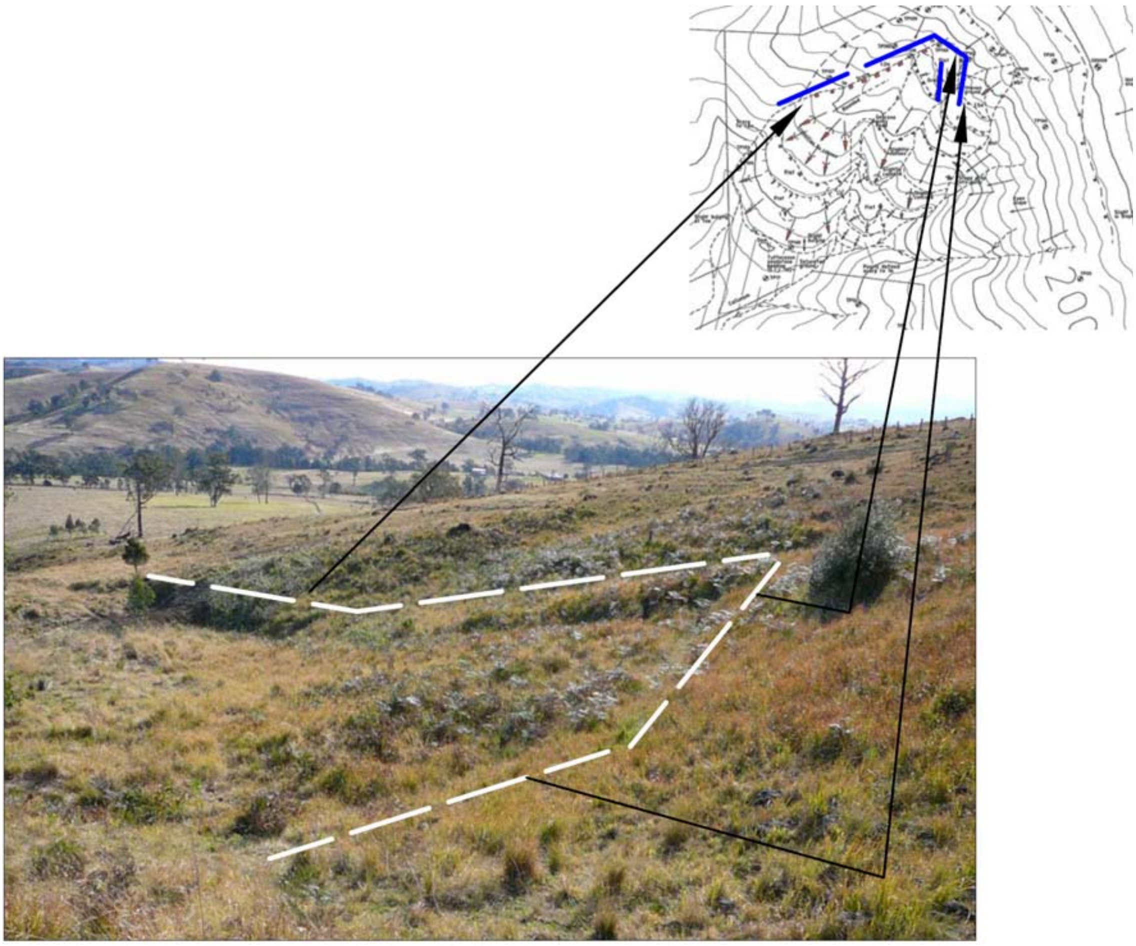

Plate 6-6 - Landslide Controls (PSM 2009)

Kinematic analysis of structural mapping data for the landslide (PSM 2009) shows that the alignment of the landslide scarps approximately matches the joint set data. This infers a bedrock-controlled sliding event. Plate 6-7 shows structural mapping data for the landslide presented as a lower hemisphere equal area stereographic projection of the poles to all planes.

The analysis also indicates that the average dip of the slide plane is 14º towards 216º (southwest), which is steeper than the ground surface slope of 11½º.

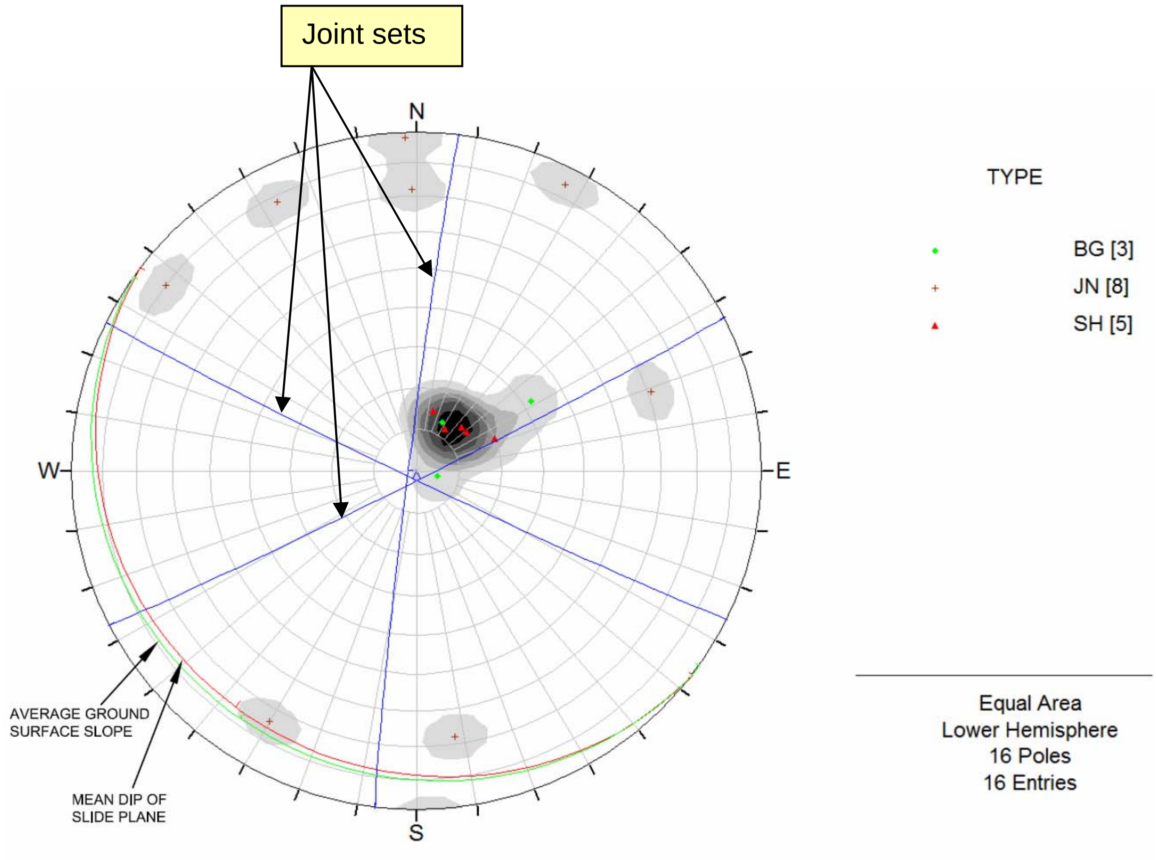

Plate 6-7 - Kinematic Analysis of Slide 2A (PSM 2009)

Test Pit TP142, is located immediately above the recently active scarp in the main lobe of the landslide. Plate 6-8 shows an indicative geological section based on field assessment of Test Pit TP142.

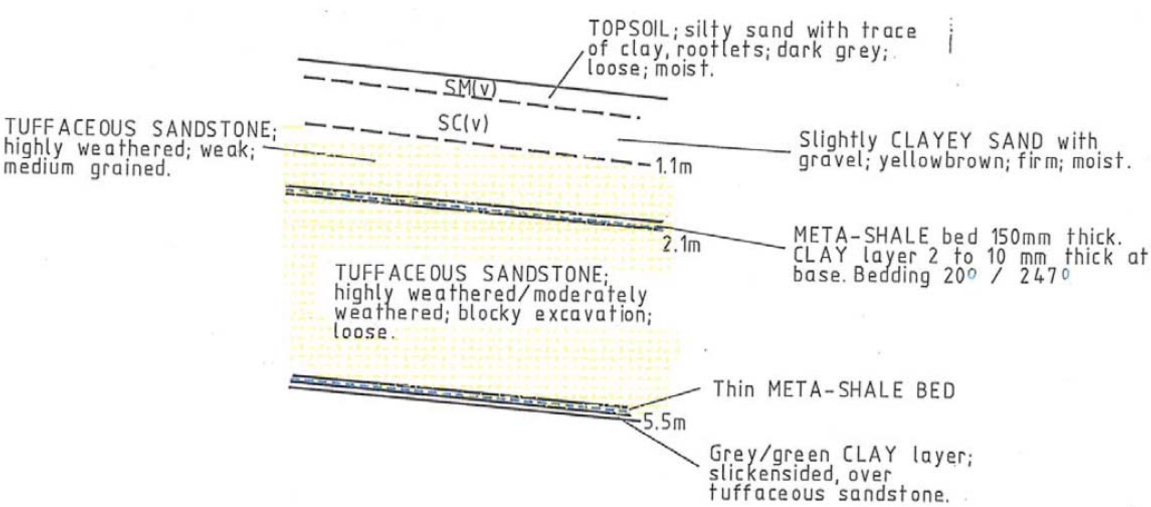

Plate 6-8 - Test Pit 142 Interpretation (2 Slide Planes)

The test pit investigations indicated:

- Two slide planes, at 2.1 and 5.5m depth were identified in TP142 immediately above the recently active scarp in the main lobe of the landslide.
- The lower slide plane is an extremely thin (<1mm thick) pale green coloured irregular slickensided clay layer (Plate 6-9).
- The upper slide plane is a meta-shale layer that is still rock-like but shows significant aperture on joints (TP142 and TP143),
- The upper slide plane has been folded by the recent reactivation (TP143).
- Test Pits at the toe of the landslide did not intersect any slide plane (TP149, TP150 and TP151).
- TP149 located at the toe of the main landslide lobe immediately above the outcrop in the farm dam showed brecciated rock with no distinct bedding or layering. This is indicative of a non daylighting toe "shove zone".

Plate 6-9 - TP142 Lower Slide Plane

Based on the mapping data, the outcrop in the farm dam and test pitting at the toe of the slide, it is clear that the landslide failure plane does not daylight.

Interpretation of the seismic refraction survey (Line 9) in combination with DDH30 showed the following:

- The absence of any low strength planes at depth in the rock mass above the slide.
- High velocity rock at relatively shallow depth.
- A shallow zone of low velocity rock, coincident with the inferred landslide and averaging around 4 to 8m depth, with some apparent deeper local pockets.
- Rock outcrop and high velocity rock around the local farm dam at the toe of the landslide.

The geotechnical model developed for Slide 2A (PSM 2009) is summarised as follows:

- The landslide is retrogressive and is a very old slide or series of slides.
- The colluvium lobe at the toe indicates a long history of land sliding in this location.
- The slide appears to be very slow moving.
- The average dip of the slide plane is 14º towards 216º, which is steeper than the ground surface slope of 11½º.
- The landslide is non-daylighting with a thick "shove zone" of brecciated rock at the toe.
- The toe of the slide is partly constrained because the dip direction of sliding is towards 216º, whereas the overall ground surface slopes on the western side of the Chichester Range towards about 260º.
- The two eastern lobes of landslide material abut intact material in the creek forming the south-eastern boundary of the slide
- The sliding planes are very thin and very irregular. They appear to have formed by weathering and/or alteration of the upper boundary of the lithic sandstones immediately below meta-shale layers.
- Surrounding the landslide in the north, northeast and east is a shallow creep zone approximately 1.5 to 2.0m deep. This zone exhibits very small scale and inferred periodic creep movement, probably under extreme rainfall conditions.
- The landslide is relatively shallow, about 5 to 8m deep. The main active landslide is about 370,000m3 and the upper creep zone about 200,000m3.
- The main landslide showed a small scale re-mobilisation around the scarp area, probably due to the 200mm three day rainfall event in June 2007.

Based on the presence of the high velocity rock on the seismic survey, the absence of any deeper slide surface in borehole DDH30 and the topography of the eastern ridge, it is clear that there is no potential for major deep seated regression of Slide 2A that could impact on the reservoir rim.

Landslide 2A is located in an area with a unique set of geological, geotechnical, geomorphologic and environmental circumstances. These same circumstances are not found elsewhere within the study area.

6.3.2 Stability Analysis

Stability analyses of Slide 2A are presented in Volume IV of the report (PSM 2009). The stability was analysed for the section shown at Plate 6-10 below, and comprised analysis of Slide 2A, the creep zone and both Slide 2A and the creep zone together.

