



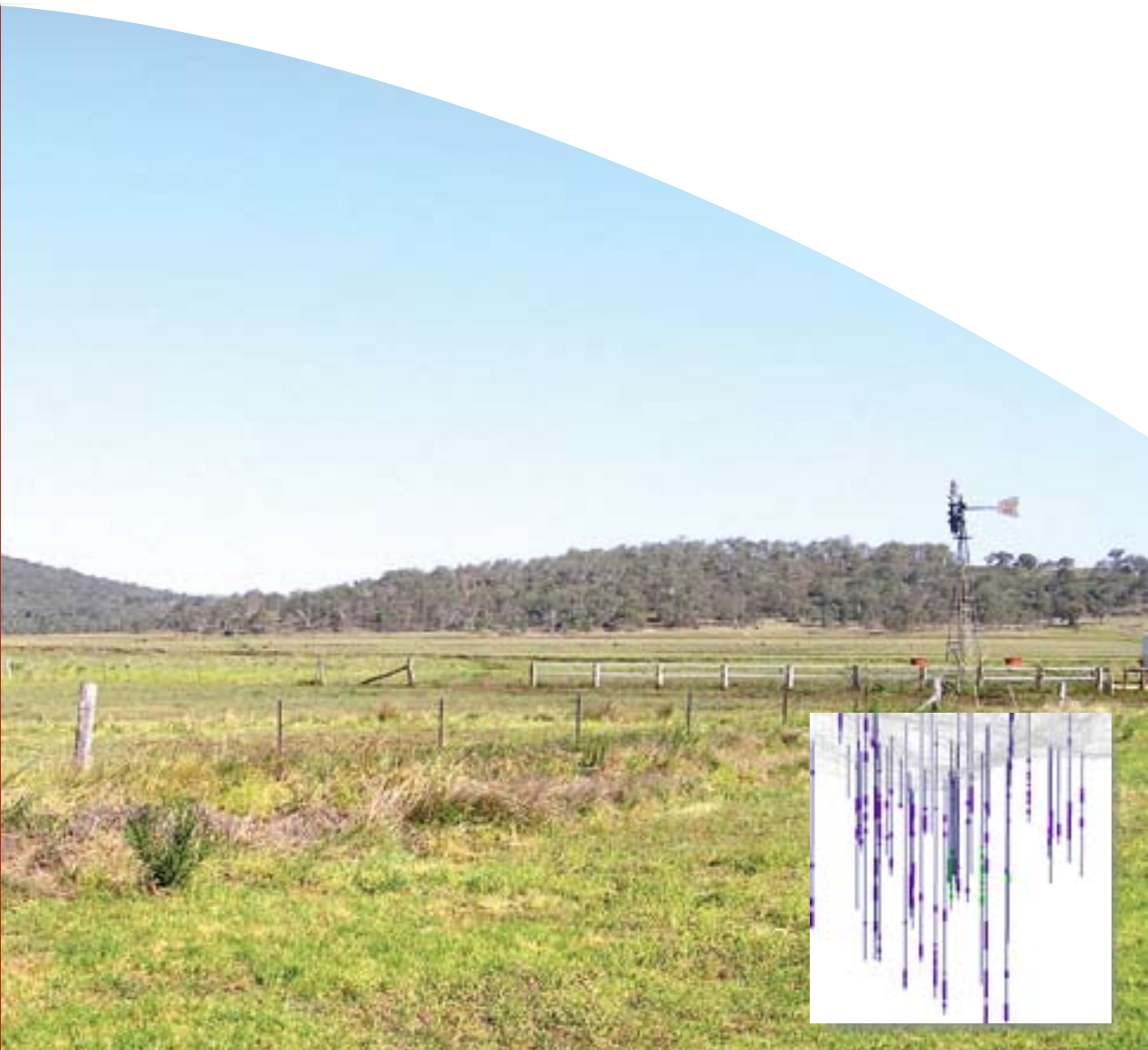
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3D Geologic Modelling for Groundwater Applications in the Condamine Headwater Sub-catchments, Queensland

P. English, J. Levett, S. Lewis and J. Sandow.

Record

2008/03



3D Geologic Modelling for Groundwater Applications in the Condamine Headwater Sub-catchments, Queensland

A Pilot Project for the Condamine Alliance

P. English¹, J. Levett², S. Lewis¹ and J. Sandow¹

GEOSCIENCE AUSTRALIA RECORD 2008/03



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Executive Summary

Geoscience Australia has developed a computer-generated 3D model which conceptualises the key hydrogeological components of the Hodgson and Kings Creek sub-catchments in south-eastern Queensland. These are headwater tributaries of the Condamine River, and are situated in the agriculturally important Darling Downs region south-west of Toowoomba. Groundwater is an important resource for rural communities and landholders in the area, and is used extensively for crop irrigation, stock and domestic purposes, and town water supplies. Our principal objective in building the 3D model was to help promote greater understanding and appreciation of the region's groundwater resources among the numerous local people and communities that rely upon groundwater, but who may not be familiar with the key concepts and principles which govern its intrinsic behaviour. Additionally, the model can be applied by surface water and groundwater scientists, water planners and natural resource managers to assist in the ongoing study, management and administration of the region's important aquifer systems.

Approximately 80 % of groundwater extracted from the Hodgson and Kings Creek sub-catchments is derived from the Main Range Volcanics (MRV). The MRV comprises Tertiary basalts and minor tuffs which are widespread across the Darling Downs, and have a nominal thickness of up to 200 m in the study area (and likely up to ~300 m beneath the nearby Great Dividing Range). A significant weathered basalt profile typifies the landscape surface, comprising fertile soils and lateritic material. Local and intermediate groundwater flow systems occur in the fractured rock aquifers of the MRV. Bore yields are highly variable due to the complex and irregular nature of high permeability networks which control the movement of groundwater. Subhorizontal water-bearing zones are predominantly hosted in weathered or vesicular basalt, commonly in the upper parts of individual layers. Significant subvertical discontinuities also provide important fluid pathways within the MRV; these include faults and fractures, columnar or radial joint networks, and the overlapping edges of terminal palaeo-lava flows.

The Jurassic Walloon Coal Measures unconformably underlie the MRV and provide locally important aquifers in the Hodgson and Kings Creek sub-catchments. Most water-bearing zones in this system occur in coarse-grained sandstone and conglomerate beds, or in narrow coal seams (mostly < 2 m thick). Regional groundwater flow systems occur in these Jurassic rocks, which have only limited hydraulic connection with the overlying volcanic rocks. Minor volumes of groundwater are also sourced from Cainozoic alluvium in both sub-catchments, particularly thicker such deposits in the valley floors. The sporadic distribution and discontinuous nature of these unconsolidated sediments however, tend to limit the usefulness and reliability of alluvial aquifers.

Development of the 3D computer-generated model relied heavily on water bore data (borehole logs) obtained from water drilling operations conducted in the local area over the past 60 years. These data were of variable quality and consistency and required significant analysis and modification to enable modelling. Data from approximately 1100 water bores was selected to build the hydrogeological model. Critical components of our 3D model include borehole collar locations and total hole depths, the significant water-bearing intersections in each hole (colour-coded based on hydrostratigraphic unit), and the boundaries of the main hydrostratigraphic units, such as the unconformable contact between the Walloon Coal Measures and the MRV. The 3D model also accurately depicts the surface topography across the sub-catchments (digital elevation model), and the location of significant natural and cultural landmarks such as streams, towns and roads. Additionally, a variety of 2D maps and images can be draped across the DEM; these include regional surface geology maps, remotely sensed satellite images, and various available coarse-

resolution geophysical datasets that cover the area, at least partially, e.g., airborne magnetics and electromagnetics survey data.

Further development of the 3D conceptual model described here is warranted to address specific natural resource management issues. Future modelling could potentially take many forms, and depends largely upon the needs and priorities of key stakeholder groups and end-users. We recommend trialling the 3D modelling approach in other sub-catchments of the Condamine River, especially those with markedly different geological structure and composition, i.e., not volcanic rock-dominated. Eventually, the entire Condamine River basin could be modelled, although this should proceed on a sub-catchment basis. Other suggestions for future work include addressing specific hydrological problems focussed on smaller areas of the Hodgson and Kings Creek sub-catchments, where more comprehensive and reliable borehole data exists, e.g., modelling temporal changes in the standing water level across multiple monitoring bores. Additionally, the 3D model could also be used to investigate hydrological processes associated with groundwater dependant ecosystems, or to better understand the nature of surface water and groundwater interactions within the sub-catchments or between these relatively well-studied areas and adjacent/subjacent aquifer systems.

Introduction

RATIONALE

The recent prolonged drought and associated water crisis in eastern Australia has highlighted the need to effectively plan the allocation of limited water resources. This requires a strategic understanding of the impacts of over-extraction of the connected groundwater–surface water resource. In areas where groundwater is a significant component of the connected water system, there is often extensive ‘point’ information about aquifers from driller’s descriptions of the materials encountered while drilling groundwater boreholes. It is not straightforward, however, to integrate this information across the landscape. Understanding the distribution of subsurface water-bearing zones, and the likely movement of groundwater within aquifers, requires considerable interpretation between water bores. This can be extremely challenging for specialists and non-specialists alike, particularly in complex hydrogeological areas such as the upper Condamine catchment, south-east Queensland.

A 3-dimensional geologic model (computer-generated) for groundwater applications has been developed by Geoscience Australia as a pilot project for the Condamine Alliance, to provide a conceptual framework for better understanding groundwater in the Hodgson and Kings Creek sub-catchments. The pilot project aims to integrate existing datasets, such as bore logs and digital elevation models, to construct a conceptual 3D geological model appropriate for land and water applications, particularly for future hydrogeologic modelling. It is hoped that this conceptualisation will advance understanding of the upper Condamine groundwater system and encourage better communication between hydrogeologists, catchment managers and land users.

THE PROJECT

The pilot project comprised two stages for the first half of 2007:

STAGE 1: Data review and feasibility assessment; and

STAGE 2: Model design and construction.

These stages are documented in the present report. Potential further work, to build 3D models of additional sub-catchments or a ‘whole-of-catchment’ groundwater model, is contingent upon the outcomes of these initial phases and stakeholder requirements.

SCOPE

The project builds on the 3D visualisation capacity at Geoscience Australia which has augmented various geologic, ore body definition and estuarine projects¹, e.g., Ruperto and Nicoll, 2007. The project also draws upon recent advances in the USA and Canada² where 3D geologic mapping for groundwater systems has been underway for approximately five years, particularly work coordinated by the Illinois State Geological Survey, e.g., Thorleifson et al., 2005; Bajc and Newton, 2005.

The Condamine 3D Project is Geoscience Australia’s first 3D application to a hydrogeologic or groundwater problem. The objective here is to provide a useful interactive tool to communicate

¹ <http://www.ga.gov.au/map/web3d/>

² http://www.isgs.uiuc.edu?3DWorkshop/nu_3d_welcome.html

complex geological–hydrogeological relationships to the Condamine catchment managers, other scientists and the wider community. At the technical level, the objective is to be able to turn data layers on and off and manipulate the model by rotating, zooming and panning to explore hydrogeological relationships from any aspect. These functions will aid interpretation of the groundwater distribution and enhance understanding of the hydrogeologic system and groundwater processes. Given that the project is a new application of 3D geologic modelling, it has experimental components for which no pre-existing templates are available. The study area in the upper Condamine catchment was selected because it is data-rich and agriculturally important; thus, an enhanced understanding of the groundwater system is highly desirable. Initial stages of the project included a field reconnaissance of the Hodgson and Kings Creek study area with hydroscintists from the Queensland Department of Natural Resources and Water (QDNRW). The project brings together relatively new 3D geologic modelling techniques – developed largely for the mining industry – with subsurface geologic and hydrogeologic datasets from a dynamic hydrologic system.

This report is a synthesis of two Geoscience Australia client reports written for the Condamine Alliance during the pilot project:

REPORT 1: '3D Groundwater Conceptual Model Pilot Project: Feasibility Report for the Condamine Alliance, Queensland' (May 2007).

REPORT 2: '3D Groundwater Conceptual Model – Pilot Project for the Condamine Alliance: 3D Modelling and Visualisation of the Hydrostratigraphic Systems in the Hodgson and Kings Creek sub-catchments' (August 2007).

Sections of Report 1 that outlined feasibility phases and ‘teething problems’ are excluded from the present report. The project has relied heavily on data provided by the QDNRW, and on Earth Decision Suite software (Gocad) and the expertise of Mira Geoscience³. This report summarises the task of generating a 3D model using Gocad and outlines the multi-step process, providing:

1. An overview of the rationale and scope of the project;
2. A summary of the geology and hydrogeology of the study area;
3. Concepts and features of 3D geologic modelling;
4. Analysis of the hydrostratigraphic data which provided the foundation for building the model;
5. An overview of Gocad software, routines and methods used to construct the 3D components of the model, including a selection of random screen snapshots;
6. An overview of the groundwater system in the Condamine headwater sub-catchments;
7. Recommendations for further work which may enhance the 3D model or for modelling wider reaches of the Condamine catchment; and
8. Appendices summarising bore data analysis, some of the technical procedures, and contour plots of total aquifer thickness and yields.

³ Mira Geoscience: <http://www.mirageoscience.com/products/gocad.php>

Existing Information

THE STUDY AREA

The pilot study area covers Hodgson Creek and Kings Creek sub-catchments, in the eastern part of the Condamine River basin, south-eastern Queensland (Figure 1). These adjacent sub-catchments are located immediately south and west of Toowoomba and form part of the eastern Darling Downs, in the northern headwaters of the Murray-Darling catchment. Topographic relief ranges from close to 700 m AHD on the Great Dividing Range near Toowoomba, to 400 m AHD at the confluence of Hodgson Creek with the Condamine River. Hodgson Creek sub-catchment covers an area of 792 km², and Kings Creek sub-catchment 796 km².

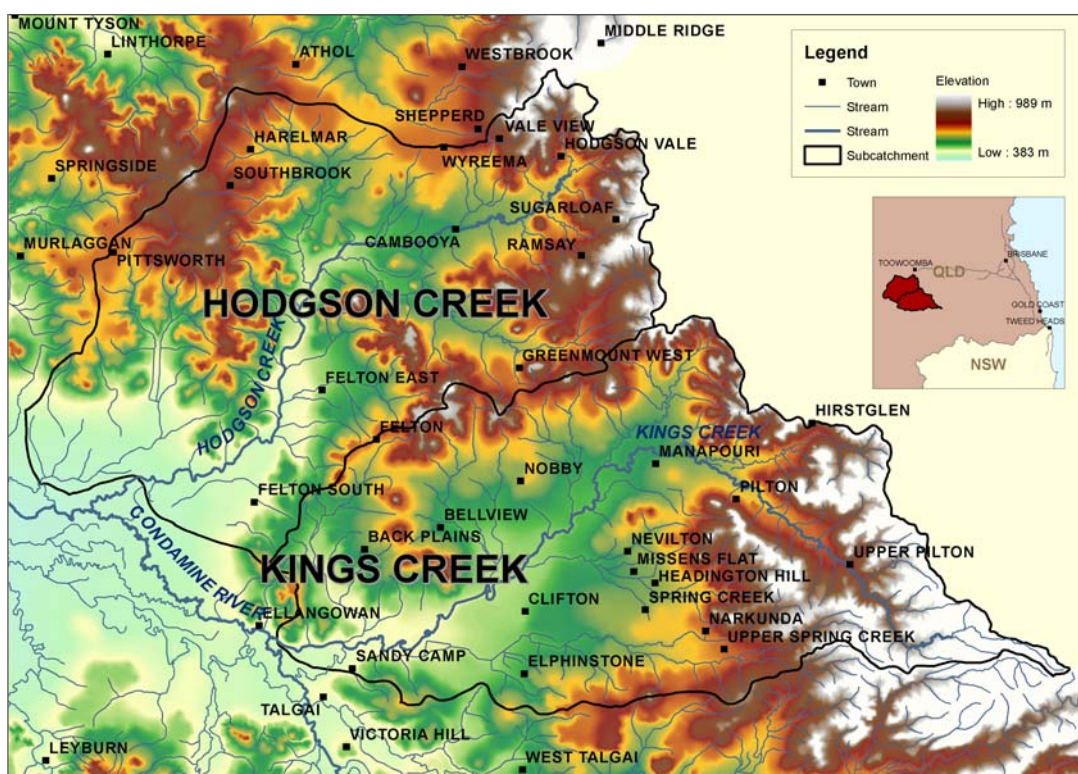


Figure 1: A shaded relief contour map showing sub-catchment boundaries (black) of Hodgson Creek and Kings Creek, the upper Condamine River drainage network and the many local communities (north to top of page). Location in south-east Queensland is shown in the inset box. Map dimensions are approximately 100 km east-west and 80 km north-south.