Soil strength properties adopted for the analysis were as follows:

- Density of slide materials: 18 KN/m^3
- Creep zone shear strength parameters:
  - Cohesion: 0 KPa
  - angle of friction: 16, 18 or 20 degrees
- Basal slide plane shear strength parameters:
  - Cohesion: 0 KPa
  - angle of friction: 16, 18 or 20 degrees
- Toe break out plane shear strength parameters:
  - Cohesion: 5 KPa
  - angle of friction: 28 degrees

It is noted that the shear strength of the creep zone is assessed to be considerably greater than the basal slide plane in the active landslide, but for the purposes of analysis has been assumed to be the same.

Table 6-1 below shows the results of the analysis for an angle of friction of 16 degrees on the basal slide plane. Results for a more realistic angle of friction of 20 degrees (PSM 2009) are provided in brackets for comparison purposes.

Table 6-1 - Summary of Stability Results for Slide 2A

Analysis Case	FOS - Slide 2A	FOS – 2A plus Creep Zone
Dry	1.79	1.74
Dry with FSL (RL152.3)	1.49	1.44
Full saturated (no storage)	*0.80 (0.98)*	*0.86*
Full Saturated with FSL	0.95 (1.29)	1.00

The results of stability analyses indicate that that with a fully saturated slope, the factor of safety for the existing Slide 2A approaches 1.0. This indicates that the slide is likely to re-activate when it becomes saturated by heavy rainfall as appears to happen at present. Re-activation of the slide is likely to be slow and intermittent in nature and can occur whether or not the slide is inundated by the reservoir.

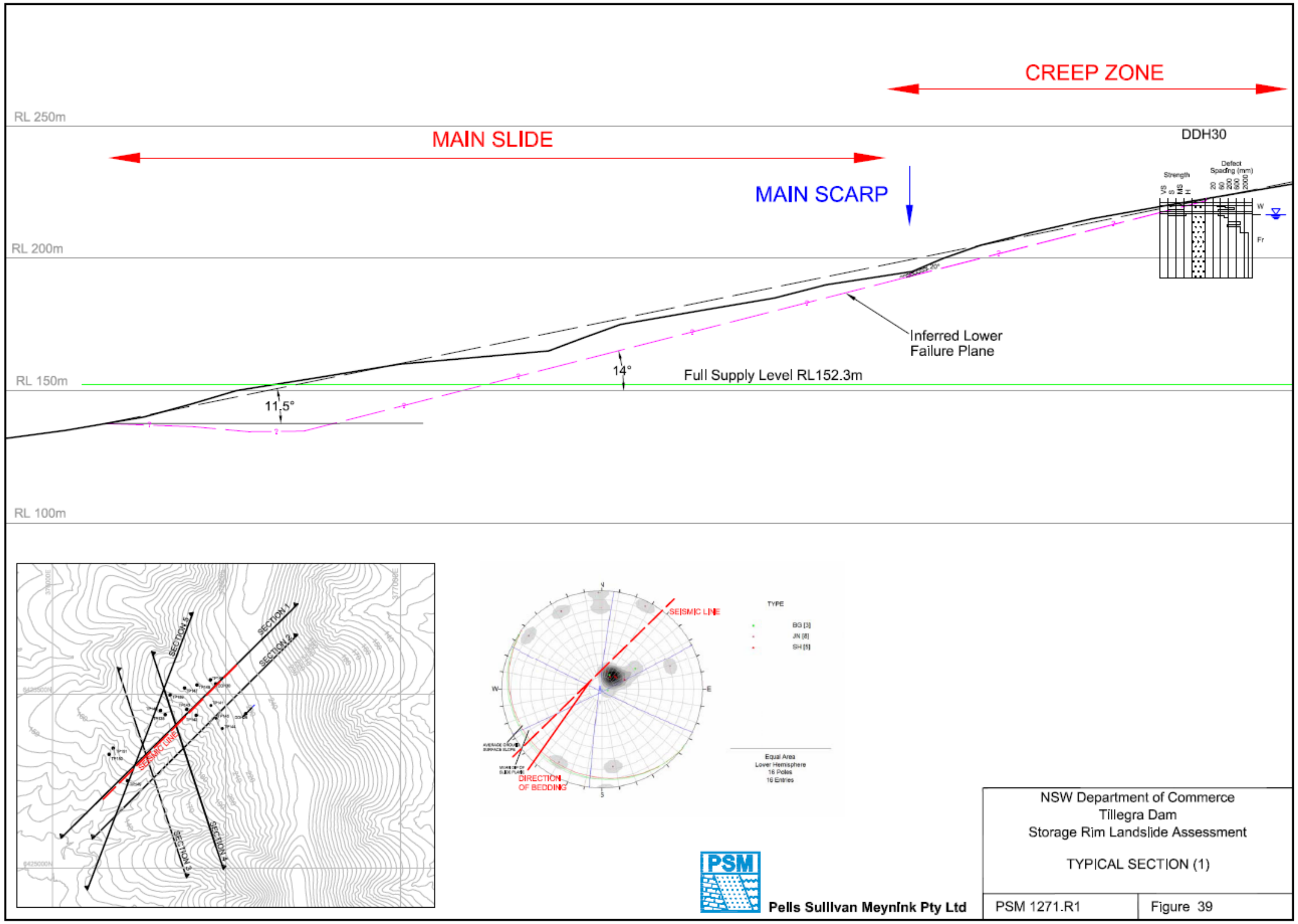

Plate 6-10 - Slide 2A Stability - Section Analysed (after Fig 39 PSM 2009)

6.3.3 Safety of the Storage

On the basis of the geotechnical model, re-mobilisation of Slide 2A and the associated creep zone up-slope cannot result in a large scale deep seated failure of the eastern ridge system (Section 6.5.2).

Given the nature of Slide 2A, re-activation of the slide is likely to be slow and intermittent in nature. Nevertheless, for the purposes of the risk assessment, it has been assumed that the slide could mobilise en-mass and that the failure could be very rapid.

The probability of mobilisation of Slide 2A leading to the formation of a wave in the storage and overtopping failure of the dam structure, is assessed to be negligible; refer to Section 6.7

6.4 Integrity of the Storage Rim

6.4.1 General

As mentioned at Section 6.1, outside the study area, the mountain range broadens considerably and stability of the storage rim is not affected by the storage (it pools on the valley floor). In addition, there are no pre-existing instability issues that could affect the integrity of the reservoir and/ or dam safety.

Note that for the purposes of the landslide risk assessment, the area north of Domain 1 was termed Domain “0” - refer Volume V of this report (URS 2009)

6.4.2 Potential for Large Scale Failure

In Domain 1, the attitude of the bedding varies from 10º to the south/southeast, to 8º to 10º to the east on the eastern side of the ridge system. Plate 6-11 below shows the typical dip slope across the ridge plateau above the Slide 1A area.

The two drill holes (DDH29 and DDH30) drilled above the Slide 2A area both encountered consistently fresh lithic sandstone around 6m depth from natural surface. Rock mass conditions are tight, with the water table recorded at depths of 5.8m (DDH30) and 13.9m (DDH29). The holes show the meta-shale beds to be typically thinly bedded and of high strength. These beds are not prone to loss of strength on weathering.

The Tillegra fault has now been accurately mapped. It extends from the Myall Creek area, past the dam site (500m downstream), to 2.6km north of the Williams River. The fault runs along the eastern toe of the Chichester Range and dips shallowly to moderately to the east, away from the dam site and the Chichester Range. The investigations have shown that it does not cross the Chichester Range, and as it projects above the ridge crest, it cannot provide a failure surface for large scale instability affecting the storage rim.

Other interpreted faults in the valley floor beneath the storage area do not affect either storage rim stability or dam safety.

Plate 6-11 - View of Dip Slope across Ridge in Domain 1

Borehole 412 by Douglas and Partners (Appendix J, Volume III) indicates a highly weathered zone up to about 10m deep in the conglomerates. This rock, when fresh will exhibit similar characteristics to the lithic sandstone prevalent at the site; i.e. it would form a “tight” low permeability rock mass of relatively high strength.

In summary, the Eastern Ridge comprises a “tight” (low permeability) rock mass, with shallow depths of weathering and shallow groundwater levels (PSM 2009).

The test pits and natural exposures in farm dams along the top of the ridge confirm the shallow depth to rock and the low permeability of the rock mass. Plate 6-12 shows one of these dams located near to the Slide 1A area.

Plate 6-12 - Small Farm Dam in Domain 1A

6.4.3 Stability Assessment - Domain 1

An assessment of the potential for first-time sliding is provided in Volume IV of this report (PSM 2009). Based on the geology, geomorphology and geotechnical conditions, no credible mechanisms were identified that could result in large scale failure of the eastern ridge system.

However, because the large scale stability of this ridge has been raised as an issue by some in the local community, and to facilitate the risk assessment process, analysis of a potential large scale slide in Domain 1 was provided to allow the quantification of probability of outer rim sliding.

Separate analyses were carried out by Commerce and PSM as part of the verification process.

The stability was analysed for geological Section AA' shown at **Figure 3**.

Commerce Preliminary 2-D Analysis

Commerce initially carried out a highly conservative 2-D analysis for the purposes of facilitating the assessment of event tree probabilities in the risk workshop.

The model assumptions and results of stability analyses for a hypothetical large scale outer rim slide through Domain 1 are presented at Appendix K, Volume III of this report.

In brief, the main assumptions for the stability analysis included:

- High natural piezometric surface adopted consistent with the tight rock mass conditions encountered at the site – typically 15m below natural surface through mountain range. Refer to Appendix K, where models PZ5 and PZ4 represent the pre and post dam piezometric conditions respectively.
- Hypothetical 0.5m thick weak slide plane, continuous 1050m in length
- Assumed shear strength properties on slide plane – cohesion 0KPa, angle of friction 12 degrees. This is lower than assessed as a reasonable lower bound by PSM based on the geology and back analysis of Slide 2A.
- Simplified 2-D slope stability analysis assuming no contribution of shear strength from side restraints

Plate 6-13 shows the critical case analysed. The failure plane extends from chainage 1175m to chainage 1750m at a dip angle of 5 degrees and then projects flat to exit the toe of the slope on the eastern side of the Range at chainage 2225m. It is not geometrically possible for steeper failure planes to affect the integrity of the storage.

Even with these very conservative assumptions, the results indicated a factor of safety greater than 2.0 for slide planes that could potentially take out the entire rim and release the storage. These analyses do not take account of the effects of side restraint, so the actual factors of safety would be greater than this.

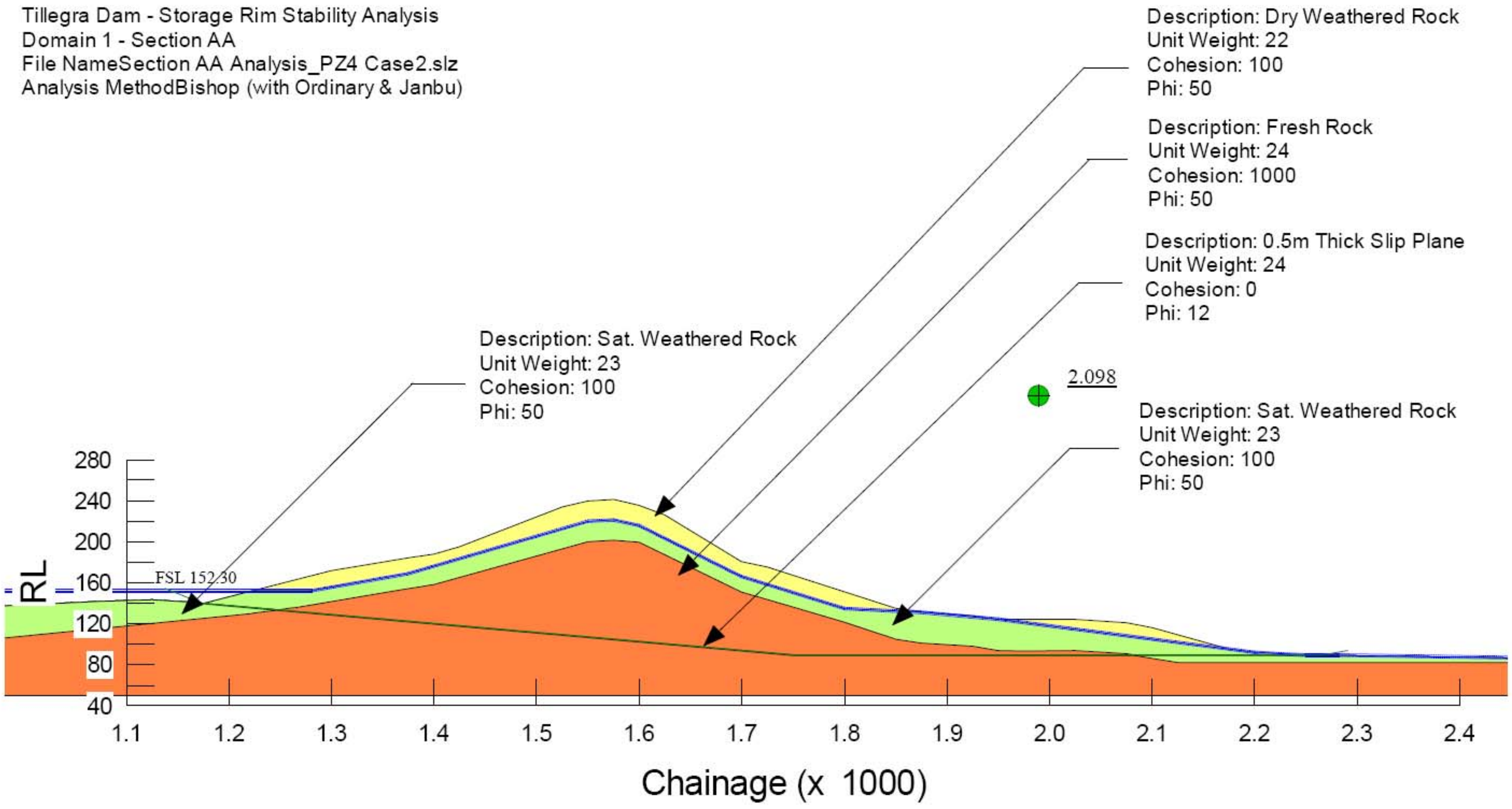

Plate 6-13 - 2-D Stability Analysis in Domain 1

PSM 3-D Analysis

A 2-D failure mechanism is not considered credible because topographic restraints limit the potential size of the slide. Hence a pseudo 3-D analysis, where the effect of side restraints is taken into account, has been carried out by PSM. The stability analysis results are presented in Volume IV of this report (PSM 2009).

The PSM analysis assumed a vertical tension crack at the ridge of the crest with full hydrostatic head applied to the head scarp and failure through the rock mass along a bedding plane dipping at 10 degrees out of the reservoir. It is noted that the dam storage could not be released by the assumed slope failure block.

The analysis methodology was approximate and entailed determining an equivalent rock mass strength based on the proposition of a 3-D failure plane comprising bedding and rock mass respectively. The factored parameters were then applied to a 2-D analysis.

The assumptions included:

- High natural piezometric surface at 10m depth and paralleling the natural surface over the full length of the slide.
- The slide plane is perfectly flat over the full 500m length. This is very unlikely and conservative.
- Assumed conservative shear strength properties on 10 degree bedding slide plane – cohesion 0KPa, angle of friction 16 degrees.
- Strength parameters of intact rock mass in the side restraints – cohesion 3500kPa and angle of friction 62 degrees.

The factored strength parameters of the slide plane to account for the side restraints are: cohesion 420kPa and angle of friction 25.5 degrees.

The results of the analysis indicate a factor of safety of around 3.1.

Safety of the Storage

The use of conservative parameters across a theoretical continuous bedding plane, the presence of topographic restraints limiting the potential size of the slide and the lack of lower strength planes at depth in all test locations, indicate that the above analyses are very conservative. The stability of the ridge system in Domain 1 is estimated to be considerably greater than indicated above.

Large scale sliding of the Chichester Range would require a continuous sub-horizontal low strength feature to be present and vertical side release mechanisms to exist for this to be a viable mechanism. There is no geological evidence that such features are present and the potential for them to exist were assessed in the risk workshop to be very low based on the geotechnical conditions in Domain 1.

The probability of a large scale slide event of this nature occurring and impacting on the safe operation of the storage is assessed to be negligible; refer to Section 6.7.

6.5 First-time Failures into the Storage

6.5.1 General

No credible mechanisms were identified such that first-time slides could affect the storage rim integrity and allow release of the storage.

The assessment of first-time slides presented in Volume IV (PSM 2009) indicates that medium scale sliding into the reservoir may only occur in areas with consistent flat to moderate dipping bedding that can daylight or has some other release mechanism.

In Domains 2, 4, 5 and 7, the bedding dips into the dam storage but as shown by **Figures 4, 7, 8 and 9**, natural slopes on the reservoir hillsides are generally flatter than bedding dips, resulting in stable slopes.

Figures 3, 4, 5 and 7 show the storage full supply level (RL152.3) plotted on Sections at a scale of 1:5000. It is clear from these figures that the storage load imposed on main eastern arm of the storage rim (Chichester Range) is minimal.

The erosion feature located in Domain 4 approximately 1.5 km upstream of the dam (Plate 6-14) is interpreted to have been caused by the northwest-southeast orientation of bedding in this area combined with an increase in dip into the gully system. Gullies run along the strike of the bedding in meta-shales, which is more prone to weathering than the sandstone beds.

As mentioned in Section 4, the strike of the bedding swings (transitions) from an east-west orientation in Domain 1 to the north-south orientation in Domains 5 and 7. Plate 6-14 below illustrates the transition in the bedding geology through Domain 4.

In Domain 4, there is no evidence of creep movements or land sliding. The folded nature of the bedding and dip direction to the southwest generally precludes any mechanisms for first time sliding in this domain.

Plate 6-14 - View of Erosion Feature in Domain 4

6.5.2 Up-slope Regression of Slide 2A

Slide 2A is a shallow feature associated with bedding dipping at approximately 14 degrees to the south-west. The average dip of the 2A slide plane is steeper than the natural ground surface of 11.5 degrees, providing a mechanism for failure but requiring a toe breakout mechanism.

Any extension of the failure through the creep zone up-slope will not impact on the overall integrity of the storage rim considering the dip and shallowness of the existing failure plane.

6.5.3 Potential First-time Sliding of Area 5A

The only area identified with potential for first time sliding is designated Area 5A, situated on the western slopes of the Chichester Range about 600m upstream of the dam site (**Figures 2A and 7**). Generally the bedding is steeper than the natural slopes in Domain 5. However, in Area 5A the dip of the bedding is parallel to the slope. Section 4.3.5 provides an engineering geological description of the area.

The slope in Area 5A is currently stable with no indication of past failure. A mechanism for toe breakout across bedding is required to cause a slope failure. Other factors that explain the current stable nature of this area include:

- Exposures on the slope show no defects present in continuous sandstone outcrop for distances up to 15m
- The sandstone is massive with no surface evidence of meta-shale layers
- Area 5A is limited in size and restrained/ buttressed by side ridges to the north and south controlling the gully complex
- There is no evidence of creep, incipient instability or previous sliding

For the purposes of the risk assessment, a medium scale slide event in Area 5A was included to allow quantification of the probability of first-time sliding into the reservoir. Area 5A is located well above the dam full supply level and would not be affected by storage operations.

Features of the potential slide from PSM (2009) include:

- Top ridge RL225m
- Location of potential toe breakout at the change in slope at RL180 to RL185
- Bedding dip 32 to 36 degrees
- Area of potential slide 200m wide by 75m down-slope (average)
- Volume of potential slide approximately 290,000m^3

2-D Stability analyses for Area 5A were carried out by PSM and the assumptions and analysis results are presented in Volume IV. This information was used to facilitate the assessment of event tree probabilities in the risk workshop. A factor of safety of 1.5 was calculated for a dry slope assuming no cohesive strength and an angle of friction along bedding of 20 degrees. If 3-dimensional effects were taken into account the factor of safety would be much higher.

Pseudo-static analysis of earthquake load for an extreme earthquake event having an AEP of 1 in 100,000, a peak ground acceleration of 0.5g, a topographic amplification factor of 1.4 and a horizontal seismic coefficient of 0.5, indicates a factor of safety in excess of 1.5.

For the purposes of the risk assessment is assumed that the slide could mobilise *en-masse* and that failure would be very rapid.

The probability of a first-time slide in Area 5A leading to the formation of a wave in the storage and overtopping failure of the dam structure, is assessed to be negligible; refer to Section 6.7.

6.5.4 Other Areas of Interest

Saddles A and B

Bedding strikes north-west to south-east through the axis of Saddle A. The saddle is interpreted to have been formed by preferential erosion in the meta-shale beds. Zones of shearing associated with bedding are expected within the meta-shales. However, no bedding or major joint sets daylight the saddle and the area is considered to be stable.

The prominent north-south lineament or fault (Brownmore Fault) passing through the storage rim at Saddle B is interpreted to be associated with sub-vertical jointing. .The fault does not present a potential stability problem because it has a steeply dipping attitude and is oriented normal to the saddle axis.

Dam Site – Upper Left Abutment Saddle

The area above the left abutment of the dam site is relatively narrow and will be subject to reservoir surcharge and potential seepage.

This area has been named “the Upper Left Abutment”. It forms part of the dam site, which is the subject of ongoing design phase investigations.

There is no evidence of localised instability or major shear zones that could cause a dam safety issue. Further field investigations are proposed in the area to confirm geological conditions for the dam design.

6.6 Impulse Wave Effects from Landslides

For landslides which may travel into the reservoir, an analysis of the size of waves that may be generated in the reservoir was carried out (PSM 2009). This information was used in the risk assessment to quantitatively assess whether the dam could be overtopped and breached. For the purposes of this assessment it was assumed there was a possibility that rapid failures could occur at each of the slopes evaluated. In reality, most slopes around the reservoir are too flat to fail rapidly or have geological structure that makes rapid failure unlikely.

Impulse wave calculations are presented in Volume IV of this report (PSM 2009).

Relevant dam storage level (m-AHD) data are as follows:

➢ Full Supply Level (FSL):	RL152.30
➢ Top Embankment Parapet:	RL160.20
➢ 1 in 100 AEP Flood Routed Storage Level:	RL154.68
➢ PMF Routed Storage Level:	RL 159.02
➢ Freeboard at FSL:	7.9m
➢ Freeboard for 1 in 100 AEP Flood:	5.5m
➢ Freeboard for PMF Flood:	1.18m

It is noted that none of the pre-existing slides (1A and 2A) or potential first-time slides (5A) face the dam directly; i.e. the effect on the dam is the edge of a diffracted wave or a generated wave reflecting off Elwari Mountain.

PSM (2009) reports the following approximate 2-D wave run-up heights based on the methods of Huber (1997) and Huber and Hager (1997):

➢ Pre-existing Slide 1A:	1.0m
➢ Pre-existing Slide 2A:	7.6m
➢ Potential first-time Slide 5A:	10.6m

PSM (2009) reports that generated wave heights based on 3-dimensional analysis methods are insignificant (less than 100mm). The 2-D results represent a very conservative upper bound whilst the 3-D wave height prediction model represents a lower bound of the actual wave heights; in this case a more realistic estimate. Because the dam site is oriented at large angles to the direction of sliding of all the potential landslides, then reflection and diffraction of the waves will occur and the heights of the indirect waves will be small.

Wave heights that are equivalent to one half of the above 2-D wave run-up heights were adopted for the purposes of risk assessment.

6.7 Landslide Risk Assessment

6.7.1 General

The landslide risk assessment was carried out in accordance with the ANCOLD Guidelines on Risk Assessment (ANCOLD 2003) and using the principles given in the Australian Geomechanics Society Landslide Risk Management Guidelines (AGS 2007).

The report presented in Volume V (URS 2009) provides full details of the risk assessment.

The key issues for the risk assessment are as outlined at Section 6.1 above.

The risk analysis was conducted by holding a risk workshop, which was attended by a panel including the risk facilitator Dr Mark Foster; representatives of Commerce and URS involved in the investigations and assessments related to storage rim stability; and Mr Tim Sullivan.

The risk workshop involved the following steps:

- Identification and screening of potential modes of failure associated with storage rim instability;
- Identification of loading events which could impact on storage rim stability;
- Estimation of probabilities of failure using event tree methods; and
- Evaluation of the risks against tolerable risk criteria.

Two potential scenarios were identified for instability of the storage rim leading to an uncontrolled release of the storage. These were:

- A large scale slide of the outer side of the storage rim where it is formed by a mountain ridge leading to an uncontrolled release of the storage through the ridge; and
- A large scale, extremely rapid landslide on the inner side of the storage rim which would generate waves in the stored water that in turn, would overtop the dam structure and cause it to fail.

Potential mechanisms of slope instability of the reservoir rim are the mobilisation of pre-existing landslides and first-time slides.

In the context if this risk assessment, the following terminology was used to describe the scale or size of existing or potential slide masses;

- Small scale slide – a feature having a volume less than about 100,000 cubic metres.
- Medium scale slide – a feature having a volume between about 100,000 to 1,000,000 cubic metres.
- Large scale slide – a feature having a volume greater than about 1,000,000 cubic metres.