Umbiram and Emu Creeks are the main tributaries in the Hodgson Creek sub-catchment. A synopsis of Hodgson Creek catchment, with respect to conceptualising groundwater–stream interaction is provided in Reid et al. (2007). The landscape varies from rocky ridges and scattered volcanic cones to undulating plains. The region has fertile soils and is a highly productive agricultural part of the Murray-Darling Basin. The area was first settled by Europeans around 1840 when it was used primarily for grazing. Floodplain and lowland regions have mostly been cleared of native vegetation including riparian and floodplain woodlands; remnant vegetation cover is around 20% (Figure 2). Mountain Coolabah and Ironbark trees are common on basalt hills, with grazing occurring under some woodland (Rattray et al., 2002). Patches of Brigalow/Belah, Poplar Box, Ironbark, Bullock and

Cypress Pine are associated with sandstone areas. Cleared land is used for dryland and irrigated cropping, pastures, grazing and horticulture. Winter crops (wheat, barley, oats and chickpeas) and summer crops (sorghum, sunflower and maize) are supported by the fertile soils and a favourable climate. Cattle and sheep are commonly grazed.

Regional issues associated with water quality include: pesticides in cropping areas; high sediment and nutrient loads in runoff from cropping, grazing and urban development; and accelerated bank and gully erosion in some areas. Valley infilling occurred after agricultural development by extensive sheet, rill and gully erosion. Groundwater is an important source of water for crop irrigation, and for stock and domestic water supplies in the rich eastern Darling Downs agricultural region. It is also a secondary source of water supply for Toowoomba (population 100 000, the second largest city in the Murray-Darling catchment after Canberra, and the largest inland city in Queensland) and surrounding communities, supplementing surface water stores, and is a strategic resource for future expansion of the peri-urban area (Willey, 2003). Average annual rainfall varies from over 900 mm in Toowoomba to 650 mm in the upper Condamine River valley, and is summer dominant. A strong rain shadow exists on the Eastern Darling Downs, in the lee of the Great Dividing Range. Irrigation water is largely sourced from basalt aquifers from a range of depths, shallow to ~ 150 m. The extent of irrigated land is greater in Kings Creek sub-catchment (20%) compared to Hodgson Creek sub-catchment (<10%). Urban expansion has placed pressure on both premium agricultural lands and water resources.



Figure 2: SPOT5 image of the study area (2.5m resolution; 15 Sept. 2006), showing the Great Dividing Range in the northeast, the Condamine River in the southwest and the largely agricultural landscape. Area shown is approximately 80 km east-west and 60 km north-south (Source: Geoscience Australia National Mapping Group).

GEOLOGY

The regional geology has been mapped and described by Wells and O'Brien (1994a and 1994b) and is also summarised by Whitaker and Green (1978). Early work on the volcanic rocks was documented by Stevens (1968), and more detailed geologic information and mapping in the study area provided by Willey (1992). The regional geomorphology was interpreted by Ollier and Harworth (1994). The area is dominated by two main rock units: a near-horizontal to gently dipping Middle Jurassic sedimentary sequence of the Moreton-Clarence Basin, part of the Great Artesian Basin, and the mid-Tertiary Main Range Volcanics (MRV), extending up to 50 km westward from Toowoomba. These strata unconformably overlie a concealed basement of Palaeozoic rocks, the New England Orogen.

Middle Jurassic sedimentary sequence

Jurassic strata crop out in the lower parts of the sub-catchments near the Condamine River; these are dominantly Walloon Coal Measures (shale, siltstone, sandstone, coal, mudstone and limestone). The Marburg Formation (sandstone, siltstone, shale, grits, conglomerate and oolitic ironstone) conformably underlies the finer-grained Walloon sediments although, in the study area, it only sub-crops in the lower part of Kings Creek sub-catchment⁴. The Marburg Formation conformably overlies the medium- to coarse-grained, quartz-rich Triassic-Jurassic Helidon Sandstone in the northern part of the study area. Recent water bore drilling in Toowoomba (RN1 19852) penetrated coarse sandstone of the Helidon Sandstone at 562 – 620 m (pers. comm., A. McKay, DNRW, May 2007). Faulting of Jurassic strata is revealed in coal seams in the gently dipping Walloon Coal Measures. In the southern part of the study area, the Marburg Formation unconformably overlies basement rocks, namely the Carboniferous Texas Beds that outcrop on the south-western bank of the Condamine River, immediately outside the study area. The Marburg Formation and underlying strata and basement rocks are not included in the 3D model because they are either absent or poorly described in the water bore logs used to build the model.

Mid-Tertiary Main Range Volcanics (MRV)

MRV basalts and derived soils make up over 80% of the study area. The MRV olivine basalts and subordinate basaltic tuffs are well exposed along the Great Dividing Range. Numerous eruptive centres are scattered across the rolling uplands (Figure 3); these comprise former lava pools that once infilled tuffaceous crater cones; the latter have commonly been subjected to post-eruptive erosion (Willey, 1995).

The MRV lie unconformably on Moreton-Clarence Basin sediments. The unconformity occurs at around 440 – 460 m AHD, indicating a nominal basalt thickness ~ 200 m, with a maximum thickness of approximately 280 m in the elevated uplands (Kalma, 1995). Basalts around Toowoomba were investigated in detail by Stevens (1969). Numerous small overlapping basaltic lava flows are represented. The prominent edges of the flows have been mapped by Willey (1992) and at least 16 flows documented (Willey, 2003); individual flows extend up to 80 km². Vertical columnar joints, and vesicular, amygdaloidal or “bubbly” flow tops produced by successive eruptions, significantly impact on hydrogeologic processes. Silcrete and ferricrete is locally associated with MRV basalt, particularly around Toowoomba. Land surfaces and soils formed on basalt flows before, during and after discrete extrusive events. Sloping MRV landscapes are mantled with shallow soils and basaltic colluvium. The heterogeneity of more porous and permeable MRV units impacts greatly on the local groundwater system (this is discussed further below).

⁴ Descriptions of sediments in logs for drill-hole in the study area do not readily distinguish between Walloon and Marburg formations. Minor outcrops of the Marburg Formation mapped at the southern edge of Kings Creek sub-catchment are not penetrated by reliable bore logs so this unit is not differentiated in the 3D model.



Figure 3: A prominent hill composed of Main Range Volcanics, representing a former eruptive centre, and a QDNRW monitoring bore in the Hodgson Creek sub-catchment.

Cainozoic alluvium and soils

Valleys incised into both the MRV units and basal Mesozoic sediments are infilled with Cainozoic colluvium and alluvium. Valleys are relatively steep-sided in up-catchment areas, grading to mature broad alluvial valleys downstream near the Condamine River. Extensive sheet, rill and gully erosion following agricultural development enhanced valley infilling in recent times. Colluvium derived from the MRV typically blankets outcrops of the Walloon Coal Measures on gentle lower slopes. Alluvium forms floodplains and river terraces in lower parts of the sub-catchments but functions as only a thin or discontinuous aquifer within the study area. Condamine River alluvium and sediments comprise a complex system of fluvial channel deposits and floodplain accumulations sourced from basalts and Jurassic sediments as well as regional basement rocks exposed in the south (Willey, 1992); sand and gravel beneath clays in the Condamine River alluvium function as aquifers.

Two general soil types are represented: **red soils** of the Toowoomba Plateau and **black-brown soils** of the eastern Darling Downs (Thompson and Beckman, 1959; Willey, 2003). Both of these soils are highly fertile. Macnish et al. (1987) argued that lateritisation or bauxitisation of weathered MRV basalt was less important in the development of the red ferrosols than derivation from widespread inter-basaltic tephra of similar composition. A strong correlation is observed between pre-exposure weathering of the substrate and soil chemistry, i.e., soils with very "old" chemistry forming in the contemporary environment, because the parent material was heavily weathered prior to being buried by subsequent basalt flows, and then re-exposed. Accordingly, these soils forming *in situ* today cannot be regarded as palaeosols; although true palaeosols occur around Toowoomba, they are not common (pers. comm. A. Biggs, DNRW, May 2007).

Additional soil types, namely skeletal soils of the rocky escarpment and sandy-gravelly soils developed on alluvium, have relatively low fertility. The approximately 60 mm difference in rainfall between the east and west of Toowoomba is reflected in associated differences in soil chemistry and

characteristics (pers. comm. A. Biggs, DNRW, May 2007). Despite contrasting pedogenesis, the soils are typically deeply weathered and highly permeable throughout the region, a factor relevant to hydrogeologic functioning.

Landforms

The landforms are closely related to the lithology and geologic history of the region. Many geological units display characteristic landform features which influence hydrology and land use (Table 1).

Table 1: Geology and landforms (after Biggs, 2000).

GEOLOGICAL UNIT	DOMINANT LANDFORM
Quaternary alluvium	Level to very gently inclined plains with levees, stream channels, ox-bows, river terraces and prior streams, commonly complex systems; associated Quaternary sandy soils derived from erosion and re-distribution can be extensive.
MRV basalts	Complex landform patterns. In the east and north are very steep mountains and low hills associated with the Great Dividing Range. A large plateau is present on the top of the range around Toowoomba. Undulating rises and rolling low hills with some steep hills and gently undulating plains. A dissected landscape has resulted from stream incision associated with uplift and eustatic change.
Walloon Coal Measures (fine grained sediments)	Gently undulating plains and rises to undulating to steep, low hills and rises; boundary between some low slope areas with associated alluvia is often indistinct.
Marburg Subgroup (coarse grained sediments)	Undulating to rolling rises and plains with some steep low hills, generally steeper than the terrain associated with finer sediments.

Hydrogeology

GROUNDWATER FLOW SYSTEMS

The following groundwater flow systems have been described within the Hodgson and Kings Creek sub-catchments (Biggs and Power, 2003):

- **Cainozoic basaltic rocks:** intermediate flow systems in basaltic rocks (MRV) on rises and low hills;
- **Cainozoic basaltic rocks:** local flow systems in basaltic rocks (MRV) on plateaux;
- **Cainozoic unconsolidated sediments** intermediate flow systems in unconsolidated sediments on alluvial plains; and
- **Terrestrial and carbonaceous sedimentary rocks:** regional flow systems in terrestrial sedimentary rocks (Jurassic strata) on rises and low hills.

Additionally, regional flow systems associated with coarse-grained Marburg and Helidon strata of the Moreton-Clarence Basin underlie the Condamine River alluvial plains and occur at substantial depth beneath the Main Range Volcanics. For example, recent drilling in Toowoomba (RN119852) encountered groundwater in the Helidon Sandstone of the Great Artesian Basin, at 562-658 m; the SWL is around 250 m depth (Table 2).

Table 2: Log for RN119852 borehole in Toowoomba, drilled in 2007.

STRATA TOP (M)	STRATA BASE (M)	STRATA DESCRIPTION	UNIT NAME
0	2	top soil	soil
2	48	basalt	Main Range Volcanics
48	85	puggy clay and shale	Walloon Coal Measures
85	113	sandy shale	
113	151	grey shale	
151	160	coarse sand and white clay	
160	188	coal bands and grey shale	
188	255	grey shale	
255	562	sandstone and clay	Marburg Formation
562	620	coarse sandstone	Helidon Sandstone
620	658	clay bands, very fine sandstone	

GROUNDWATER PROCESSES

Within the Cainozoic MRV systems, vesicular basalts and associated red weathering products/soils are important horizontal water-bearing zones (van der Zee and Macnish, 1979). Irrigation water is largely sourced from basalt aquifers, e.g., [Figure 4](#). The presence of numerous small, overlapping lava flows and columnar joints associated with former eruptive centres (e.g., [Figure 3](#)) creates vertical and horizontal hydraulic discontinuities compared to the groundwater system in the underlying Walloon Coal Measures (Kalma, 1995). The upper weathered basalt unit at the top of the MRV is important for groundwater recharge during heavy precipitation events, with a delay period of about a month between rainfall and recharge. This major recharge zone feeds creekbeds incised into the permeable pallid base of the weathered unit, even during dry periods (Willey, 2003). The dominant stream alluvium in upper valleys is cracking clay; baseflow here relates to springs

discharging at the edges of streambed aquitards. The main features of the hydrological system in the Hodgson and Kings Creek sub-catchments are shown in [Figure 5](#).

Groundwater recharge occurs following rainfall rates of 100–150 mm/month, with 3–6 days delay between rainfall events and peak groundwater levels in the upper catchments (Willey, 2003), and lag times of the order of 4–7 months for bores in basalt beneath deep clay alluvium (Silburn et al., 2006). Unlike drier regions elsewhere in the Murray-Darling catchment, the unsaturated zone here does not appear to have a large historic moisture deficit that needs to be filled for deep drainage to become recharge. Thus, deep drainage recharges aquifers within several months and excess groundwater is accordingly transferred down-gradient to the land surface or streams within a year (Cresswell et al., 2006). Surface permeability has decreased across the Toowoomba Plateau through urban expansion, for example sealed roads and rooftops now intercept rainfall and reduce recharge.



Figure 4: *Sprinkler irrigation drawing on groundwater, Hodgson Creek sub-catchment.*

Watertable depths in monitoring bores range from <2 to 50 m below ground (Natural Surface = NS). In Hodgson Creek sub-catchment the watertable height decreases from 517 m to 426 m AHD over a distance of ~25 km, a hydraulic gradient of 0.003. Groundwater salinity increases progressively down-gradient, indicating continuity of the flow path (Cresswell et al., 2006).

Hodgson Creek is a ‘gaining stream’, receiving discharging groundwater as streamflow, although dry periods may see a reversal, with streambeds locally recharging underlying strata. The presence of baseflow is strongly influenced by the depth of stream incision. Baseflow no longer occurs in several streams, for example, in Hodgson Creek downstream of Cambooya, below the area of greatest groundwater use (Reid et al., 2007). Relatively stable groundwater levels occur at shallow depths throughout most of the alluvium (< 5m). Depth of stream incision and groundwater use for irrigation largely control the presence or absence of baseflow, e.g., groundwater is generally not far beneath the creekbed in non-irrigation areas. The system is strongly predisposed to groundwater–surface water interaction. The Kings Creek system shares similar characteristics (Huxley 1982).

Compared to the southern parts of the Murray-Darling Basin, salinisation is a minor problem. Typically in the upper Condamine catchment, saline outbreaks occur where groundwater flow is restricted at:

- a. Impermeable interbeds in the MRV or where there are permeability contrasts between different basalt layers;
- b. The boundary between basalt and underlying Walloon Coal Measures in lower parts of sub-catchments; and
- c. Creeks incised into alluvial aquifers where the hydraulic conductivity of a valley is very low, causing groundwater levels to rise (Kalma, 1995).

A notable saline outbreak occurs in the upper part of Umbiram Creek where a constriction in the MRV inhibits groundwater flow.

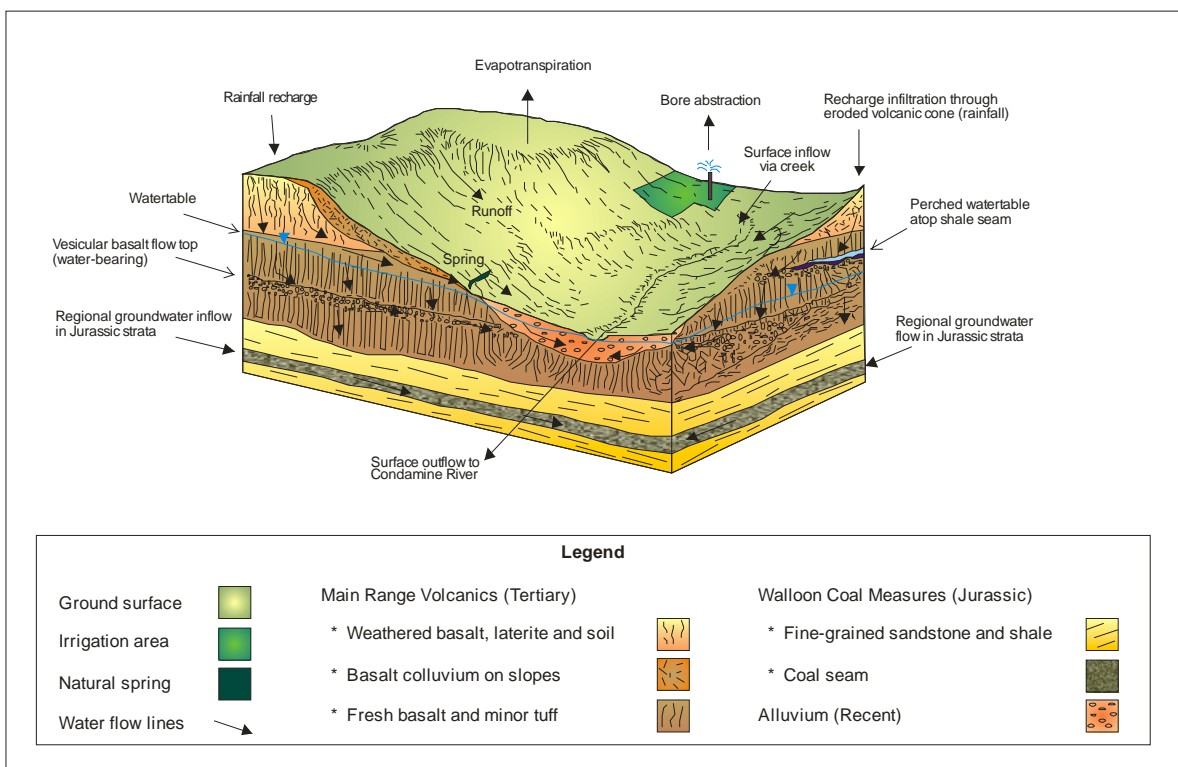


Figure 5: Conceptual model of groundwater systems in the Hodgson and Kings Creek district. The local to intermediate groundwater flow systems in the Main Range Volcanics (MRV) supply most of the agricultural and domestic water users in the region. Yields are highly variable in the MRV due to the complex and irregular distribution and interaction of subvertical and subhorizontal flow-paths, such as columnar jointing, vesicular zones and other structural discontinuities. Groundwater interaction occurs readily across the boundary between the MRV and alluvial sediments, but regional flow systems are dominant in the underlying Jurassic strata (diagram modified after Willey, 2003).

Aspects of the hydrology, hydrochemistry and salinity of the area, focussing on Hodgson Creek, are outlined by Dutta and Silburn (2005), McNeil and Silburn (2005), Silburn et al. (2005, 2006) and

Cresswell et al. (2006). Recharge in Hodgson Creek sub-catchment is estimated at around 14 mm/year; groundwater pumping rates (for crops, stock and domestic use) vary depending upon locality, but are in the order of 7–8 mm/year, with the difference contributing to baseflow in streams (Dutta and Silburn, 2005; Silburn et al., 2006). High recharge rates are likely to be promoted in the vicinity of the large number of MRV eruptive centres where columnar jointing is common.

The following observations by Cresswell et al. (2006) are based on hydrochemical data for over 470 bores in Hodgson Creek sub-catchment. Groundwater salinity increases down-gradient, ranging from 300 to 1300 mg/l Total Dissolved Ions (TDI). Most groundwaters are of Mg-Na-HCO₃-Cl type, reflecting the influence of weathering of the basaltic host rocks. More Na-Cl-rich groundwaters in the upper slopes may relate to evaporative concentration of infiltrated rainfall stored in the upper weathered unit at the top of the catchments. Stable isotope data indicate that the aquifers have been recharged dominantly from slightly evaporated rainwater (Cresswell et al., 2006). Radiocarbon (¹⁴C) determinations indicate that most groundwaters are modern (<100 years). Very low ¹⁴C concentrations (indicative age ~20 000 ka) from one deep bore may represent regional groundwaters in Walloon Coal Measures beneath the MRV (Cresswell et al., 2006). Streamwater samples that are dominated by groundwater input are more saline (EC ~1500-1800 µS/cm²) than those dominated by overland flow. Average stream salinity is around EC 300 µS/cm; salt export from the near-surface system is flushed from the sub-catchments during a few large annual flood events.

3D Model Development

PRELIMINARY STAGES

Initial phases of the project included field reconnaissance of the Hodgson – Kings Creek study area and a workshop in Toowoomba with hydroscintists from QDNRW, Geoscience Australia, CSIRO and Flinders University. Preliminary data review for the feasibility assessment involved the following datasets, information sources and tasks:

- A 25 m resolution digital elevation model (DEM);
- Surface geology map;
- Drainage and infrastructure map;
- Landsat TM data;
- Excel spreadsheets of water bore logs: Registered Numbers, coordinates, elevations, stratigraphic logs, bore construction details, groundwater monitoring data, etc;
- Assessment of surveyed bore collar elevation measurements with respect to the DEM;
- Creation of a 3D GIS environment; and
- Comprehensive literature review.

OVERVIEW OF THE 3D HYDROGEOLOGICAL MODEL

The model developed in Earth Decision Suite (Gocad) provides a functional 3D display of the Hodgson and Kings Creek sub-catchments. Methods used for this project are only an example of the tools available to 3D modellers, and it must be noted that model outputs are wholly dependent on the nature and quality of input data. The on-screen display can be viewed from any user-defined orientation, as the model can easily be moved, rotated and zoomed with simple commands. The following summary outlines the main components of the model:

Topographic features

- 1) **Digital Elevation Model** (DEM) showing the topography of the Hodgson Creek and Kings Creek sub-catchments. Created from a detailed 25 m resolution model and interlaced with coarse-scale DEM (300 m resolution) to cover discontinuities and expand the model beyond the catchment boundaries;
- 2) **Surface hydrological features** such as stream channels, water bodies and the location of (sparse) natural springs;
- 3) The boundaries of the **Hodgson and Kings Creek catchments**; and
- 4) The main **cultural features** such as towns, roads and railways;

Water bores

- 1) **Surface location of all water bores** in the Hodgson and Kings Creek catchments selected for use in this modelling exercise (core dataset); and,
- 2) **Vertical down-hole representations of borehole depths**, with marker zones down each hole trace showing the upper and lower boundaries of each stratigraphic unit and individual water-bearing zones.

Geological units

- 1) The unconformable **geological boundary** between the **uppermost surface of the Walloon Coal Measures and the lower Main Range Volcanics (MRV)**. This important geological horizon is represented as a surface across the entire region, i.e., a former planation surface on the Clarence-Moreton Basin, developed prior to extrusion of the basalts;
- 2) The interpreted **base of the Walloon Coal Measures**. This surface is a theoretical boundary only as most water bores in the area do not penetrate the base of the Walloon Coal Measures. The distribution of bores that penetrate to underlying strata is too sparse to generate additional surfaces. Such bores are included wholly in the 'Walloon Coal Measures' layer. This lowermost surface forms the base of the geological strata in the 3D model⁵;
- 3) The layer of Quaternary sediment cover and soil which blankets most of the region is too thin to be accurately represented as a continuous surface and has thus not been modelled; and
- 4) Surface geological boundaries showing **outcrop zones** of the Quaternary sediments and MRV across the catchments, as depicted on the 1:500,000 geological map (Wells and O'Brien, 1994), [Figure 8](#).

Geophysical datasets

- 1) **Gravity data**. A map of gravity data obtained from the on-line Geophysical Archive and Data Delivery System (GADDS) coincident with the catchment boundaries;
- 2) **Magnetics data**. Airborne magnetics data acquired by the Queensland Geological Survey and stored in GADDS, partially coincident with the catchment boundaries; and
- 3) **Remote Sensing data**. A SPOT5 satellite image of the Hodgson and Kings Creek region showing land use distribution and many natural and cultural features of interest ([Figure 2](#)).

⁵ The lowermost surface provides a base for the 3D model; it does not represent the lower limit of potential aquifers in the region nor a stratigraphic contact, but rather a surface that encompasses the bottom of bores used for model-building.

HYDROSTRATIGRAPHIC DATA ANALYSIS

Construction of the 3D model relied on water bore data for Hodgson and Kings Creek sub-catchments provided to GA by the QDNRW. These data required substantial modification and rationalisation before they could be used in the modelling software. This work involved scrutiny of approximately 2200 borehole logs to select a core dataset (~1100 logs in total) which satisfied the following criteria:

- a. Adequate geological information for modelling;
- b. Representation of the main water-bearing units (aquifers);
- c. Broad geographic distribution of boreholes across each catchment; and
- d. Availability of accurate coordinate and elevation data, e.g., GPS or survey measurements.

The distribution of bores used for model generation is shown in Figures 6–8, and bore data is summarised in [Appendix 1](#).

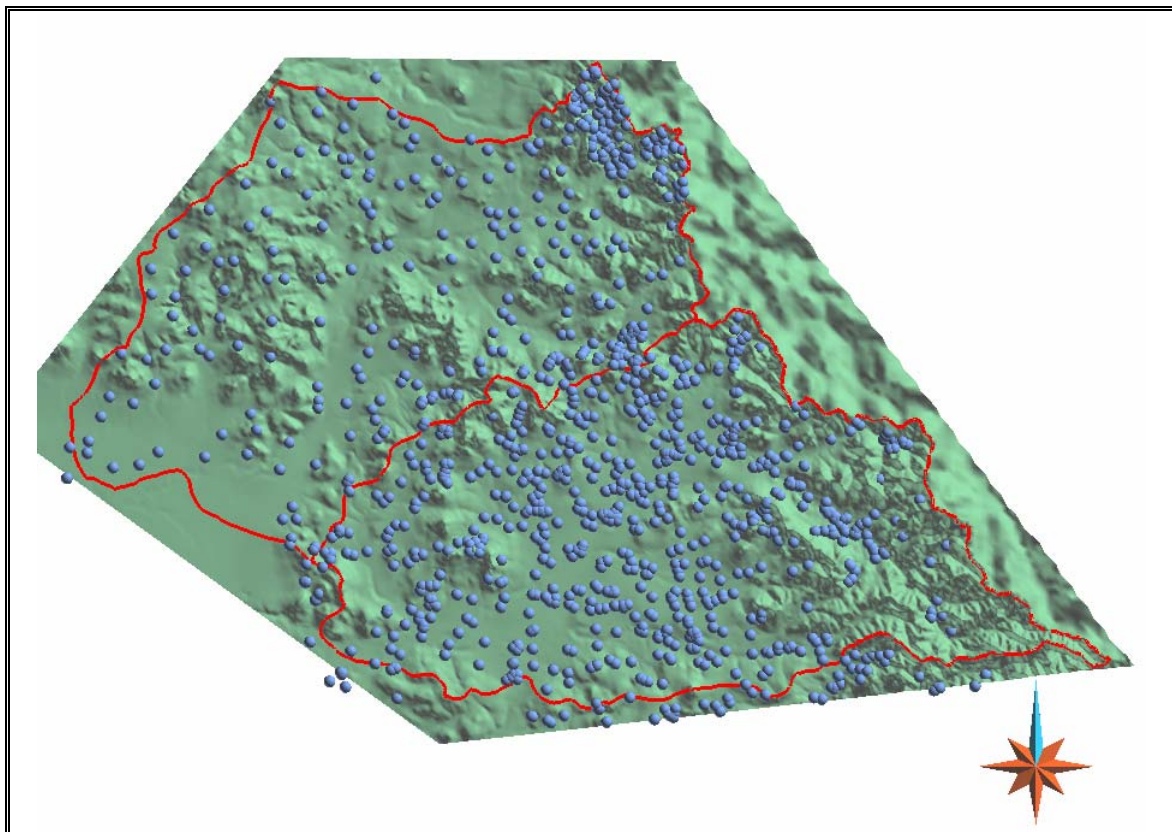


Figure 6: Distribution of bores across the Hodgson and Kings Creek sub-catchments (blue spheres) used for 3D model generation. Plan view shown on the DEM surface. North to top of page, with sub-catchment boundaries shown as red lines. The combined sub-catchment area is approximately 70 km east-west and 45 km north-south.

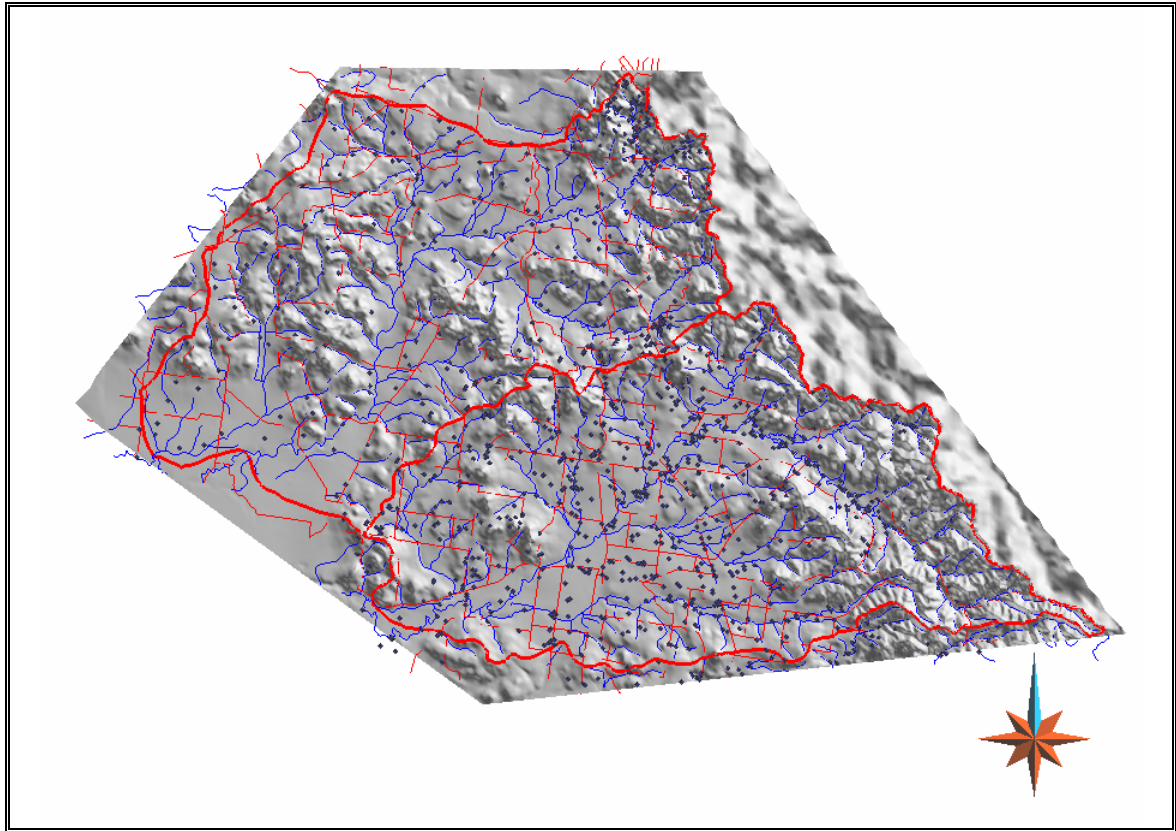


Figure 7: Bore distribution and drainage lines. Plan view on the DEM; bores shown as dark blue squares, streams in blue, sub-catchment boundaries as thick red lines and roads as thin red lines.