Loading states included:

- Normal operation of the reservoir.
- Large rainfall event (1 in 100 AEP rainfall and associated flooding in the dam)
- Extreme flood event (PMF).
- Maximum Design earthquake (MDE) event (1 in 10,000 AEP earthquake).
- Maximum Credible earthquake (MCE) event (1 in 100,000 AEP earthquake).

Quantitative event tree techniques were used to define the sequencing of events and pathways that could lead to loss of storage, whereby the probability of an outcome given an initial event is determined by multiplying the annual probability of the initiating event by the product of all the conditional probabilities along the event tree path leading to that outcome.

6.7.2 Results of the Risk Assessment

The failure modes screening identified that the following potential failure modes should be used for evaluating risks:

- Domain 1 – Potential large scale, first time slide of the ridge leading to uncontrolled release of the storage.
- Domain 2 – Mobilisation of the pre-existing medium scale slide 2A feature, leading to the formation of a wave in the storage and overtopping failure of the dam structure.
- Domain 5 – Potential medium scale, first time slide of the inner slope leading to the formation of a wave in the storage and overtopping failure of the dam structure.

The probabilities of failure for each of the potential failure modes for all loading events are as follows:

Failure Mode	Probability of Failure
Domain 1 large scale landsliding of storage rim resulting in loss of the reservoir	5.1×10^{-13}
Mobilisation of Slide 2A with overtopping failure of dam	3.3×10^{-11}
First-time Slide 5A with overtopping failure of dam	5.2×10^{-10}
Total Probability of Dam Failure and Loss of Storage	**5.6×10^{-10}**

6.7.3 Discussion

The estimated probabilities of failure for each mechanism of storage rim instability are extremely low; i.e. many times less than an annual probability of 1 in 10,000,000 which is the estimated probability of the PMF loading event used for designing the dam/ spillway configuration.

Domain 1 (Large Scale Failure of Storage Rim)

The Tillegra Fault does not pass under the ridge. Large scale sliding of the Chichester Range would require a continuous sub-horizontal low strength feature to be present and vertical side release mechanisms to exist for this to be a viable mechanism. There is no geological evidence that such features are present. Stability analysis assuming such features exist indicates an acceptable factor of safety, even with conservative assumptions.

The annual probability of a large scale first-time failure of the Chichester Range ridge system leading to uncontrolled release of the storage was assessed to be negligible (5.1×10^{-13}).

Domain 2 (Slide 2A)

Stability analysis (PSM 2009) indicates the factor of safety for Slide 2A is reduced by filling of the storage. However, the analyses show that both reservoir filling and full saturation of the slope is required for the factor of safety to fall below 1.0, implying remobilisation.

The landslide is non-daylighting with a thick “shove zone” at the toe. If the slide remobilises, then it is expected that it would move very slowly. Extremely rapid movement of the slide mass was judged to be unlikely based on the assessment that the surface of the rupture is already at residual strength and the average dip of the slide planes is only 14 degrees.

Assessment of this slide for impulse wave effects in the reservoir (Section 6.6) assuming rapid movement indicated that the embankment design has adequate freeboard to absorb the generated wave unless the slide occurrence coincided with a peak storage level caused by extreme flooding (PMF) in the dam catchment.

The annual probability of wave generated overtopping failure of the dam caused by a rapid failure of Slide 2A was assessed to be negligible (3.3×10^{-11}).

Domain 5 (Area 5A)

A first-time slide in Area 5A would require a bedding plane failure within the rock mass and a breakout across bedding in strong, unweathered rock. There is no geological evidence of adverse features which could provide such a failure mechanism. The outcrops at Area 5A show massive sandstone with no evidence of meta-shale layers.

The area is located well above the full supply level and will not be affected by storage operations.

Pseudo-static stability analysis for an extreme earthquake event (1 in 100,000 AEP) having a peak ground acceleration of 0.5g, indicated a factor of safety in excess of 1.5 (PSM 2009). The risk of sliding is therefore negligible, even for a very large earthquake event.

Assessment of this slide for impulse wave effects in the reservoir (Section 6.6) assuming rapid movement indicated that the embankment has adequate freeboard to absorb the generated wave unless the slide occurrence coincided with a peak storage level caused by extreme flooding (PMF) in the dam catchment.

The annual probability of wave generated overtopping failure of the dam caused by a rapid failure of Slide 5A was assessed to be negligible (5.2×10^{-10}).

Total Annual Probability of Failure

The analysis demonstrates that even if sliding occurs, the likelihood of it impacting on the safe operation of the storage is negligible. The total annual probability of loss of storage is 5.6×10^{-10}.

A key finding of the risk assessment is that a sequence of events is required for failure to occur and since each of these loading events has a very low likelihood of occurring, the outcomes of the assessment are not sensitive to major changes to any one or two of the event probabilities.

Comparison to Risk Criteria

The risks resulting from the landslide hazard are significantly lower than the acceptable levels under the NSW Dams Safety Committee and ANCOLD risk guidelines for new dams for both individual and societal risk. The very low probabilities of dam failure and loss of storage are consistent with the normal design objective of new large dams to safely handle extremely rare loading events such as extreme floods and earthquakes.

7 Seepage Potential

7.1 Controls on Groundwater

Groundwater conditions at the dam site and in the Chichester Range north of the site are described at Section 4.2.4. The geotechnical investigations for the storage rim area along the Chichester Range confirm a typically tight rock mass, with shallow depths of weathering and groundwater levels relatively close to the surface. For example, water table readings were recorded at depths of 6m and 14m in boreholes DDH30 and DDH29 respectively. In addition, the presence of a number of small water retaining farm dams situated on the Chichester ridgeline confirms the low permeability nature of the rock (refer Plate 6-12). Natural springs have also been observed high on the eastern slopes of the ridge.

Away from the dam site and the three (3) saddle areas, the storage rim topography rises significantly to in excess of RL200m. It is interpreted that the full supply level lies well below the natural water table in the more elevated parts of the ridge systems surrounding the dam site. In these areas, there is no potential for leakage from the storage to the adjacent valley. In fact seepage will continue to be from the ridge towards the reservoir.

7.2 Sites with Leakage Potential

Three (3) saddles have been identified as areas of potential leakage from the storage. The saddles include:

- The saddle located immediately east of the left abutment. Diamond borehole DDH8 was drilled across the saddle (Section 4.3.5). Water pressure testing has identified a permeable zone extending to RL126m, 26.3m below the FSL. It is anticipated that the embankment grout curtain will be extended to lower the leakage potential through the saddle.
- Saddle A is located to the south of the proposed dam (**Figure 2B**). The lowest point in the saddle is approximately RL165m, 12.7m above the FSL. Meta-shale occurs in the saddle, striking normally to the saddle axis and dipping at moderate angles to the southwest. It is anticipated that minor shearing associated with bedding could occur through the saddle. The leakage potential of the area will be investigated during the design stage geotechnical investigation and grouting carried out if necessary.
- Saddle B is located to the southeast of Saddle A (**Figure 2B**). Meta-shale occurs in the saddle, with tuffaceous sandstone occurring in the higher ground to the east. It is interpreted that the saddle is the result of faulting associated with a steeply dipping major joint set striking normal to the orientation of the saddle (the Brownmore Fault). The leakage potential of this saddle will also be investigated during the design stage geotechnical investigation and grouting carried out if necessary.

Elsewhere around the perimeter of the storage, the minimum flow paths are in the order of 300m close to the dam up to 650m through the Chichester Range north of the dam.

The major joint set striking east-west, normal to the axis of the Chichester Range, has the potential to facilitate leakage at the southern end of the range. However, rock will be tight at depth in the ridge, and in view of the high water table in the ridge, groundwater flow will be from the ridge into the reservoir, not from the reservoir.

7.3 Future Investigations and Possible Treatments

As mentioned in Sections 4.4 and 6.5.4, further drilling investigations are proposed during the design phase to confirm the geotechnical model and leakage potential in the upper left abutment area and in Saddles A and B. The boreholes will be water pressure tested at 3m depth intervals and standpipe piezometers will be installed to monitor groundwater conditions.

The upper left abutment of the dam site at the southern end of the Chichester Range is relatively narrow near the DDH8 location, and grouting works are expected to be required in this area. It is possible that leakage through the abutment could be sufficient to be noticeable and may affect the stability of surficial colluvium deposits on the downstream side of the abutment. If this is the case, then it may be necessary to carry out some works in the area to cater for seepage and reduce its impacts. Further geotechnical assessments of the upper left abutment area are targeted for the design phase (Section 6.5.4).

In the extended left and right abutments at the dam site, the full supply level will lie above the natural water table. Grouting to a tight basement using conventional techniques will be required in these areas to form an impermeable barrier to flow through open defects above the water table. Similar conditions remain a possibility in Saddles A and B.

The Brownmore Fault will also be investigated to confirm that it doesn't contain dispersive clay material that may be prone to internal erosion through open defects. If such material exists, then samples will be collected and tested for classification/ grading and dispersivity. The data obtained would be used to design filter treatment provisions (if required) at the Saddle B location.

8 Conclusions

This report describes the geology and assesses the potential influence of geological features and land sliding on the stability and watertightness of the storage rim. It is based on extensive field investigations and the outcomes of landslide risk assessment studies. The work carried out is considered to form a sound basis for the evaluation of site conditions.

The dam site itself (including the embankment footprint, left and right abutments, spillway, diversion and outlet works etc.), together with the extension of the left abutment, are being investigated in detail as part of the final design stage of investigation.

The Tillegra Fault has now been accurately mapped. It is aligned along the eastern toe of the Chichester Range and dips at shallow to moderate angles to the east, away from the dam site and the Chichester Range. The fault projects above the ridge crest and cannot provide a failure surface for large scale instability affecting the storage rim. No other faults are interpreted to cross the eastern ridge system to the north of the dam site.

Several faults have been identified in the valley floor, including the Native Dog Creek arm of the storage. The Brownmore Fault passes through the storage rim at Saddle B in a direction normal to the axis of the saddle. Given its orientation and steeply dipping attitude, it does not present a potential stability problem.

The faults identified are not features that affect either rim stability or dam safety.

A number of small-scale landslides occur within the storage and on the eastern slopes of the Chichester Range. Most of these are located well above full supply level and will be unaffected by storage operations. The smaller slides were screened from the risk assessment study as being too small to affect reservoir rim stability or dam safety.

A medium scale retrogressive dip slide, designated Slide 2A, was identified in Domain 2. Any extension of the failure through the creep zone up-slope will not impact on the overall integrity of the storage rim considering the low dip angle and shallowness of the existing failure plane.

The results of stability analyses indicate that the slide is likely to re-activate when it becomes saturated by heavy rainfall as appears to happen at present. Re-activation of the slide is likely to be slow and intermittent in nature and can occur whether or not the slide is inundated by the reservoir. For the purposes of the risk assessment, it was assumed that the slide could mobilise *en mass* and that the failure could be very rapid.

The likelihood of Slide 2A remobilising and impacting on the safe operation of the storage is negligible.

The Eastern Ridge comprises a “tight” (low permeability) rock mass, with shallow depths of weathering and shallow groundwater levels. No credible mechanisms were identified that could result in large scale failure of the eastern ridge system and loss of storage. Stability analyses for hypothetical large outer rim slides through Domain 1 indicated stable conditions.

The only area identified with potential for first time sliding is Area 5A, situated on the western slopes of the Chichester Range about 600m upstream of the dam, where the dip of bedding is parallel to the natural slope. Area 5A is currently stable with no indication of past failure. Field mapping of the area indicates massive sandstone beds with no evidence of meta-shale layers. The area is limited in size and restrained by side ridges to the north and south controlling the gully complex below the feature.

Stability analyses of potential Slide 5A indicate that sliding is very unlikely, even in the event of a large earthquake. The likelihood of a first-time slide in Area 5A occurring and impacting on the safe operation of the storage is negligible.

It is concluded that engineering works are not required to stabilise the storage perimeter surrounding the Tillegra Dam site.

The full supply level lies well below the natural water table in the more elevated parts of the ridge systems surrounding the dam site. In these areas, there is no potential for leakage from the storage to the adjacent valley.

In the extended left and right abutments at the dam site, the full supply level will lie above the natural water table. Grouting to a tight basement using conventional techniques will be required in these areas to form a low permeability barrier to flow through open defects above the water table. Similar conditions remain a possibility in Saddles A and B. The leakage potential in these areas is being investigated as part of the design phase investigations for the dam site.

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FIGURES

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

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NSW Department of Commerce

TILLEGRA DAM STORAGE

AREA OF INVESTIGATION

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DESIGNED	DATE		
DRAFTED	VERIFIED		

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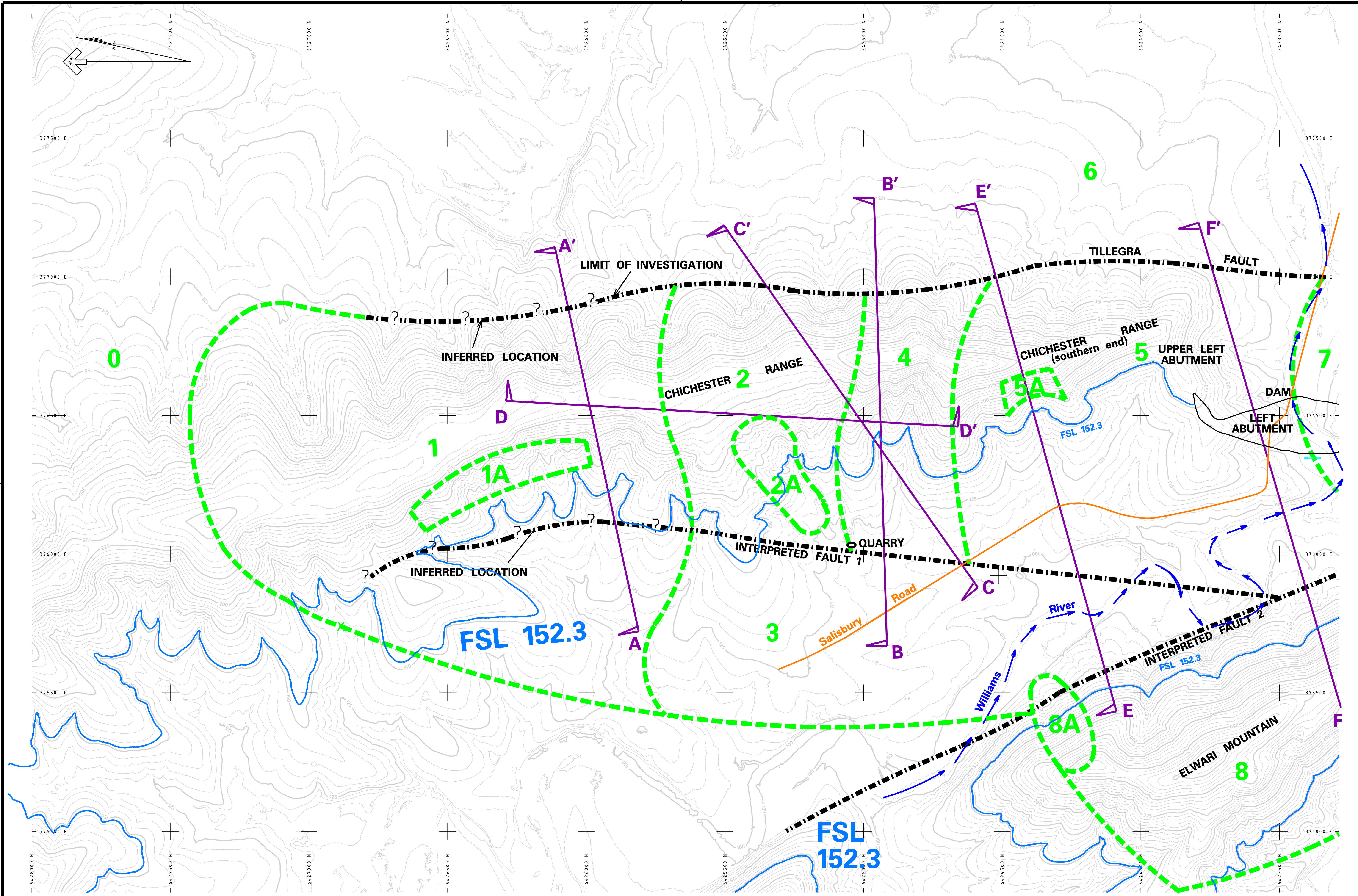

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TILLEGRA DAM
Interpreted geological domains showing section locations

FILE NO. GN31A
FIGURE NO. 2A

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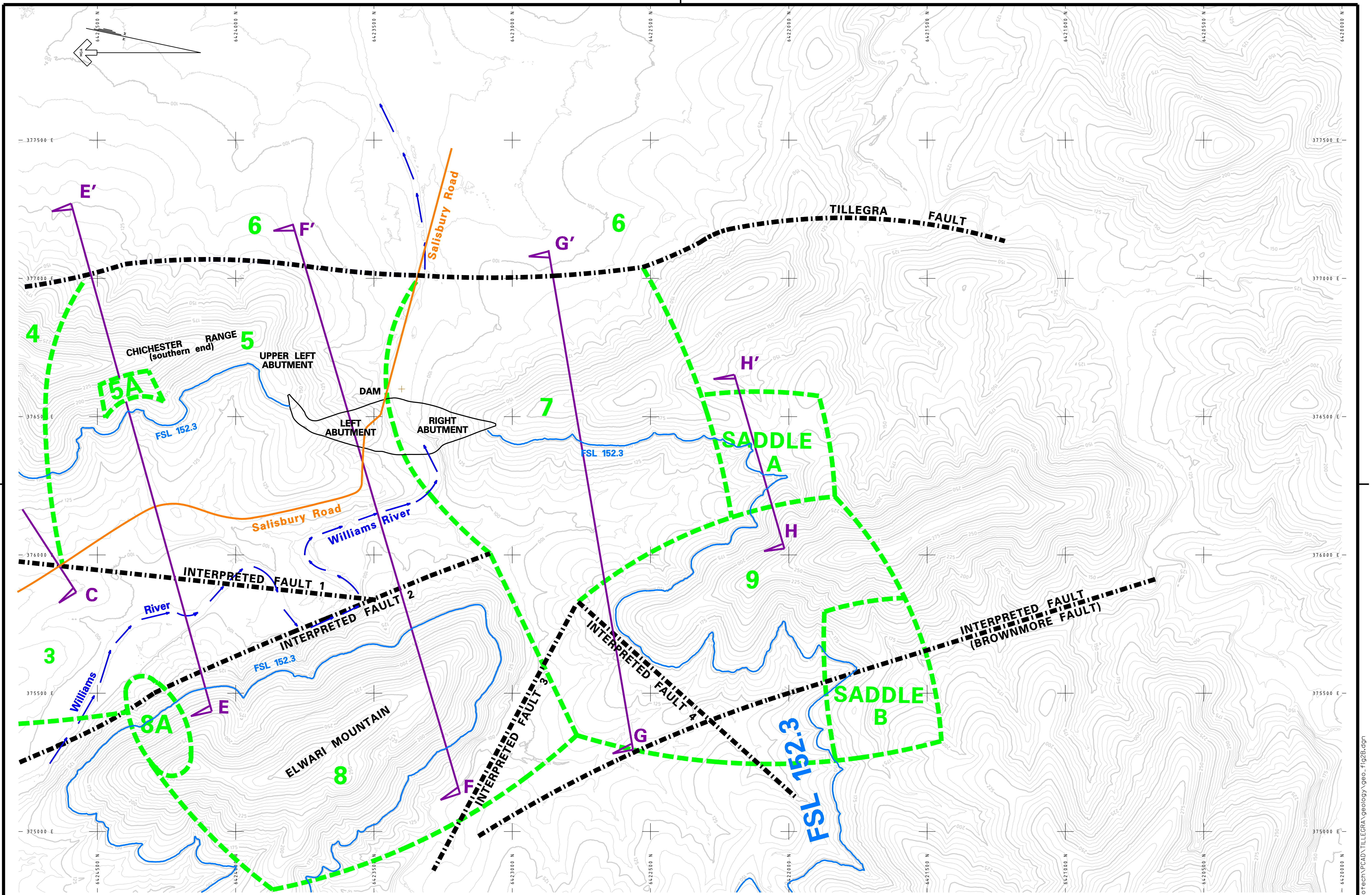

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TILLEGRA DAM

Interpreted geological domains showing section locations

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FIGURE NO. 2B

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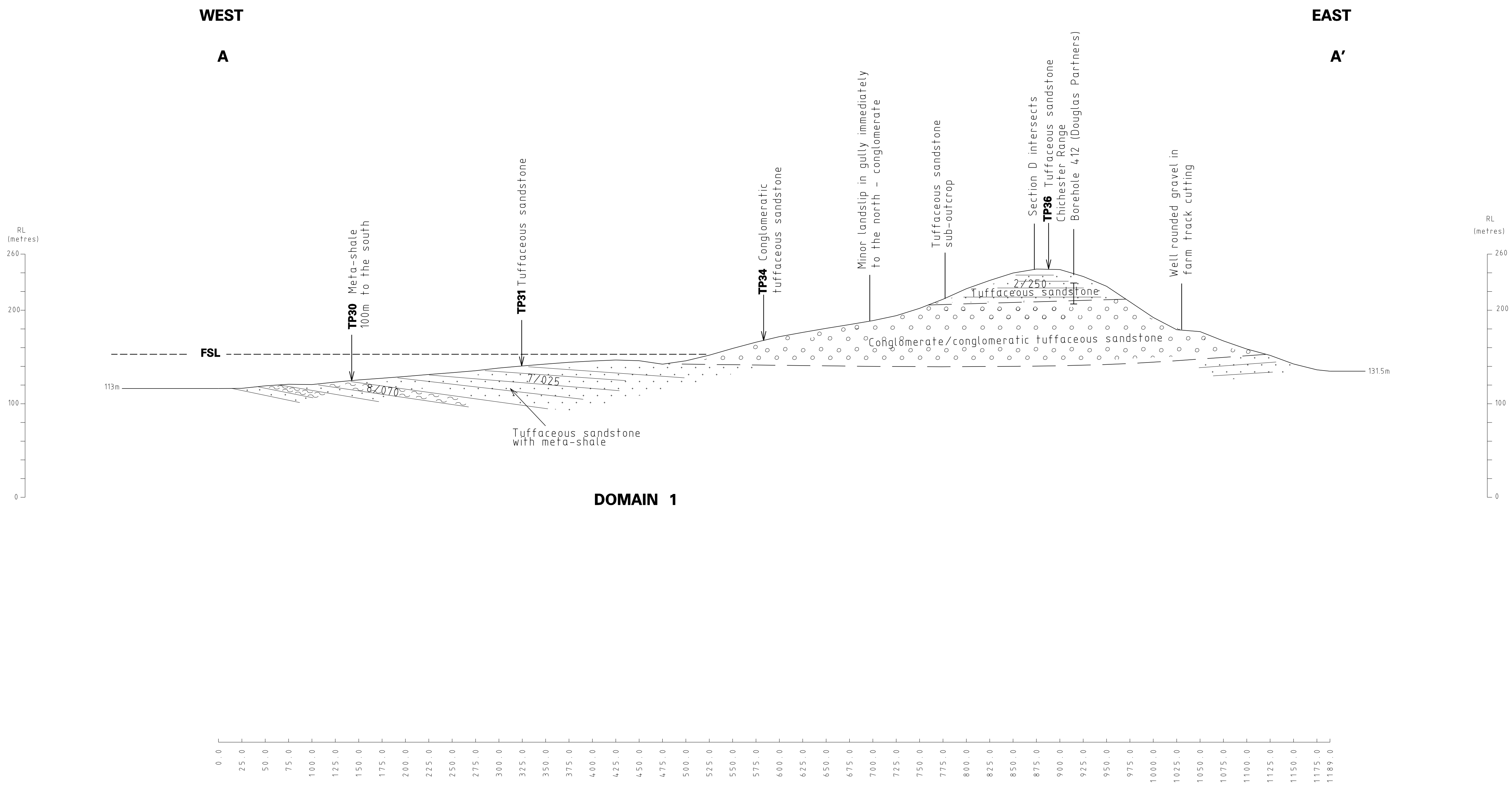

SECTION AA

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TILLEGRA DAM
SECTION A – A'
Chichester Range