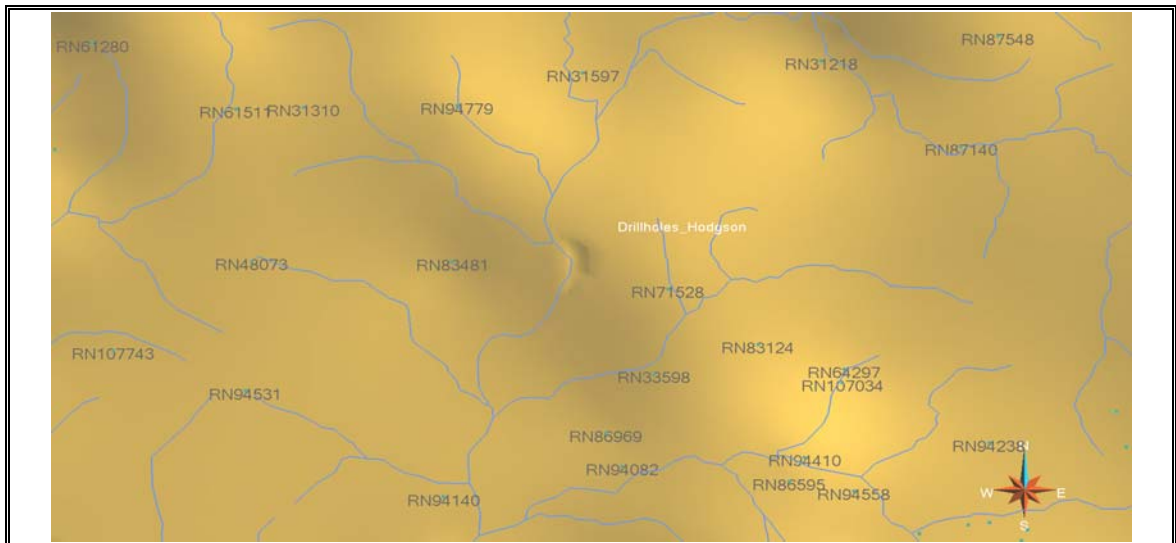


Figure 8: Detailed example of borehole distribution in the Gocad model (area about 50 km²), Hodgson Creek sub-catchment (RN = registered number).

The original bore log dataset incorporated approximately 35 rock type codes; these were subsequently rationalised to 15 main lithological types for modelling purposes (Appendix 1). Most rock units also have water-bearing zones (designated 'WB' in the lithological code index). For the Hodgson Creek catchment 323 bores were selected, whereas 761 bores were used for the Kings Creek district. For the purposes of constructing the 3D model from these data, all rock codes were further simplified into three main stratigraphic units:

- **Quaternary Alluvium**, e.g., gravel, sand and silt⁶;
- **Tertiary Main Range Volcanics (MRV)**, dominated by basalt (weathered, massive or vesicular) and volcanic ash;
- **Jurassic Walloon Coal Measures**, e.g., coal, sandstone and shale, representing the bulk of Clarence-Moreton strata/aquifers within the study area.⁷

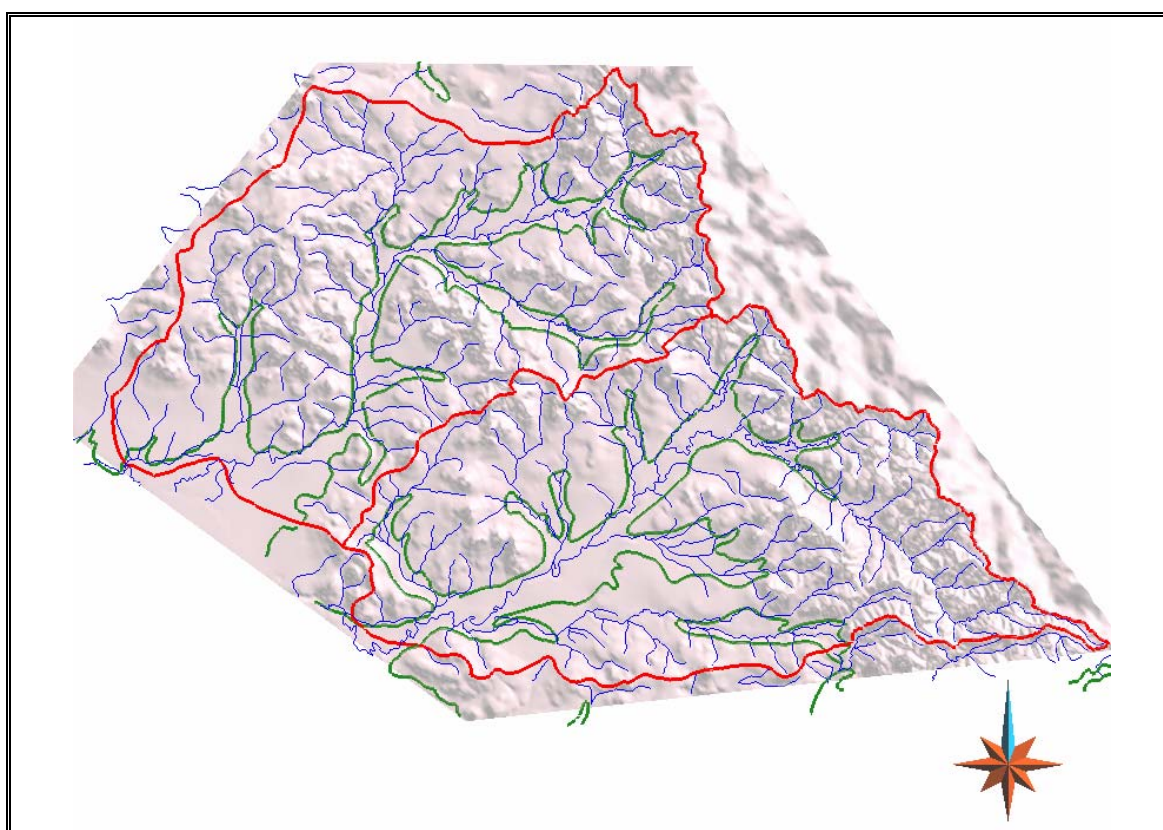


Figure 9: Mapped surface contact ('surface curves') between Quaternary alluvium and MRV shown as green lines. Streams in blue and catchment boundaries in red on the DEM. The geologic contact shown here is derived from the 1:500 000 geological map of the region (Wells and O'Brien, 1994).

⁶ Quaternary alluvia functioning as aquifers proved to be limited in distribution and thickness, typically < 4 m.

⁷ Bore RN119852, sunk in Toowoomba in March 2007, to 658 m depth immediately outside the study area, is too deep to be included in a model dominated by ~70 m deep bores (average depth). Surfaces for the base of the Marburg Formation – top of the Helidon Sandstone were not generated in the model.

The relevant borehole data were compiled into Excel spreadsheets for use in the modelling software. These modified datasets comprised:

- a. Bore number;
- b. Geographic coordinates (UTM easting and northing);
- c. Elevation (Australian Height Datum in metres above sea-level);
- d. Total borehole depth;
- e. Downhole geological composition (based on rationalised lithological codes and main stratigraphic groups); and
- f. Aquifer details, e.g., downhole water-bearing intervals, standing water levels (SWL), water yield and potability⁸.

3D MODELLING USING GOCAD

Gocad is an advanced 3D modelling and visualisation package used extensively in the mining and petroleum industry and can be described as a 3D Geographic Information System (3D GIS); it is used extensively by Geoscience Australia. The program is particularly well suited to constructing, visualising and manipulating 3D models based on actual geological, geophysical and hydrogeological datasets, e.g., borehole logs. The software also supports 3D vector and raster overlays such as geophysical or remote sensing images, and a variety of spatial queries, e.g., volumes and distances. These properties make it particularly well suited to building and viewing the conceptual 3D groundwater model developed for this project.

IMPORTING DATA INTO GOCAD

Borehole data

Data import was carried out using a combination of native Gocad import routines and proprietary import filters created by Mira Geoscience. As Geoscience Australia has only one node-locked licence of the Mira Mining Utilities application, most data were imported using basic Gocad filters. However, this created some conflict errors in borehole orientations; for example, modelling is typically undertaken with the depth-positive axis upwards, whereas the default option when modelling in Gocad has the depth positive axis downwards (depth below the natural ground surface increasing downwards). Use of the proprietary Mira import filters is therefore recommended, if available, as they readily correct such conflict errors.

Importing the required borehole data was relatively straightforward as all holes were assumed vertical. However, in the initial model-building stages there was uncertainty about which geological contacts would be modelled, and how this would be achieved in Gocad, e.g., modelling stratigraphic boundaries as either upper or lower surfaces. It was eventually decided that modelling the MRV-Walloon unit contact as the top of the Walloon unit would be the most efficient way to achieve the desired model using the structural modelling workflow (SMW) routine in Gocad. The uppermost

⁸ These datasets are not available for every borehole; unfortunately, they have not been systematically recorded in all drillers' logs in the QDNRW archive.

Quaternary alluvium layer, logged in most boreholes as a thin unconsolidated veneer, proved too problematic to model accurately, especially in the undulating north-eastern part of the catchment.

Lithological marker horizons (rock unit zones) were initially defined in each borehole using the three main stratigraphic units: Quaternary alluvium, MRV and Walloon Coal Measures. This stratigraphic column was defined in Gocad and applied to all boreholes to standardise the modelling process. Software functionality using the stratigraphic column approach also allows contact surfaces to remove unrealistic geological horizons.

Correlating borehole collars to the topographic surface created by the DEM proved difficult and time consuming. A wizard routine in Gocad was used to shift individual hole collars vertically (either up or down as needed), to ensure they were properly located on the topographic surface. This is an important step, especially where thin surface layers such as Quaternary alluvium unit are present. Borehole collars placed incorrectly in vertical space may position contacts deeper than they actually are, or even arbitrarily remove them completely if the collar is located above the DEM surface. For each borehole, markers were assigned for the geological contacts and for each water-bearing unit.

Topographic data (Digital Elevation Model)

The proprietary Mira utilities routine allows the direct import of ESRI ASCII grid files to a 2D voxel (modelling box). This object can easily be resampled at lower resolution, and modelled surfaces generated directly. A 25 m ESRI ASCII grid in UTM format of the catchment area was imported into Gocad and resampled to 50 m resolution. This was then used to create the topographic DEM surface for the model (Figure 10).

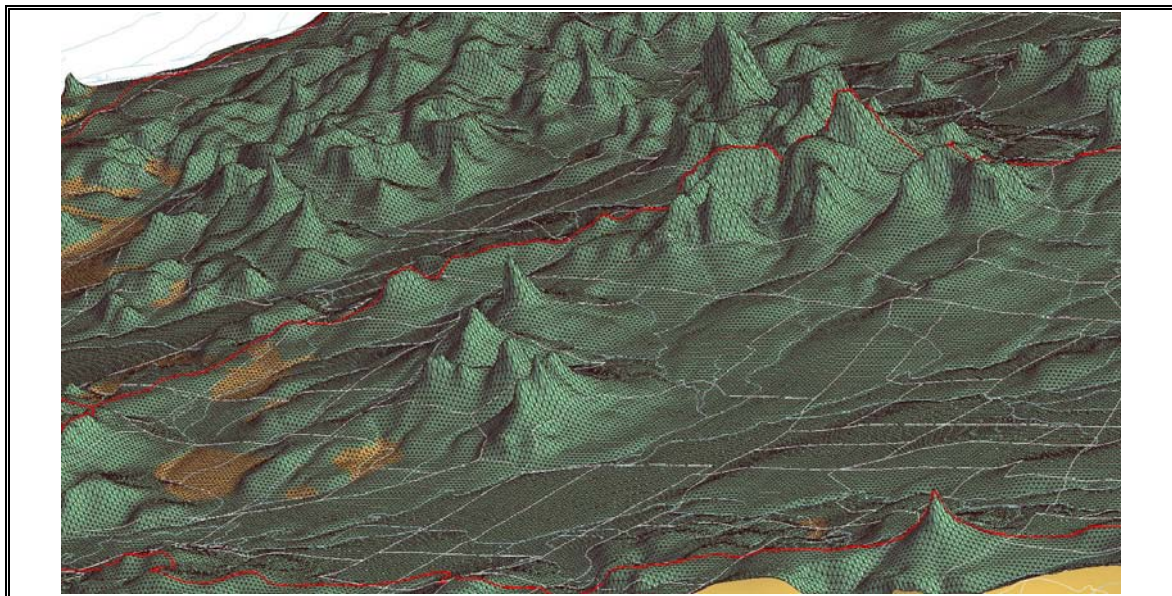


Figure 10: *Oblique view of part of the DEM showing the fine triangular mesh generated in Gocad from 25 m resolution data; a x 10 vertical exaggeration is shown; sub-catchment boundaries/watersheds shown in red, roads in grey; orange areas depict outcropping Walloon Coal Measures.*

Unfortunately, the available 25 m DEM coverage had previously been cropped along the north-eastern edge of the sub-catchments, creating an uneven edge in the modelled topographic surface particularly along the Great Dividing Range. To compensate for these irregularities, and also to

match the dimensional extents of the structural and stratigraphic grid models (created using a straight-edged volume of interest, VOI), a relatively low resolution DEM (approximately 300 m-scale) of the adjacent area was interlaced with the 50m DEM (Figure 11). Although the joining seam between these two DEMs is not a perfect match, the surface properties of the final grid are interpolated only within the catchment boundaries. Thus, the join does not directly affect the broad-scale geologic/hydrogeologic model. To overcome this problem for future projects, high-resolution DEM data should have geographic extents slightly greater than the area of interest, i.e., not cropped precisely to the catchment boundaries.

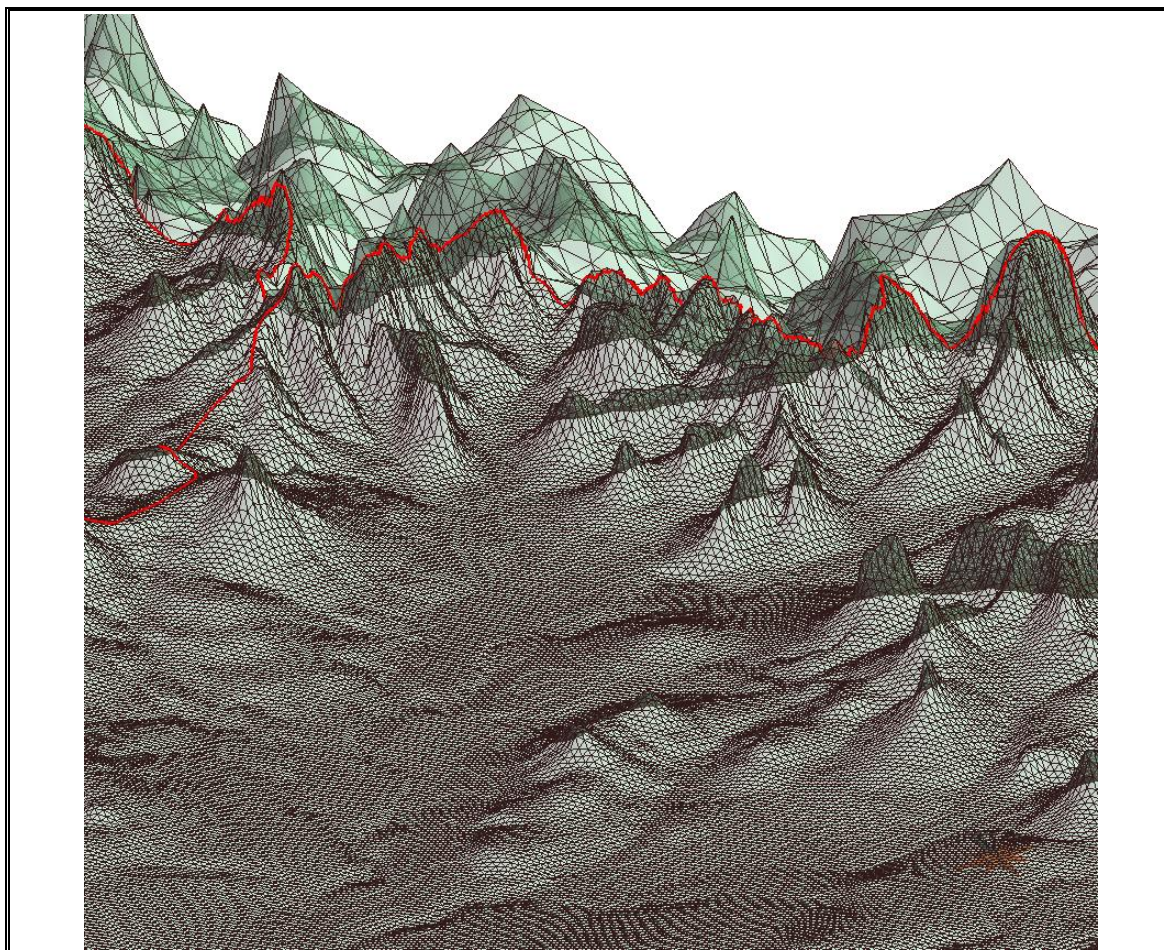


Figure 11: *Oblique view of part of the DEM showing the contrasting resolution of DEM data that allowed extension of the model beyond the catchment boundaries, as described in text.*

Remotely sensed images

Remotely sensed data such as satellite imagery can be imported into Gocad as world files using standard routines in the Mira utilities application. This allows for correct geographic registration of imagery. World file images can also be correctly registered using the native “resize voxet with vectors” command in Gocad.

ESRI shapefiles

Using either the native Gocad shapefile importer or Mira utilities application, useful ESRI shapefile data were imported and edited so that surface curves mapped the stratigraphic contacts as unit bases.

Geophysical data

Colour contoured gravity and airborne magnetics data partially coincident with the catchment area were obtained from Geoscience Australia's Geophysical Archive Data Delivery System (GADDS). These datasets were imported into Gocad using Mira utilities import tools, to provide optional new data layers to the model. The new data layers were added to the model from ERMapper (image processing software package) grid files via conversion to Geosoft ASCII GXF file format. Spot location gravity data were also downloaded from GADDS and imported into the model using Gocad column file import utilities. Unfortunately, due to their relatively coarse resolution, the geophysical datasets did not aid construction of the 3D model.

SURFACE MODELLING

Structural modelling using Gocad workflows

The structural modelling workflow (SMW) routine in Gocad is designed as a specific aid for constructing 3D common-earth models. Workflows guide novice users step-by-step through the modelling procedure, and also allow more advanced users the benefit of decision-driven modelling while still retaining full control of the model-building environment. Workflow routines also fully document each modelling step, permitting the user to add notes and snapshots whenever necessary. The SMW reporting methodology was fully utilised during this project and can be referred to for this stage of model construction ([Appendix 2](#)).

For boreholes which terminate in the MRV (thus lacking a marker for the top of the Walloon unit), the main geological surface (uppermost Walloon contact) was modelled to pass smoothly below the bottom of the borehole. In the absence of less arbitrary data or additional information about the depth of the MRV for these boreholes, this represents the most appropriate modelling procedure.

Final surface modelling

Local editing of surfaces constructed using SMW's is commonly required in most Gocad models. This section discusses some important observations relating to the MRV-Walloon boundary surface, and describes how major problems have been resolved.

To examine the surface constructed using the workflow process, the vertical thickness from the DEM surface to the top of Walloon contact was computed using basic Gocad commands. The final output was then colour contoured ([Figure 12](#)).

The uncoloured (white) parts of [Figure 12](#) shown along the south-western margin and near the eastern catchment boundary represent either:

- Upper Walloon borehole markers located at the landscape surface, indicating outcropping Walloon Coal Measures and no alluvial cover (as in the south-western margin of the sub-catchments);
- The upper Walloon boundary is located close enough to the surface (minimal cover sequences) that local topographic variations smoothly fit the borehole data and project above the topographic surface. This phenomenon causes the anomalous uncoloured region in the topographically rugged area along the north-eastern boundary, and also the flat low-lying area in the south west, or;

- The edges of the modelled surface project above the DEM surface beyond the edges of the model area, but at a relatively steep slope, such that the surface within the catchment area is affected. This is best observed to the immediate north of Hodgson Creek catchment.

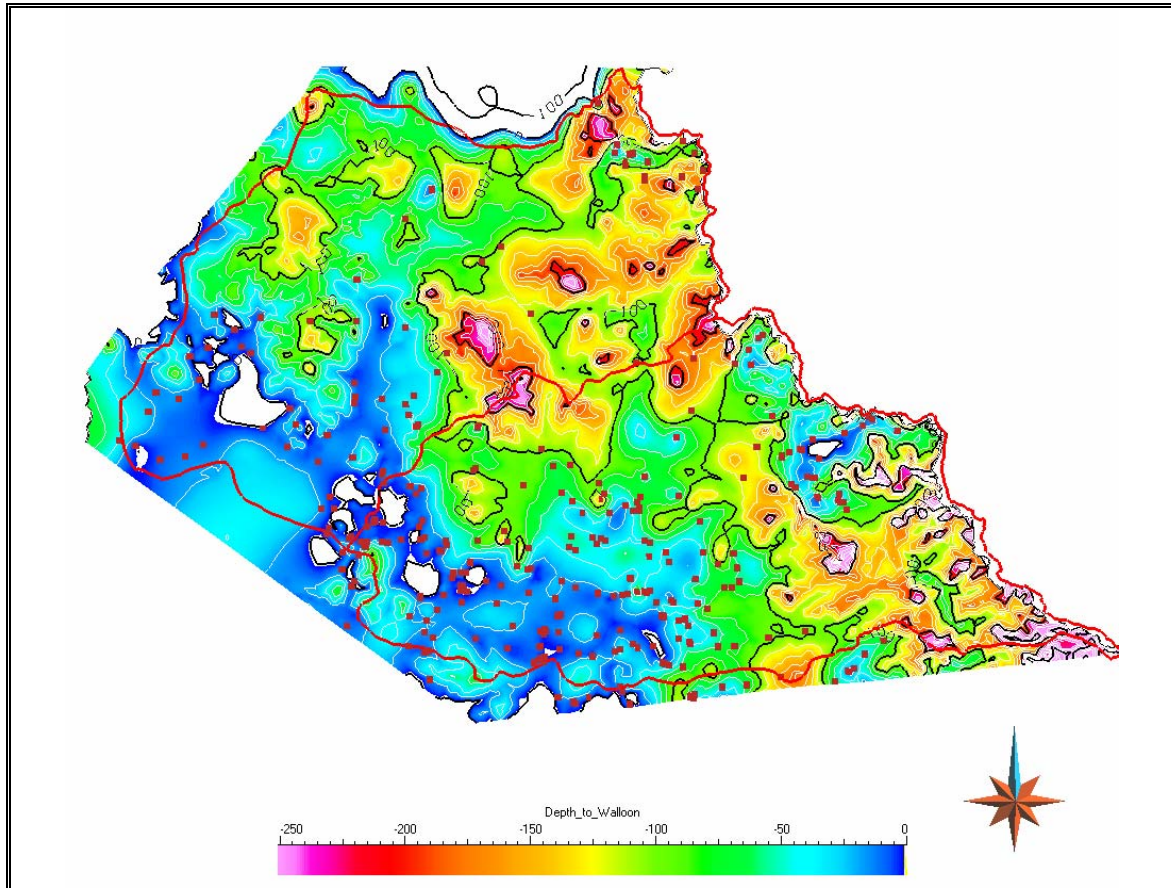


Figure 12: Contour plot of total vertical thickness (in metres) from the natural topographic surface, as modelled by the DEM, to the top of the Walloon Coal Measures. Relevant borehole markers are displayed as small red squares, and the boundaries of the Hodgson and Kings Creek sub-catchments as red lines. Regions where the uppermost Walloon Coal Measures are outcropping or virtually exposed/subcropping at the modelled topographic surface in the south-western area are shown as white areas, explained in the text below.

Furthermore, although local windows through the Quaternary cover are likely, sharp changes in contact elevation significantly affect the geometry and are considered unrealistic. The extensive region to the north of the catchment which was originally modelled as projecting above the topographic surface provides a good example. The local boreholes have scant Walloon Coal Measures in proximity to the topographic surface, indicating that the modelled geometry was unrealistic. On closer inspection of the primary data, an error was detected in the stratigraphic column for a single borehole (basaltic rocks erroneously assigned as Walloon Coal Measures), thus causing the modelling error. When this borehole error was corrected and the surface remodelled, simply by running the SMW once more with amended input data, the new iteration provided a significant improvement in the model. In addition, the same area was locally edited so that the uppermost Walloon boundary was consistently below the topographic surface (Figure 13).

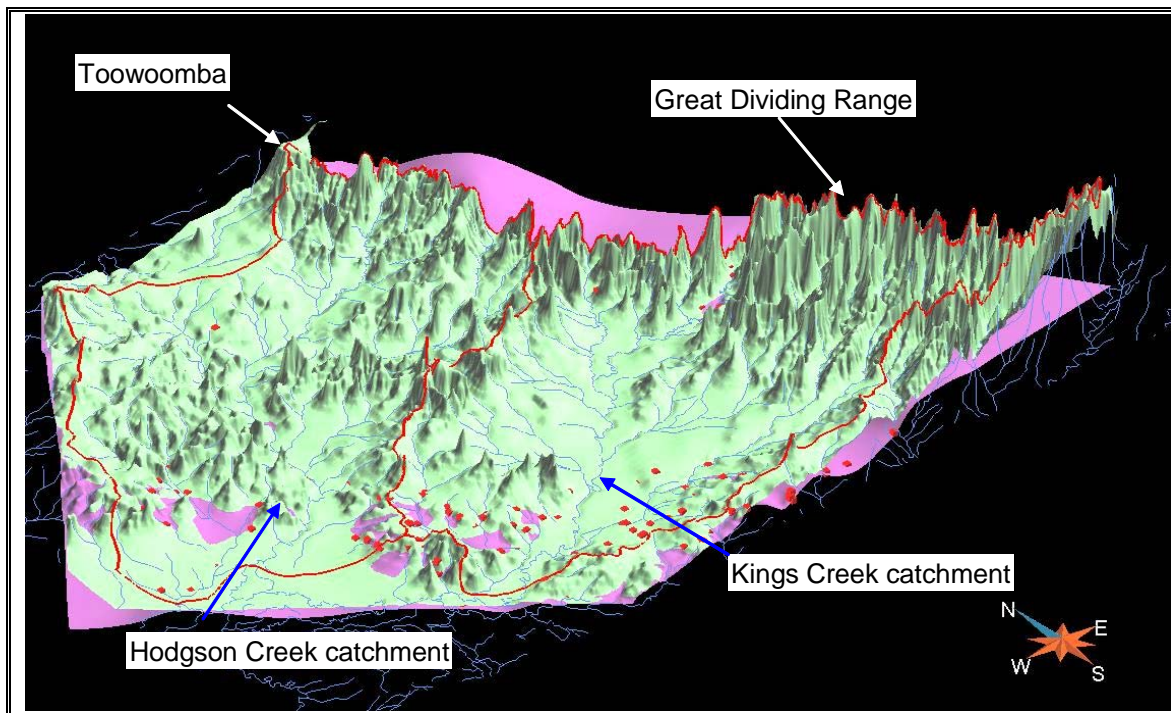


Figure 13: Tilted isometric view looking towards the north-east (with 10-times vertical exaggeration applied). This Gocad image shows the disposition of the DEM topographic surface (green, vertically stretched) and the uppermost surface of the Walloon Coal Measures (pink). Note the irregular-shaped exposures of the Walloon sedimentary unit exposed in the lower reaches of the sub-catchments, and the relatively flat-lying Walloon strata continuing eastward beneath thick MRV units of the Great Dividing Range. Stream channels shown as blue lines and catchment boundaries as red lines.

The disposition of the uppermost surface of the Walloon Coal Measures generated from the bore data is consistent with exposed Jurassic strata of the Clarence-Moreton Basin mapped by Wells and O'Brien (1994) near the Condamine River in the south-west, and also north-eastward beyond the present study area at the base of the escarpment (east of the Great Dividing Range).

To overcome most of the modelling problems outlined above, additional data from boreholes located outside of the area of interest (beyond the catchment boundaries) enabled a more accurate and realistic contact surface geometry.

The lowermost surface (base of model) was created by replicating the upper Walloon Coal Measures surface and translating this vertically downwards to a depth just slightly below the deepest borehole in the study area (Figures 14–16). Although this only represents a theoretical base, it allows the model volume boundary to be created in the absence of actual data (recall that none of the boreholes used to create the model could confidently be shown to have penetrated the base of the Walloon Coal Measures)⁹. Relevant Gocad procedures are described further in Appendix 2. The heterogeneous distribution of water-bearing zones is shown in Figures 17–19.

⁹ Refer to the previous Data Import section for discussion of the method used to edit the DEM and ensure the correct geographic extents for the model.

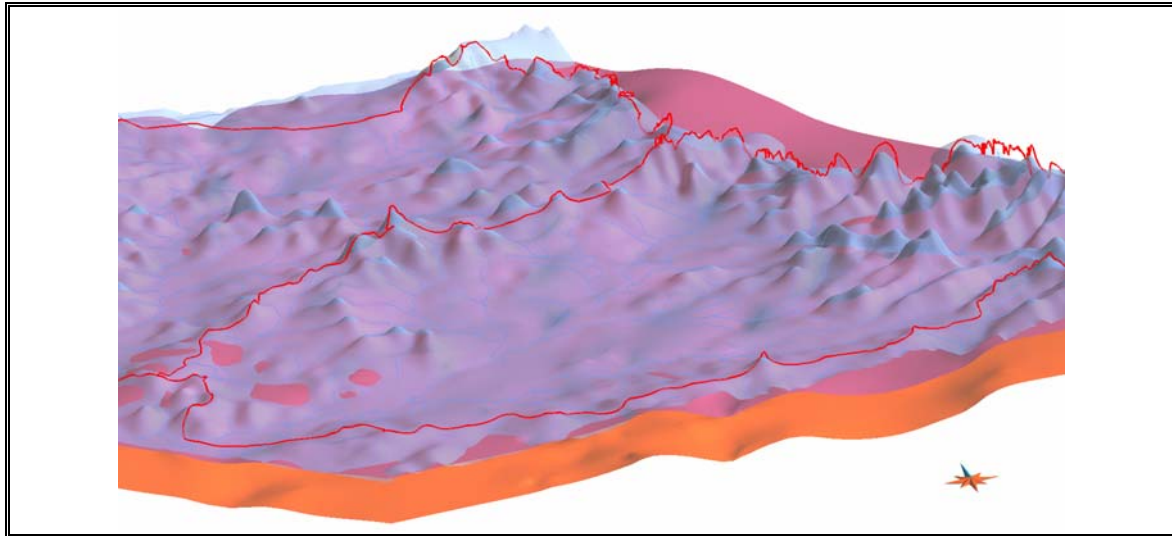


Figure 14: Oblique north-north-east view showing the semi-transparent DEM surface (blue-mauve), base of MRV-top of Walloon Coal Measures contact (pink), and the base of model (orange); sub-catchment boundaries in red.