FILE NO. GN31A
FIGURE NO. 3

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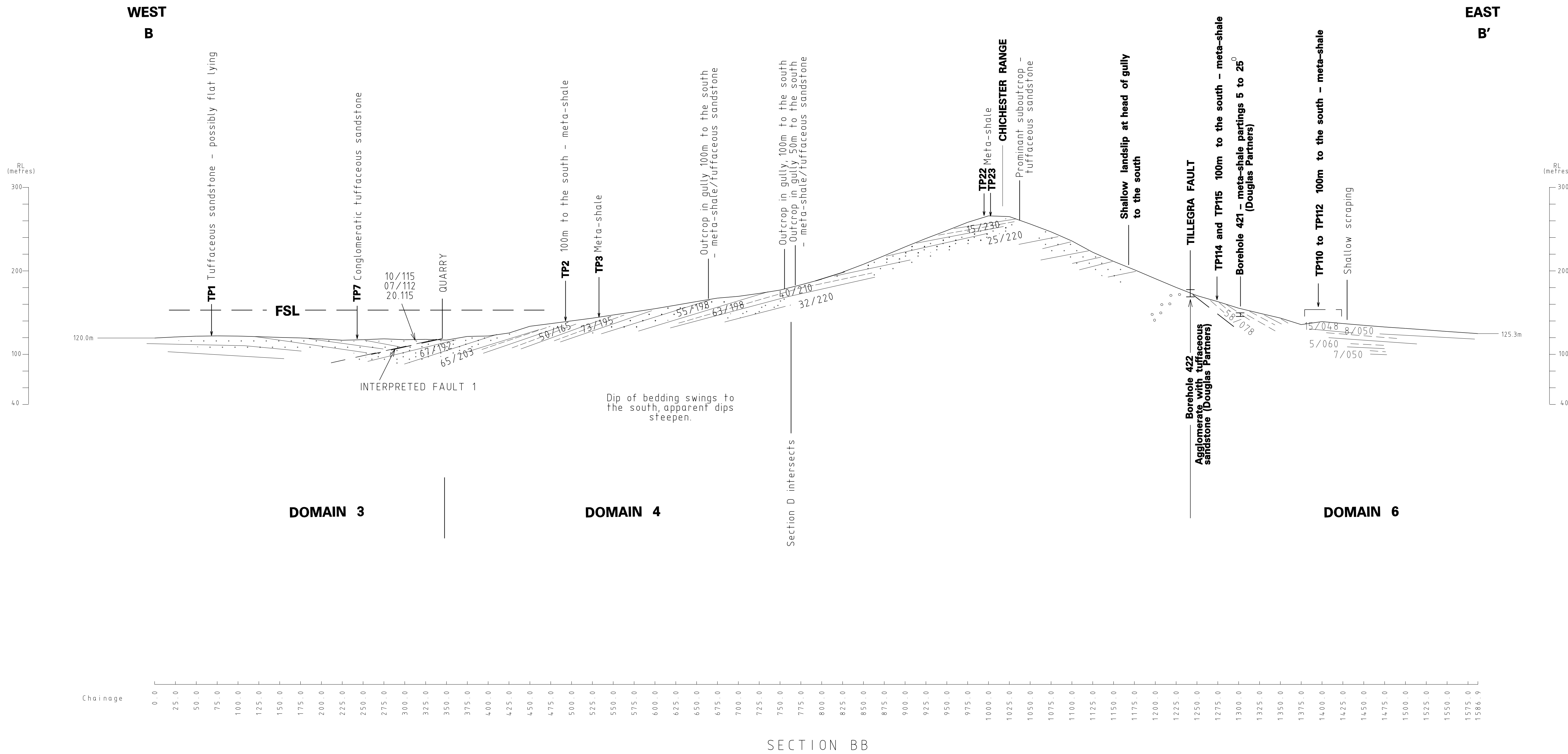

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TILLEGRA DAM
SECTION B - B'
Chichester Range

FILE NO. GN31A
FIGURE NO. 4

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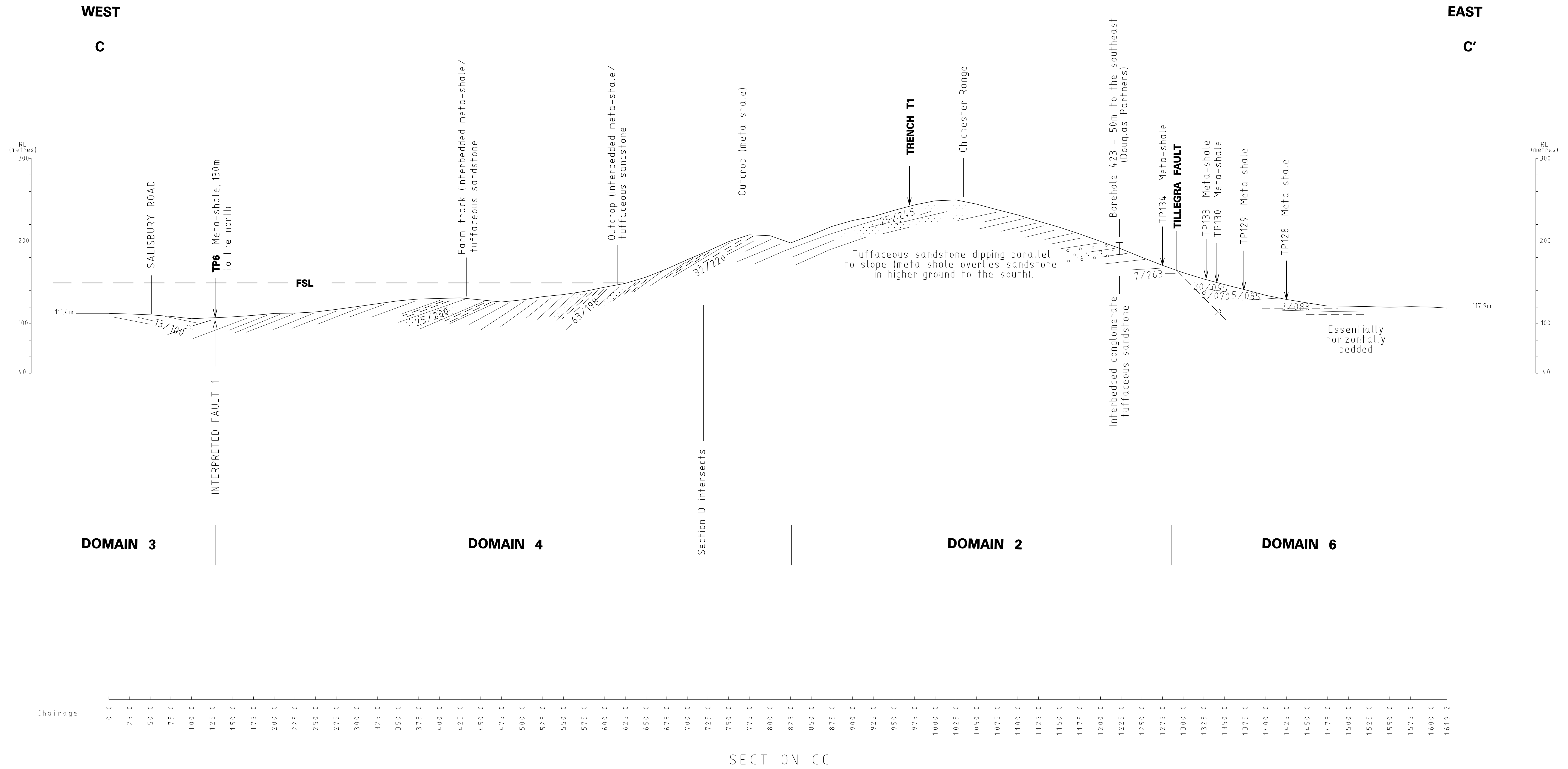

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TILLEGRA DAM
SECTION C – C′
Chichester Range

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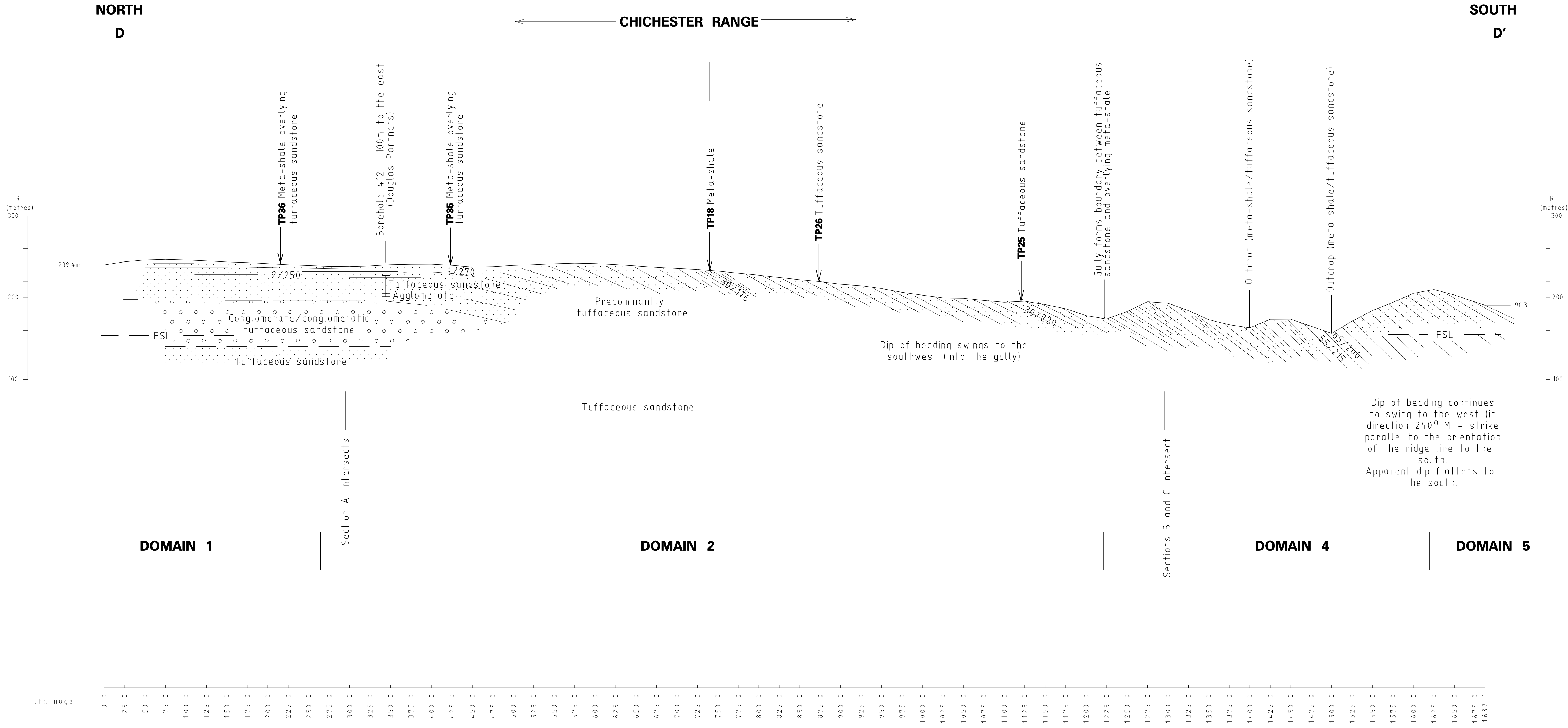

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TILLEGRA DAM
Section D - D'
CHICHESTER RANGE

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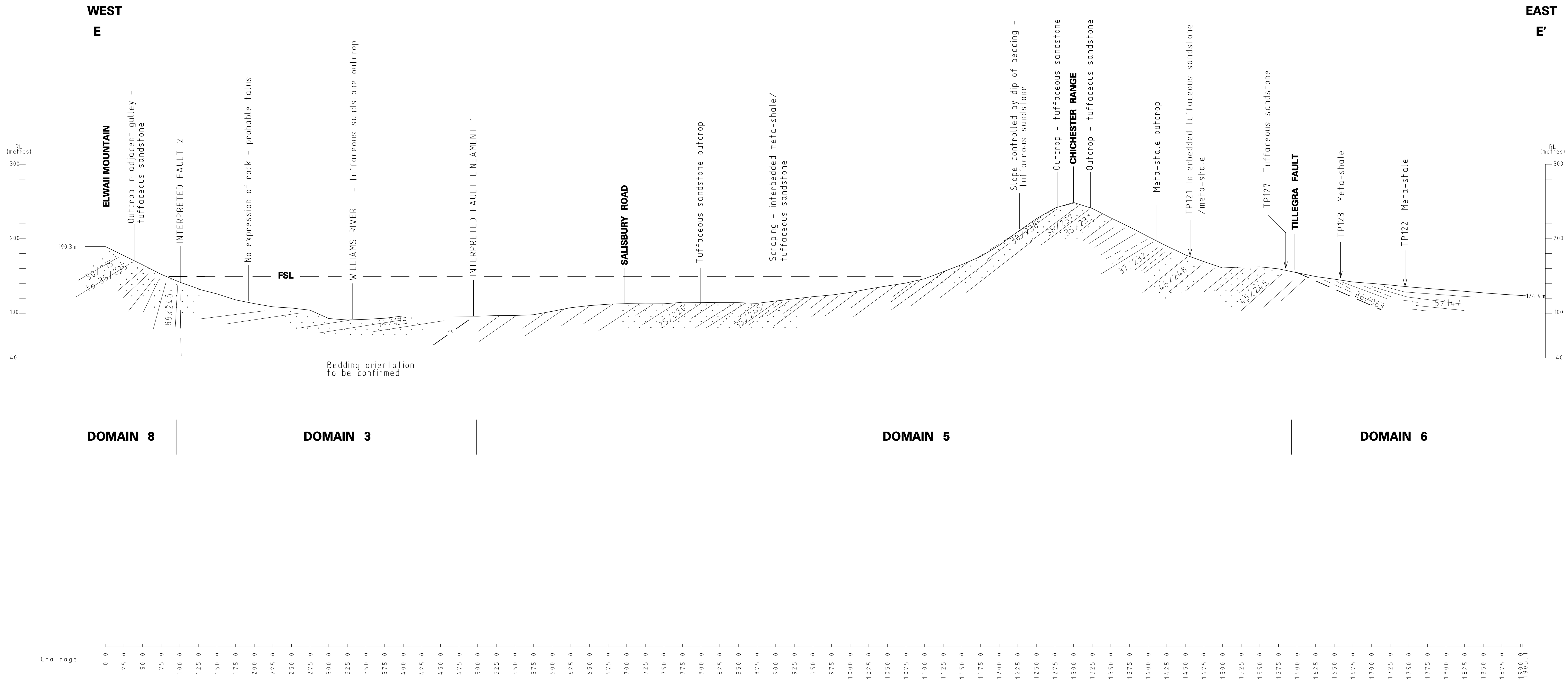

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CHECKED: J.F.YOUNG — JANUARY 2009

NSW Department of Commerce

TILLEGRA DAM
SECTION E – E'
CHICHESTER RANGE

FILE NO. **GN31A**
FIGURE NO. **7**

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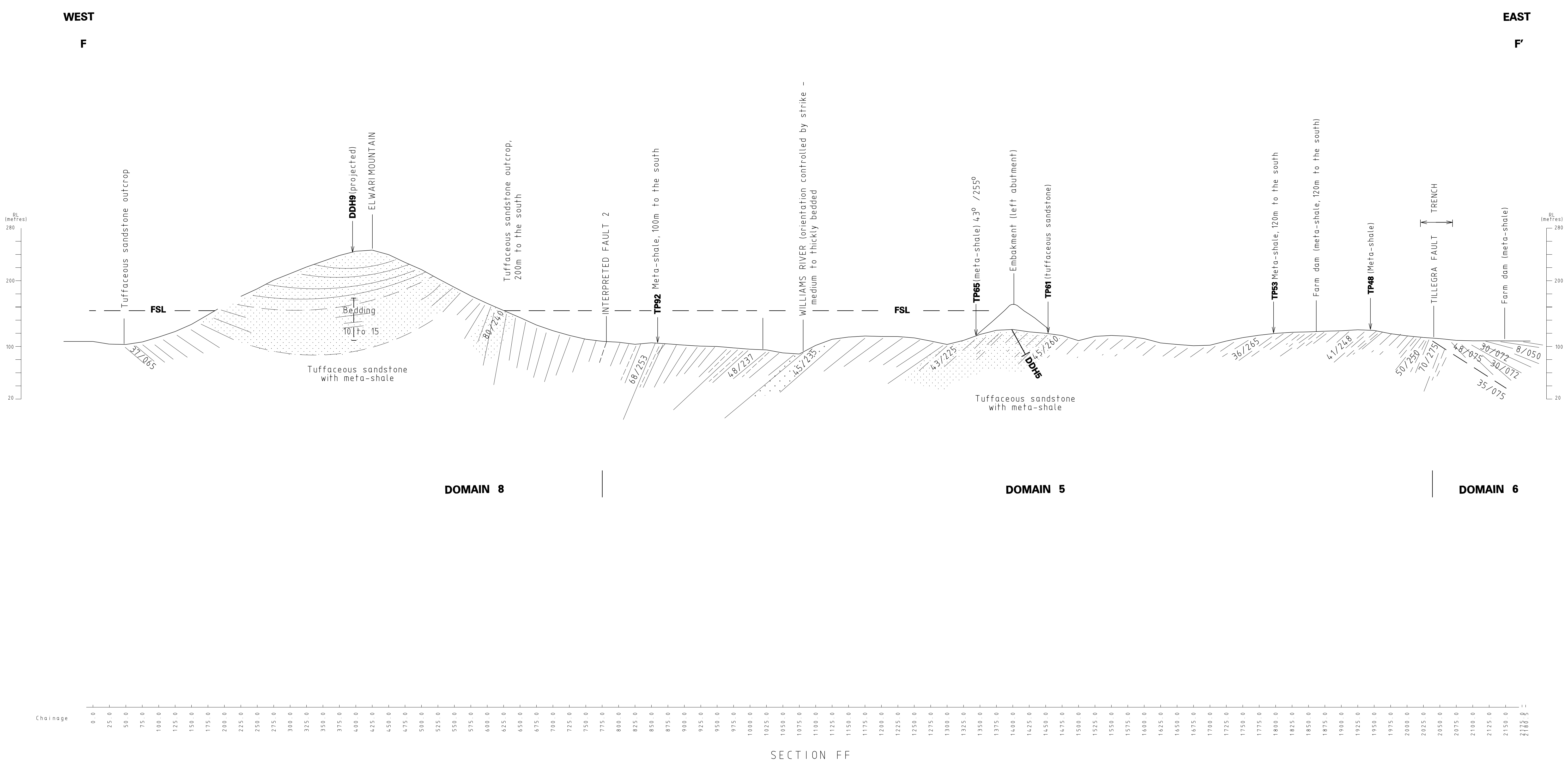

DAVID CALLAHAN Acting Director General – N.S.W. Department of Commerce NEW SOUTH WALES WATER SOLUTIONS WATER TECHNOLOGIES LEVEL 13, McKELL BUILDING 2-24 RAWSON PLACE SYDNEY 2000 PHONE (02) 93727873 FAX (02)93727877	GEOTECHNICAL & ENVIRONMENTAL	PROJECT GEOLOGIST J.F.YOUNG SUPERVISOR DRAFTED J.D.EDWARDS CHECKED J.F.YOUNG JANUARY 2009	NSW Department of Commerce	TILLEGRA DAM SECTION F – F' Left Abutment

FILE NO. GN31A

FIGURE NO. 8

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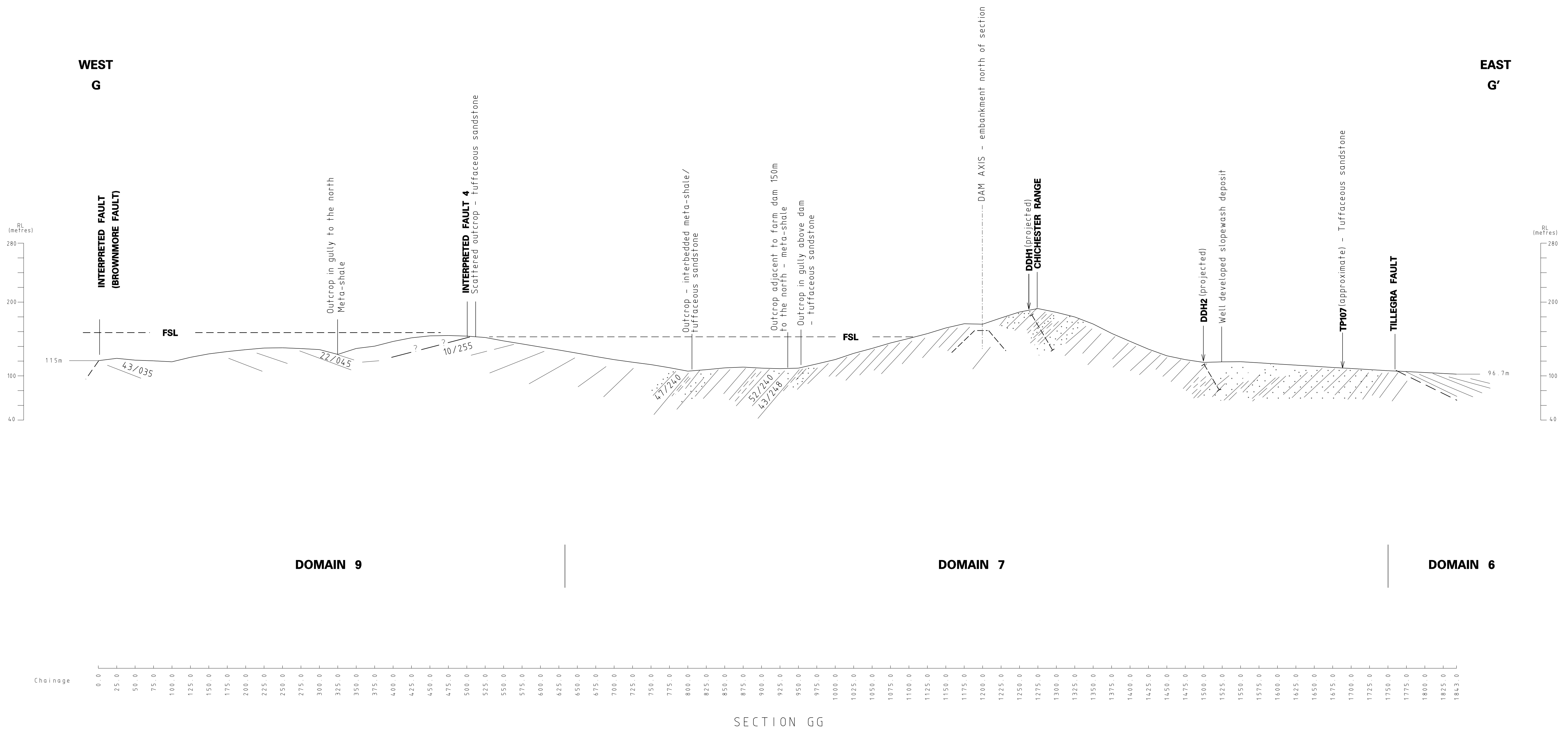

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TILLEGRA DAM
SECTION G – G'
Right Abutment

FILE NO. **GN31A**
FIGURE NO. **9**

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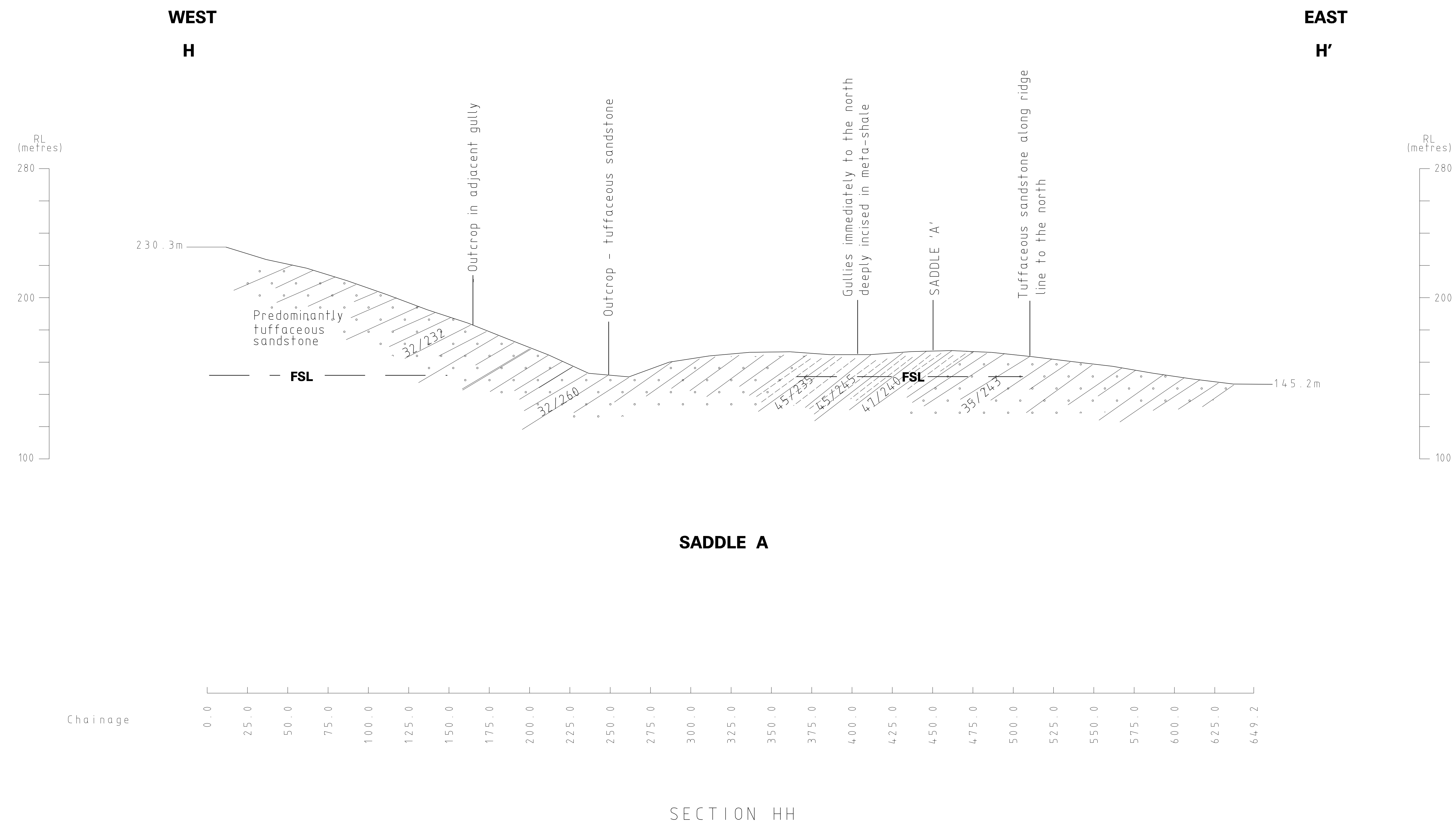