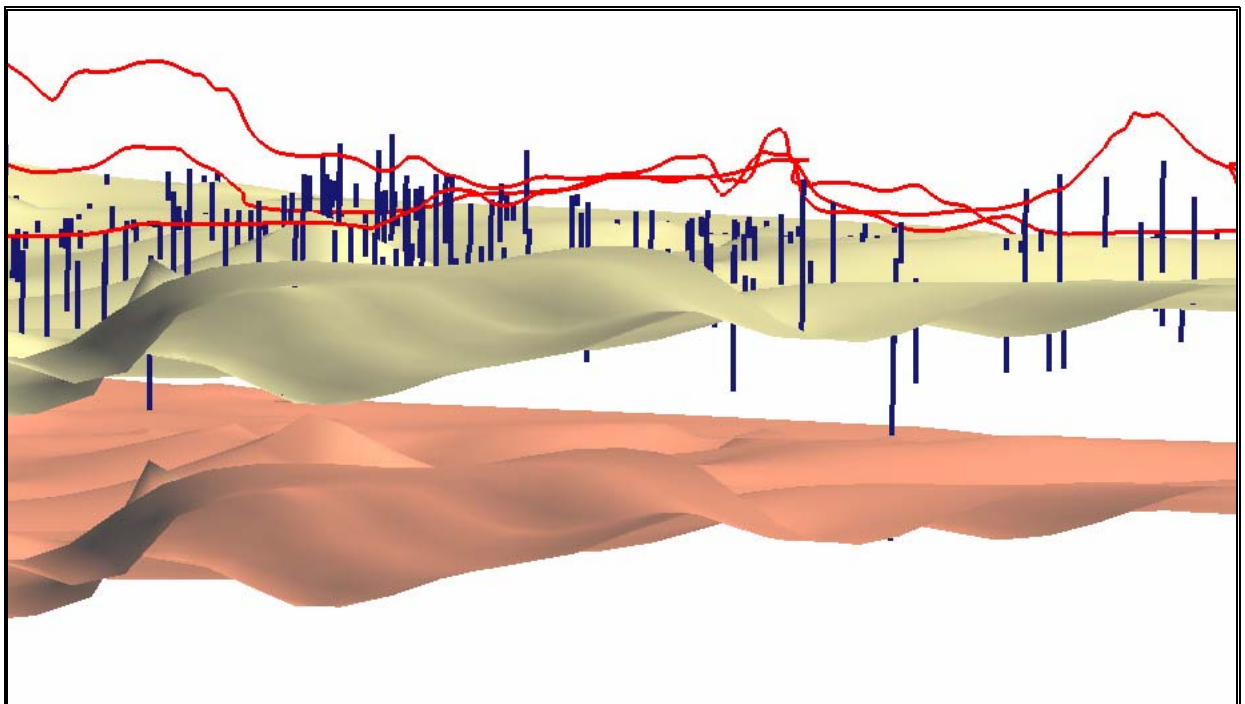


Figure 15: A random side view of the model showing the topographic relief as red outlines which largely represents the top of the MRV. Boreholes are shown in dark blue, the MRV-Walloon contact in yellow, and the base of the model in pink. The top of each borehole corresponds with the landscape surface at each bore location, as conveyed in Figures 14 and 16 using a transparent DEM. The base of the model does not represent the Walloon-Marburg contact but, rather, the bottom of bore holes in the study area.

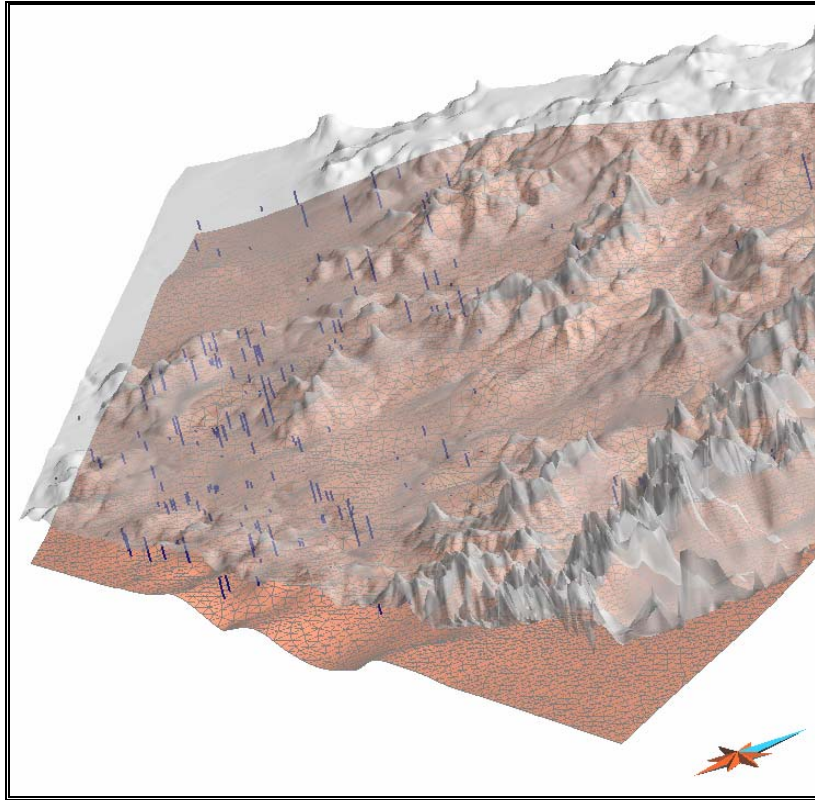


Figure 16: Oblique west-north-west view across the two sub-catchments showing the DEM surface (50% transparency), boreholes (dark blue), and base of the model (orange surface), the latter with constructional triangles revealed.

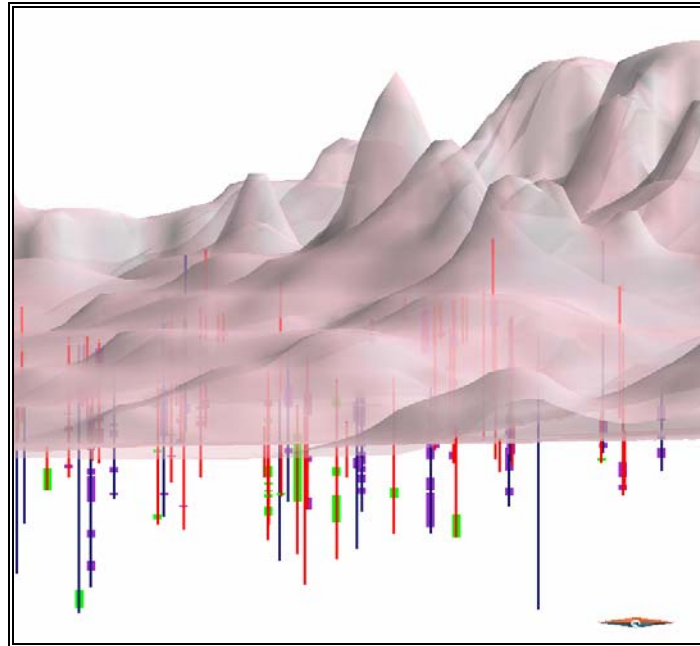


Figure 17: A random side view of the model showing a vertically exaggerated semi-transparent DEM, Hodgson boreholes (dark blue), Kings boreholes (red), MRV aquifers (purple), and Walloon aquifers (green); dry bores are present in both sub-catchments.

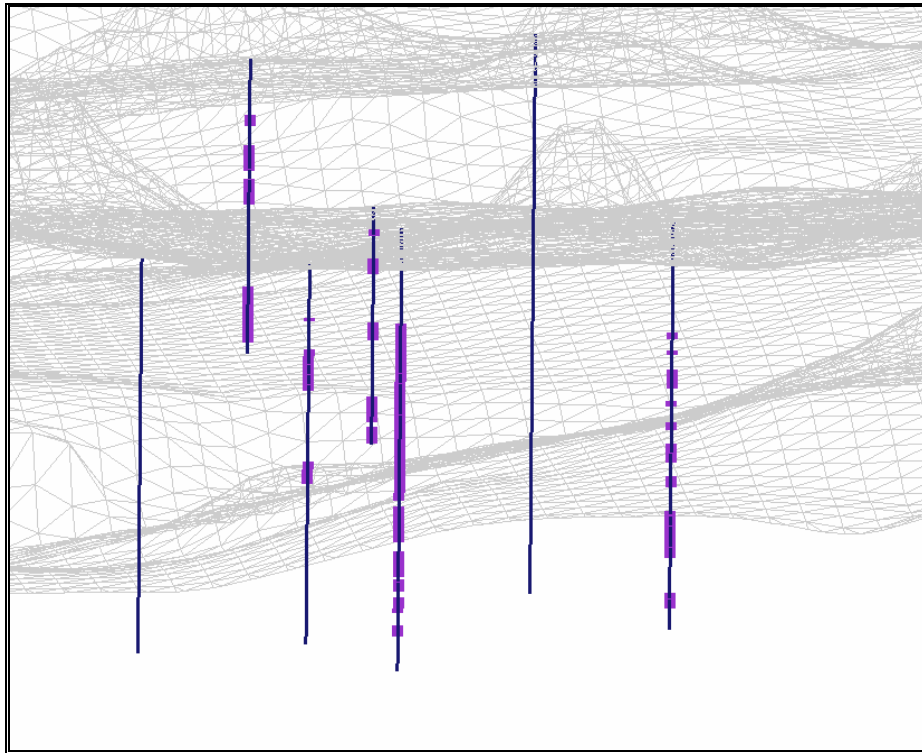


Figure 18: Side view of part of the model for the Hodgson Creek sub-catchment looking beneath the DEM (grey line-work showing triangular construction mesh); boreholes (dark blue) and MRV aquifers (purple). This view reveals the extreme heterogeneity of water-bearing zones within the MRV, within a relatively small area (several kilometres). Several of the bores shown here penetrate numerous water-cuts of variable thickness, ranging from relatively narrow zones less than 2 metres up to several tens of metres thick. There are also several boreholes which have failed to intersect any water-bearing zones and are dry. This heterogeneity is caused by the very irregular nature of basaltic discontinuities (both sub-horizontal and sub-vertical) within the Main Range Volcanics which play an important role in controlling the nature and distribution of water-bearing zones.

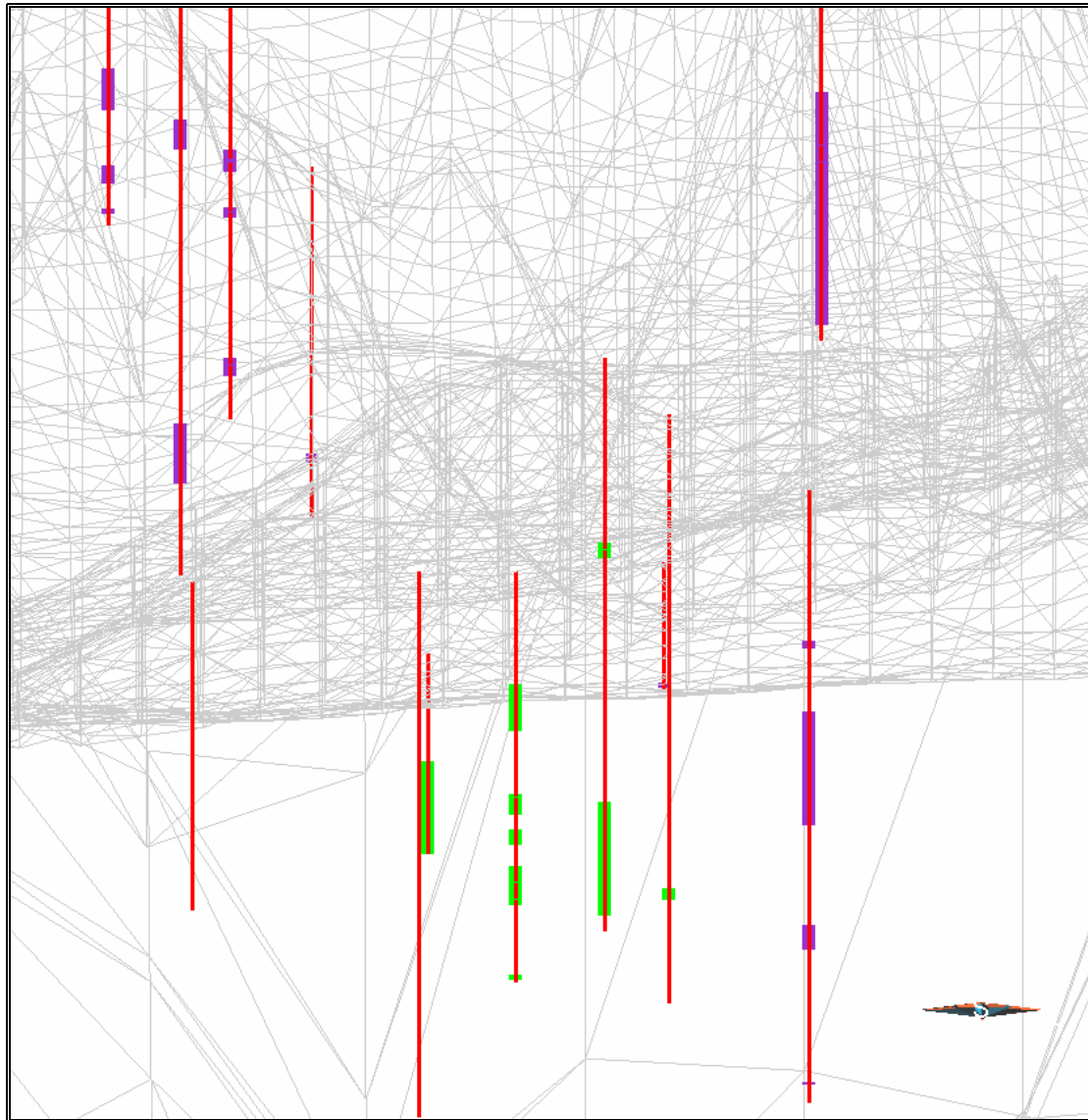


Figure 19: Side view of part of the model for the Kings Creek sub-catchment looking beneath the DEM (grey line-work). Boreholes are shown in red, MRV aquifers are purple zones on the drillhole stems, and Walloon aquifers are green zones. This view again reinforces the extremely heterogeneous nature of the sub-surface distribution of water-bearing zones within the stratigraphic units of the Condamine headwater sub-catchments.

3D Model Enhancement and Further Analysis

X3D REPRESENTATION OF THE GOCAD MODEL

The Gocad Model has been converted to an X3D (Extensible 3D) interface to provide the Condamine Alliance and other stakeholders with web-based access, in the absence of the specialised software used to generate the 3D model. The X3D interface – and its precursor, Virtual Reality Modelling Language (VRML) – can display large volumes of complex 3D geological and hydrogeological information (data volumes up to 22 MB) via the internet and World Wide Web. X3D is still under development; it is an XML (eXtensible Markup Language) syntax for VRML, with improvements, and is interoperable with other XML formats. X3D is an open and free ISO standard for 3D graphics on the internet, and is supported by the Web3D Consortium. This enables management and exchange of large amounts of data and a wide range of geometric features to represent geoscientific features. X3D format enables substantial file compression, compared to VRML, and allows easy interaction with other XML formats. The interfaces are user-friendly and provide users with a high level of interaction with complex information (Beard, 2005; Beard et al. 2005). Geoscience Australia has published complex 3D geologic models on the web since 2001¹⁰. X3D will be one of the tools that Geoscience Australia will continue to use to deliver 3D content over the internet in the coming years, in conjunction with other tools such as 3D PDF and Google Earth applications.

THE GROUNDWATER SYSTEM OF THE CONDAMINE HEADWATER CATCHMENTS

For the purposes of building the 3D model, the respective geological units were regarded as essentially flat-lying with sub-horizontal stratigraphic contacts, an inference which holds true for most sedimentary strata of the Clarence-Moreton Basin (Wells and O'Brien, 1994). As previously mentioned, this conceptualisation was borne out when constructing the MRV-Walloon contact from the Hodgson and Kings Creek bore logs.

On a regional scale, the basaltic rocks of the MRV erupted across a relatively flat planation surface over the Jurassic strata (Ollier and Haworth, 1994). However, the MRV were not formed as thick and laterally continuous flood lava flows – as originally perceived – but rather as multiple eruptions from discrete volcanic cones scattered across the region (Free, 1989), e.g., [Figure 3](#). These form distinctive topographic features across the present land surface, a reflection of differential erosion between massive basalt (former lava pools in vents) and surrounding pyroclastic deposits and volcanic breccias. Additional to the numerous eruptive centres and fissures, a chain of large shield volcanoes trend north-west to south-east through the region, including the Bunya Mountain Volcano north-west of Toowoomba and Tweed Volcano to the south-east in coastal NSW (Ollier and Harworth, 1994). The study area encompasses adjacent parts of two such shield volcanoes; Hodgson Creek is a radial drainage line of the erstwhile Toowoomba Volcano, and Kings Creek is a gutter drainage-line formed at the junction of two coalescing volcanoes, the Toowoomba Volcano and the Main Range Volcano to the south-east. These original large volcanoes are now severely eroded, with their main craters further degraded by westward retreat of the Great Escarpment (Ollier and Haworth, 1994). It is possible that significant volumes of volcanic material (both lava flows and pyroclastic ejecta) were erupted concurrently across a significant area and period of time (Free, 1989).

¹⁰ Geoscience Australia Web-based 3D geologic models: <http://www.ga.gov.au/map/web3d>.

Around Toowoomba much of the basaltic rock is relatively compact and impervious; however, the weathered zone and intense jointing – particularly vertical joints – are highly significant features for groundwater processes (Armstrong, 1974). Fractured rocks of the MRV produce the highest groundwater yields from individual water bores, for example: max. 35 L/sec, compared to 30 L/sec from unconsolidated alluvial sediments, 12 L/sec from fractured Walloon Coal measures and 5 L/sec from the Marburg Formation Sandstones. According to Carberry and Walker (1993) all aquifers in the region have low average minimum yields of ≤ 1 L/sec. Notwithstanding, bore data analysed for this project showed sparse scattered bores with high yields, to 25 L/sec. Bore RN44659 in Kings Creek sub-catchment, sunk into fractured and vesicular basalt at 38 m depth, yielded 56 L/sec during pumping tests conducted in 1974. Sparsely distributed high-yielding bores most likely correspond with significant structural features such as intersecting discontinuities (faults or conjugate joints). Such structures are likely to promote vertical connectivity between aquifers by providing secondary conduits. In places however, especially where water-bearing zones appear to end abruptly, structures and stratigraphic offsets likely impede groundwater flow and connectivity.

Basalts worldwide are renowned for their anisotropic and heterogeneous nature; a wide range of hydraulic conductivities are recognised, generally ranging from 10^{-2} – 10^{-7} m/s (Freeze & Cherry, 1979). Locally, the presence of intrusive and extrusive volcanic features and significant lateral discontinuities in the MRV are further compounded by widespread vertical and horizontal joints, e.g., radial and, potentially, concentric fractures. Such discontinuities impact significantly on the storage and transmission of groundwater in the local area (Free, 1989). Typically, the MRV consists of an upper unconfined weathered and fractured zone, representing a semi-permanent aquifer, a mid-level semi-confined aquifer, and a lower confined vesicular and fractured zone (Free, 1989; QDNRW pers. comm., 2007). Varying degrees of vertical continuity exist between these respective zones, as well as between individual aquifers in each zone (Free, 1989). Multiple buried weathering surfaces, former ash deposits, and possible sedimentary interbeds between basalt flows exacerbate complexities and substantially influence groundwater storage and movement.

The high degree of aquifer heterogeneity precludes generation of a realistic dynamic 3D model at sub-catchment scale. A 3D model for a relatively small area, encompassing ~20 bores for example, could be built using detailed logs and reliable lithological information to incorporate primary and secondary properties and groundwater features. This type of high-resolution system could potentially accommodate detailed monitoring of watertable levels aimed at generating a dynamic model to show groundwater responses to variable climatic factors and groundwater use scenarios. However, this degree of stratigraphic and hydrogeologic detail could not plausibly be extrapolated across the entire catchment, nor would it be appropriate to inform decision-making about the distribution of water resources over large spatial and temporal scales. Inconsistencies and discontinuities in or between water-bearing units revealed in the present 3D model are representative of the varied and intrinsic characteristics of the MRV, such as the aquifer heterogeneity illustrated in [Figures 17-19](#). Accordingly, the 3D model represents the sub-surface heterogeneity as faithfully as possible at the sub-catchment scale but cannot represent fine-scale anisotropy or heterogeneity in the MRV or associated groundwater complexity.

The 3D model reinforces the classic hydrogeologic interpretation for the Condamine headwater region (e.g., Free, 1989) while portraying the actual magnitude of variability of the subsurface geologic and hydrogeologic environment. If the 3D model is further developed in the future, additional insight into the distribution of groundwater and hydrogeologic processes in the region is likely to be revealed. While it is widely known that there is a substantial degree of connectivity between MRV aquifers and streams in the headwater region, an outstanding issue relates to

improving knowledge of the magnitude of connectivity between MRV and underlying Walloon sequence aquifers.

The Toowoomba Bypass tunnel currently being excavated through the Main Range to the north of Toowoomba is providing new information about the properties of MRV basalt such as texture, degree of weathering, porosity, permeability and hydraulic conductivity. This information, currently being assessed and described by QDNRW, in conjunction with the analysis and 3D synthesis of bore data undertaken for this project, will significantly enhance our understanding of the local hydrogeology. Further collaboration between Geoscience Australia and QDNRW hydrogeologists is expected to result in increasingly reliable depth to water table and potentiometric models and groundwater yield data that accommodate seasonal fluctuations and decadal-scale trends; these are important considerations for water resource management in the upper Condamine catchment.

UPGRADING THE EXISTING 3D MODEL

Geoscience Australia has developed a relatively simple but realistic and effective 3D computer-generated model of the Hodgson and Kings Creek catchments. This model accurately shows the topographic and hydrogeological architecture of the region, and provides a novel visualisation tool which could prove useful for groundwater management. The current version of the model may be further enhanced through integration of other datasets such as geophysical and remote-sensing images, and could be further refined by undertaking more detailed work, such as:

Improving the contact geometry of the MRV – Walloon boundary

The current modelled surface between the MRV and the Walloon Coal Measures is the smoothest possible 3D boundary given the available borehole data. However, by integrating down-hole and/or regional geophysical datasets it may be possible to improve the accuracy of the surface geometry. In particular, the following techniques could prove useful:

- a. **3D inversion of gravity data** – open-file gravity survey data across parts of the Hodgson and Kings Creek catchments are freely available through GADDS. It may be possible to re-process some datasets and apply current inversion methods to potentially re-model the contact surface (and possibly other surfaces such as the base of the Walloon Coal Measures).
- b. **Electro-magnetic (EM) data** – At least one Airborne EM survey has previously been conducted across parts of the study area (Kalma, 1995). It may be possible to re-process AEM data using new analytical routines, and potentially improve the quality of this data-set, especially as it relates to groundwater resources and depths of various lithological contacts.
- c. **Seismic reflection profiles** – regional seismic investigations have previously been undertaken across the Clarence-Morton Basin. At least one survey line is likely to have passed either directly across or proximal to the study area. Although the seismic data would likely be ‘noisy’ at the relatively shallow subsurface depths relevant to this project, it may help to elucidate deeper geological boundaries and provide information about potential deep aquifers in the basin.

Geostatistical simulation of 3D aquifer geometries

The 3D geometry of the main water-bearing zones in the MRV and Walloon Coal Measures could be modelled using geostatistical simulations of the rock units. This type of modelling is analogous to facies modelling undertaken by the petroleum industry where the various rock types identified from drillhole data (sandstone, shale etc.) are modelled to generate a 3D visualisation of petroleum-bearing zones. A possible approach for this project would be to simulate four distinct hydrogeological facies, these being: dry MRV zones, water-bearing MRV zones, dry Walloon zones, and water-bearing Walloon zones. The overall objective would be to model possible connectivity between isolated water-bearing zones and represent these as 3D surfaces. As the model currently stands, the thickness of water-cuts are marked on respective drillhole paths – however, it would require a detailed geostatistical analysis to actually model lateral (and vertical?) water-bearing connectivity between drillholes. Ultimately, this approach would be difficult to implement due to the extreme spatial heterogeneity of water-bearing zones in the MRV.

Modelling potential sub-vertical fluid pathways

As postulated in the section describing the groundwater system of the MRV, considerable sub-vertical connectivity between water-bearing zones is inferred. This is especially likely where discontinuities associated with successive volcanic events are common, e.g., columnar cooling joints, eruptive cones and associated concentric fractures, variable weathering patterns. Present-day remnants of volcanic centres and fissures act as preferential recharge zones due to the high degree of sub-vertical connectivity. Although there are no large-scale faults mapped in the area, the Jurassic sedimentary rocks underlying the MRV are likely to be cross-cut by localised faults and fracture zones which also act as preferential fluid flow paths. Detailed analysis of relevant geophysical datasets (as outlined previously) could help better delineate crustal discontinuities which are locally important zones for surface water infiltration and groundwater flow.

Structural lineament analysis could also be applied where the model reveals abrupt disconnections or irregularities between multiple water-bearing layers. High-resolution satellite (e.g. ASTER) and RadarSat imagery, potentially coupled with appropriate airborne geophysical data, may reveal distinct structural zones that act as conduits for (or barriers to) groundwater flow, e.g., columnar or concentric jointing associated with eruptive centres.

Scope exists in the future to apply more complex remote sensing and GIS techniques to defining groundwater recharge and discharge areas (and other processes) over the entire Condamine catchment. For example, recent work focused on Tertiary basalt aquifers in the Glenelg–Hopkins catchment of western Victoria (Tweed et al., 2007), along with other work conducted by the Cooperative Research Centre for Landscape Evolution and Mineral Exploration (CRC LEME), may be applicable to future hydrogeologic projects in the Condamine region.

Integrating other hydrological applications with the 3D model

We suggest exploring the usefulness of the 3D model as a platform for other hydrological analytical methods. For example, it may be possible to integrate the existing conceptual model with numerical groundwater simulations and thus improve the usefulness of both techniques (previously used independently). Discussions with experienced numerical modellers would initially be required to evaluate the viability of integrating numerical groundwater solutions with the 3D conceptual model.

Incorporating hydrochemical data into the model is another potential application for which few precedents currently exist. An extensive hydrochemical dataset of the groundwater resources in the Hodgson Creek catchment has been compiled by various research groups over the past few years (R.

Cresswell, pers. comm., 2007). These data could be readily integrated into the existing 3D model as extra data layers. For example, water quality could be colour-coded to show spatial variation of potable versus stock-quality groundwater within the catchment – this would be especially useful if 3D groundwater simulations were developed and integrated with the existing model.

FURTHER 3D MODELLING IN THE CONDAMINE CATCHMENT

This report captures various static screen snapshots of the Gocad model to convey recognition of the various datasets and provide an indication of the model's substance and potential (Figure 10–18). Export of the Gocad model to the web-enabled X3D version maximises access and utility for Condamine catchment managers and other stakeholders, while presentation of the Gocad version using 3D visualisation facilities optimises two-way communication between modellers and catchment users.

The present 3D model shows unique sub-surface perspectives of Hodgson and Kings Creek catchments. The model also promotes understanding of the spatial distribution of groundwater-bearing zones beneath any part of this important agricultural area, where the level of dependence on groundwater resources is high. The model graphically reinforces the existing perception of highly complex aquifer systems and heterogeneous groundwater distribution, gained from traditional hydrogeological studies over recent decades. The model enables and enhances groundwater conceptualisation in 3D space to promote communication among stakeholders. For example, the model may aid informed site selection of future boreholes, and guide ongoing monitoring of aquifers which are currently exploited, particularly those in areas of intense irrigation and peri-urban development.

Based upon the results of this pilot study, and the lessons learnt during design, development and implementation, further 3D modelling in the Condamine region is considered possible. However, any future 3D groundwater modelling project would need to address questions such as:

Can the model as it stands be used to calculate groundwater volumes in aquifers?

The 3D model accurately represents all water-bearing zones logged in over 1000 of the most reliable and representative boreholes from Hodgson and Kings Creek sub-catchments. Enormous heterogeneity of lateral aquifer distributions and vertical extents has subsequently been revealed. Commonly there are several or many thin water-bearing zones (<2 m thick) proximal to significantly thicker saturated zones of limited spatial extent. Additionally, completely dry boreholes also occur close to bores that intersect multiple water-bearing units of variable thickness. These observations were heralded by the early hydrogeologic work of Free and others, who recognised the typically non-uniform lithological character of the Main Range Volcanics (MRV) and the magnitude of conspicuous fracturing, faulting and structural disruption around volcanic eruptive centres. As the random snapshots showing distribution of water-bearing zones over small parts of the study area indicate (Figure 16–18), it is unrealistic to simply join up water-bearing units (sub-horizontally) to form laterally extensive 'layer-cake' surfaces for estimating contained aquifer volumes. Thus, even though Gocad is capable of such analytical simulations, this would be a completely contrived exercise for the Hodgson–Kings 3D model. This volume estimation procedure would be perfectly feasible in other groundwater systems characterised by relatively uniform and laterally extensive aquifers; the reliability of estimated groundwater volumes would then be dependent upon the homogeneity of the aquifer's various hydraulic properties.

On the positive side, the spatial heterogeneity of the Hodgson–Kings aquifers is well conveyed in the 3D model; this is perhaps more important to catchment managers, users of groundwater resources, and water planners than a contrived and non-representative numerical volume. Depiction of each borehole, (for example, [Figures 17–19](#)) provides a reliable indication of the constituent water-cuts and the potential groundwater storage capacity beneath the landscape, particularly if information about aquifer hydraulic parameters and yields is also considered. Used in conjunction with existing bore yield data and future pump tests, a general impression of underlying groundwater resources can be obtained for small-scale areas. Although not precise in volumetric terms, this information is more relevant than the likely misinformation conveyed if laterally continuous layer-cake aquifers with homogeneous or predictable hydraulic parameters (such as storativity, transmissivity and yield) are assumed in the sub-surface.

Can Standing Water Levels (water tables/groundwater levels) be conveyed, and updated SWL scenarios represented in the model?