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TILLEGRA DAM
SECTION H – H'
Saddle 'A'

FILE NO. GN31A
FIGURE NO. 10

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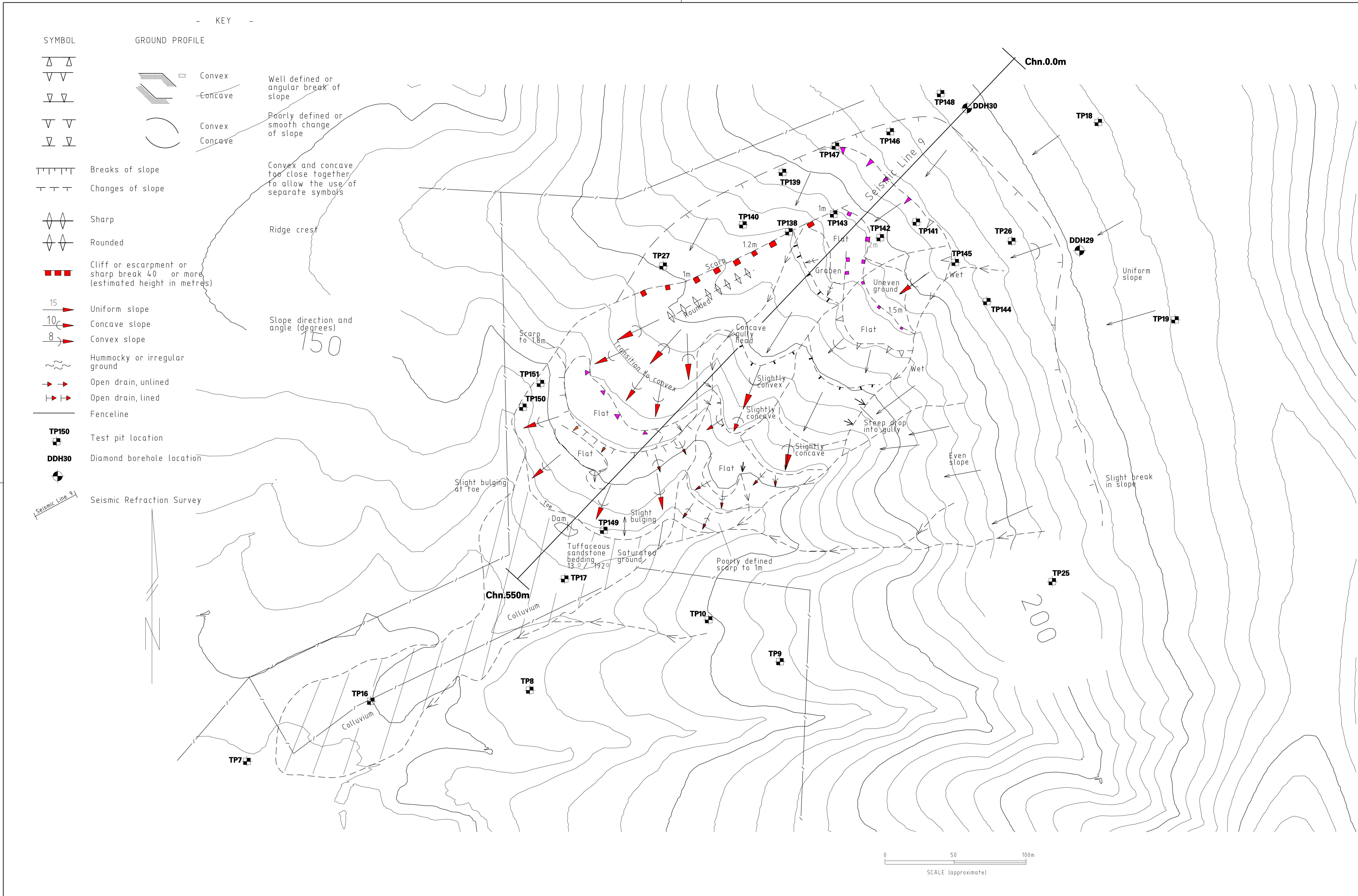

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NOVEMBER 2008

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TILLEGRA DAM
SLIP 2A
Geomorphological Map

FILE NO. GN31A
FIGURE NO. 11

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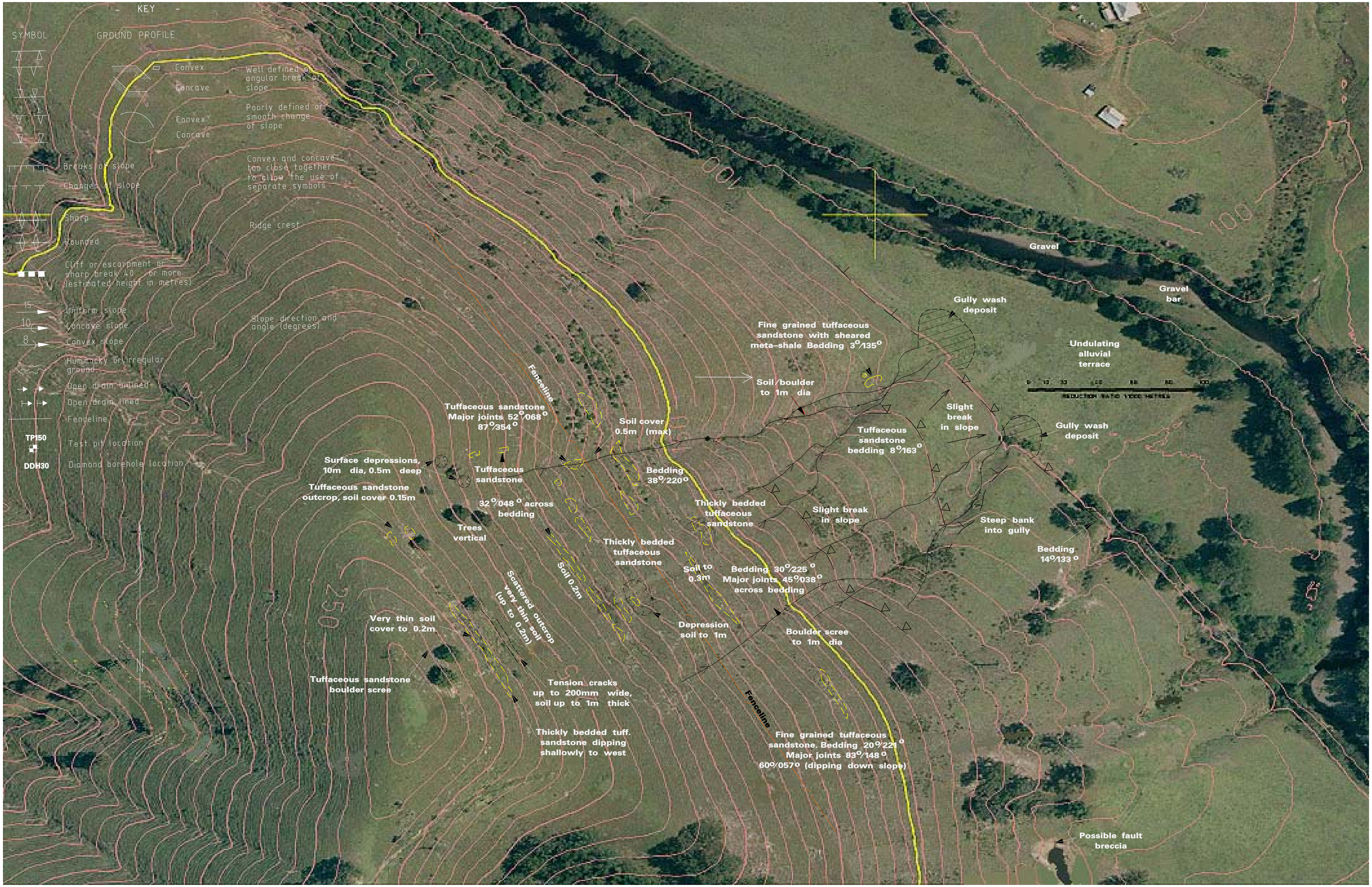

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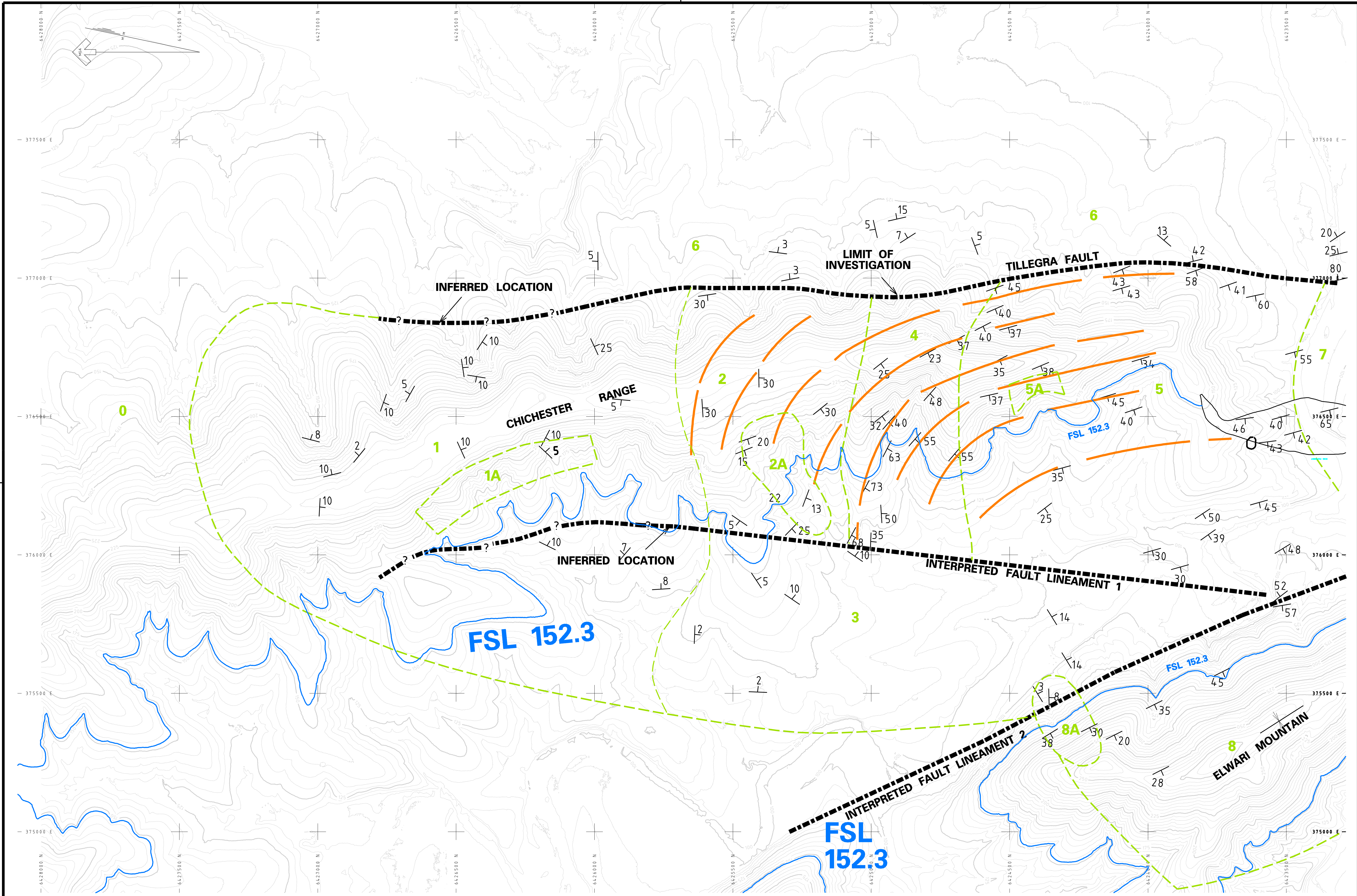
TILLEGRA DAM AREA 8A

FILE NO. GN31A
FIGURE NO. 12



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

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TILLEGRA DAM
Bedding Orientation
CHICHESTER RANGE

FILE NO. GN31A
FIGURE NO. 13

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