Standing water level (SWL) measurements for the suite of over 1000 bores are haphazard, spanning some 50 years of observations and encompassing seasonal and decadal-scale fluctuations, and highly variable extraction rates. Creating a single catchment-wide SWL surface based on the available data for Hodgson and Kings Creeks would be unrealistic and non-representative. If the SWL of every bore used in the model was measured at approximately the same time then a 'typical SWL surface' could be generated. This could, for example, potentially show seasonal watertable fluctuations associated with climate variations. However, such SWL surfaces would not be representative of the sub-catchments for long periods of time. Similarly, scenarios of extraction and recharge, or comparisons between dryland, irrigation and native vegetation areas, cannot be represented in the model without appropriate time-series data.

At present, the 3D model is a conceptual model that represents the stratigraphic architecture and distribution of water-bearing zones (albeit from historical records spanning some 50 years) as accurately as possible in x-y-z space, i.e. the 'whole-of-catchment architecture'. The groundwater system essentially represents a 4th dimension of the model, dependent on the physical constraints of the 3D geologic environment but independently responding to hydrologic and meteorologic fluxes and land-use changes over time. The existing datasets currently preclude including more realistic or dynamic representations of the watertable and groundwater processes. However, temporal variations in groundwater levels could potentially be included in the 3D model if the necessary datasets were available, although this would present new challenges in model design and development.

Is the process likely to work for the whole of the Condamine catchment?

The heterogeneity disclosed in the 3D modelling exercise for Hodgson and Kings Creek sub-catchments indicates that, in areas of the upper Condamine dominated by the MRV, 3D modelling is more suited to small- or medium-sized areas rather than broader regions. Developing the present 3D model of the Hodgson and Kings Creek sub-catchments required considerable analysis and rationalisation of lithological data from the original bore logs. For larger regions of the Condamine catchment, or indeed for the entire Condamine Basin, the magnitude of analysing and consolidating borehole descriptions would be extremely time-consuming and labour-intensive, as it would likely involve many thousands of bores and numerous stratigraphic units.

Downstream in the Condamine catchment, away from the heterogeneous MRV basalts and the structural complexity imposed by numerous volcanic eruptive centres and the uplifted Great Dividing Range, 3D modelling is likely to present a more straightforward exercise and significantly different outcomes. Seismic data may be more useful and readily available to help model the basin

architecture and major structural zones. Relatively thick strata of the Cainozoic Surat Basin and Jurassic Clarence-Morton Basin also likely correspond with thicker and more laterally extensive water-bearing units than occurs in the MRV. If the latter proved to be the case, then calculation of aquifer volumes incorporating temporal variations is possible. Since the data density in other Condamine sub-catchments is less than in the Hodgson and Kings sub-catchments interpolation between data points would be greater. This would increase uncertainty involved in generating catchment-wide geological boundaries and the thicknesses, continuity and lateral extents of the contained aquifers.

Ideally, 3D modelling in the Condamine would be best to proceed at the sub-catchment scale. A geologically different sub-catchment is most appropriate for the next phase of 3D model generation, i.e., a sub-catchment located away from the inherent complexities of the MRV and the upland areas, and for which there is an adequate distribution of representative and well-documented boreholes and groundwater monitoring data. A 3D model of the whole Condamine catchment is technically feasible. For example, broad-scale, data-rich regional 3D geologic models for groundwater applications have been developed in recent years in North America, e.g., Thorleifson et al., 2005; Bajc and Newton, 2005.¹¹ Such models require large resources in terms of personnel, expertise and time, especially as thousands of bore logs and supporting geologic/hydrogeologic data requires significant analysis and interpretation to generate a useful conceptual model. Modelling a large area invariably implicates increased generalisation and simplification – or ‘lumping of variability’ to manageable levels – of stratigraphic units, geologic contacts, aquifer distribution and properties, and groundwater data. Such generalisation involves concomitant lessening of reliability and applicability for catchment or water resource management issues. The decision would always be whether to represent and understand small sub-catchments reasonably well or a large catchment in a potentially more schematic manner.

¹¹ http://www.isgs.uiuc.edu?3DWorkshop/nu_3d_welcome.html

Key Recommendations

The 3D hydrogeological model of the Hodgson and Kings Creek sub-catchments developed for this project has shown the feasibility of building such models, and their usefulness as tools for better understanding and evaluating groundwater systems. However, the current version of the model is clearly not definitive, and should only be considered as a stage in the ongoing development and application of this technology. Further work is contingent on the requirements of the main stakeholders, and should be undertaken in close consultation with the Condamine Alliance.

Building upon the comments provided in the previous section, our key recommendations for future studies related to the Hodgson and Kings Creek 3D model are to:

1. Develop a similar 3D hydrogeological model in another Condamine River sub-catchment, focussing on an area with markedly different hydrogeological characteristics to those of the Hodgson and Kings Creek district, i.e., groundwater flow systems not hosted in volcanic rock-dominated domains;
2. Integrate other sources of geological and geophysical data into the development of this (and other) 3D models to improve their accuracy and scientific validity. These could include geological data from mineral exploration or coal-seam methane exploration drillholes, or local electromagnetics or radiometrics surveys;
3. Consult closely with other natural resource management sectors with a vested interest in the Condamine region, in order to broaden the scope of the current 3D model and make it more useful to a wider environmental audience. Specific work examples could include tackling problems associated with groundwater dependant ecosystems such as wetlands or springs, or integrating overlays of soils or landuse data with the digital elevation model; and
4. Further develop the model by focussing the model on a smaller scale area of either the Hodgson or Kings Creek sub-catchment, where reliable monitoring bore data from multiple sites is available. This would allow better resolution of hydrogeological properties, e.g., modelling individual water-bearing zones based on the lithological and hydraulic parameters of the water-bearing zone. Modelling the standing water-level and investigating temporal variations in the watertable level could also form part of a more detailed modelling investigation.

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APPENDICES

Appendix 1: Lithological Borehole Codes

Appendix 2: 3D Grid Construction

Appendix 3: Gocad Object Definitions

Appendix 1 – Lithological Borehole Codes

Code	Number of uses	Type	Stratigraphic unit
TSOIL	701	Topsoil	Quaternary
WBSLT	728	Weathered Basalt	MRV
WBSLTWB	200	Weathered Basalt - Water-bearing	MRV
BSLT	2216	Basalt	MRV
BSLTWB	127	Basalt - Water-bearing	MRV
FBSLT	144	Fractured Basalt	MRV
FBSLTWB	166	Fractured Basalt - Water-bearing	MRV
HBSLT	534	Honeycomb Basalt	MRV
HBSLTWB	707	Honeycomb Basalt - Water-bearing	MRV
BSLTSOAP	40	Basalt with soapstone	MRV
BSLTSOAPWB	4	Basalt with soapstone - water-bearing	MRV
BSLTASH	39	Basaltic Ash	MRV
BSLTASHWB	2	Basaltic Ash - Water-bearing	MRV
CLAY	881	Clay	ALL
CLAYWB	13	Clay - Water-bearing	ALL
CLAYG	43	Clay - with gravel	Quaternary
CLAYGWB	14	Clay with gravel - Water-bearing	Quaternary
CLAYS	43	Clay with sand/silt	Quaternary
COAL	157	Coal	Walloon
COALWB	198	Coal - Water-bearing	Walloon
GRAV	115	Gravel	ALL
GRAVWB	71	Gravel - Water-bearing	ALL
SAND	24	Poorly consolidated sand	Quaternary
SANDWB	32	Sand - Water-bearing	Quaternary
SDST	474	Sandstone	Walloon, MRV
SDSTWB	90	Sandstone - Water-bearing	Walloon, MRV
SHLE	257	Shale	Walloon, MRV
SHLEWB	12	Shale - Water-bearing	Walloon, MRV

Appendix 2 – 3D Grid Construction

Preparation for creating the 3D grid

The Sgrid object in Gocad (an application for creating stratigraphic grids) was successfully used to generate the main stratigraphic units in the Condamine 3D model. The advantage of using this method is that the cells of the SGrid can be deformed and eroded to represent the true geometry of the stratigraphic units.

Surfaces used for constructing Gocad SGrids must conform to the following rules:

- They must have the same lateral extents and the same number of border segments (hence the need to use the low resolution DEM data to extend the topographic surface beyond the catchment boundary);
- They must be continuous across the entire model area, i.e., windows through a geological unit must be locally represented by 0 m thickness; and
- Faults must be represented on the uppermost and lowermost surfaces from which the SGrid is constructed (not an issue in this version of the model as no faults are modelled).

With regard for these rules, the topographic surface had to conform to the extents of the upper Walloon surface as constructed in the structural modelling workflow (SMW). Thus, all ‘windows’ in the top of Walloon surface had to coincide with the topographic surface. This was achieved by mutually cutting the two surfaces with each other, and retaining the necessary parts of these surfaces to create a new and continuous surface.

SGrid Construction

The SGrid construction workflow in Gocad has the same philosophy as the SMW; it is a decision driven process and automatically generates a report as the workflow progresses. Unfortunately the resolution of the 50 m DEM was too detailed for the SGrid routine to process, so the 100m DEM was used instead.

SGrids are specifically designed to mimic stratigraphic units. The corners of each cell hold their XYZ locations so that the cells can be deformed to more accurately represent the true sub-surface geometry of the geological units. Cells at erosional contacts are able to be collapsed to 0 m thickness if the erosion has completely removed that particular cell in the column.

Two approaches were attempted to determine the best way to create the SGrid model. The most successful approach involved constructing individual SGrids for the MRV and Walloon Coal Measures as:

1. The spatial extent of the 3D model when the Hodgson and Kings Creek catchments are combined is too large to generate a functional SGrid model; and
2. The stratigraphic column for the model was too simple to define discrete layers within the SGrid workflow.

To improve model functionality the cell layering in the MRV and Walloon grids varies slightly. In the MRV grid (termed ‘strat_grid_4’) cells are 2 m thick and parallel to the modelled MRV-Walloon

contact. These are then eroded by the topographic surface (remembering that the thin upper Quaternary layer could not be effectively modelled) to represent the possible basalt flow geometry as closely as possible. Zero volume cells (i.e., topographically eroded cells) are registered as 'invalid', so that in future property modeling only the valid cells will be used. In the Walloon grid (termed 'strat_grid_5'), the cells are also 2 m thick, but distributed proportionally between the upper and lower surfaces. Ideally, as the MRV-Walloon interface is an unconformity, the cells should also parallel the bottom surface; however, as the base is a downward-translated copy of the upper Walloon surface, the proportional distribution is considered the best representation.

Given the way in which the geometries of the cells are stored, the grid uses more computer memory than the other type of grid object in Gocad, i.e., voxets. As a result, maintaining the detailed vertical resolution (2 m) in the grids resulted in decreased lateral resolution. This required the lateral resolution to be set at 400 m x 400 m. Although this is not ideal, it is well correlated with the average distance between the main source of input data, i.e., the water bore data.

Appendix 3 – Gocad Object Definitions

The objects constructed in Gocad are organised into “Favourites” folders within the project. Arranging objects like this allows them to be grouped according to the data types as opposed to object types. This makes it easier for users to find particular objects when they may or may not know the object type that support the data that they are most interested in. The following descriptions explain the main data types used in the 3D model.

Borehole data

Drillholes_Hodgson – a drillhole group containing all holes in the Hodgson catchment area. Contains markers for the tops and bottoms of all stratigraphic and aquifer units as well as continuous zones for the stratigraphy and zones for the aquifers.

Drillholes_Hodgson_MRV – a curve object representing the drillhole zones for the MRV unit on the Drillholes_Hodgson group. The same object exists for each of the zones on the drillholes.

Drillholes_Hodgson_paths – 1 single curve object what represents the drillholes traces. Included as a lighter representation of the drillhole locations for visualization purposes.

The same nomenclature has been used for all the drillholes in the Kings Creek catchment.

Walloon_top_marker_points – points from top of Walloon markers within the drillholes.

Geology

3_Walloon_base_sgrid – the surface representing the base of the SGrid is below the deepest aquifer from all drillholes.

3_Walloon_top_ts_edited_for_100m_DEM – the final surface from the Structural Modelling Workflow (SMW), but with portions of the 100m DEM surface inserted where there is 0 m thickness of MRV.

Strat_grid_4 – the stratigraphic grid created to model the MRV over the two catchment areas. Vertical cell resolution 2m, lateral resolution 400 m x 400m. Cells parallel to *3_Walloon_top_ts_edited_for_100m_DEM*. Some sections may show graphical artefacts where the grid has 0 m thickness, i.e., MRV absent.

Strat_grid_5 – the stratigraphic grid created to model the Walloon over the two catchment areas. Vertical cell resolution 2m, lateral resolution 400 x 400m. Cells proportional to *3_Walloon_top_ts_edited_for_100m_DEM* and the surface *3_Walloon_base_sgrid*.

Surface Data / Base_ – the curve edited from a shape file representing the contact on the 1:500,000 mapsheet.

Surface Data / Base_Quaternary – the curve edited from a shape file representing the contact on the 1:500,000 mapsheet.

Walloon_top_marker_points – points from top of Walloon markers within the drillholes.

Geophysics

(Object names are derived from the data files supplied directly from GADDS)

Gravity / gravmapDec2005_cropped – GADDS gravity grid cropped over model area

Gravity / gravmapDec2005_regional – GADDS gravity grid.

Gravity / V_GRAV_JETSTREAM – GADDS gravity points data. Properties are Bouguer, FreeAir and Gravity from the processing stream. Bouguer is set to be displayed by default.

Magnetics / GSQP1108tmig – GADDS magnetic grid

Magnetics / GSQP792tmig – GADDS magnetic grid

Remote sensing

Condamine_SPOT5_pseudonatural_resampled_small – Spot 5 satellite image

Topography

Cultural Data / Boundary – catchment boundaries

Cultural Data / dam_wiers_56 – points representing dam weirs within the model area imported from ArcGIS. Same for Rail, Roads, Springs3D, Streams, and towns_56_objects.

DEM_100m_surface – Topography surface created from resampled 25m resolution DEM with low resolution areas (~300 m) stitched onto the surface where data was absent. Properties IO_4/JO_4/KO_4/tmp__IO_4/temp__JO_4 all created within the SGrid workflow. Thickness properties are Depth_to_base_sgrid / Depth_to_Walloon_contact / Depth_Walloon_to_base.

Additional procedures

To import a drillhole path – the file “deviation_final.txt” is in the correct format – hole_id, depth, azimuth, dip. Things to remember are that the final depth entry needs to be the length of the hole and a vertical dip entry is 0 while a horizontal one is 90.

The command is found at File > Import Well Data > Path > from column-based file.

Import everything at 0,0,0. The holes will be correctly located in the next step.

File > Import Well Data > Locations from column-based file – the file “collar.txt” is in the right format – hole_id, X, Y, Z (the Depth entry is superfluous). Note that KB (or Kelly Bushing) is the Z value, use the option “move existing wells”.

Once this command has been executed, then the drillholes will be in the correct location.

The next steps are to add properties and geological information as needed.

Adding properties – The file “assay.txt” is a combination of Mira and Gocad format. Mira uses from-to fields to plot the property value at the mid-point whereas the Gocad import filter plots the property at the mid point (To_mid in this file). So the two filters plot the data at the same point, they get to the same result in slightly different ways. The Gocad command is found at: File > Import

Well Data > Logs > From column based file. Do not use the option to add all the properties, it is best to manually add the properties in the next window of the filter.

Adding geology zones – The file “geology.txt” is the correct format for both the Mira and EDS importers – Hole-id, from, to, lithology. The command to create well zones is found at File > Import Well Data > Well Zone and Values

Adding geology markers – The file “geology.txt” is used for this command as well which is found at File > Import Well data > Markers > Column based file, depending on whether you want the marker at the top or the bottom of the interval, you select the From or To field as your Measured Depth column. Remember, placing the marker at the bottom of the interval will place a marker at the very end of the drill hole which almost certainly ends in the middle of the lithological unit, these markers should not be used to constrain a surface.