Disclaimer

This document is based mainly on specific materials supplied by the OGIA. The scattered spatial and temporal data limits the accuracy of the presented model from being use for different purposes other than the one specified here.

Citation

Dafny E., 2013. Groundwater flow model for the Lucky-Last spring group. University of Southern Queensland, Toowoomba, Australia.

Authors

Dr. Elad Dafny is a hydrogeologist with more than 10 years of experience in industry and academy, with special expertise in applied hydrogeology, environmental impact assessments, modelling and isotope hydrology.

Abbreviations

CSG- Coal Seam Gas

DNRM- Department of Natural Resources and Mines

GAB- Great Artesian Basin

OGIA- Office of Groundwater Impact Assessment (Formerly: QWC)

CMA- Cumulative Management Area

QWC- Queensland Water Commission (Now: OGIA)

SIMS- Spring Impact Management Strategy

USQ- The University of Southern Queensland

UWIR - Underground Water Impact Report

Table of Contents

Tables list

Figures list

1 Introduction

Three springs clusters are located approximately 20km north-east of Injune, in the north-eastern margin of the Surat Basin (Fig. 1). These are:

- The ‘Lucky Last Springs’ cluster (#230) with vents 287 and 340;
- The ‘Springrock Creek’ cluster (#561) with vent 285;
- The ‘Abyss Springs’ cluster (#592) with vents 285a, 285b and 286.

The geological setting in the realm of these springs is complex, including a number of faults (marked in black in Figure 1) which may act as a preferential flow conduits and/or hydrogeological barrier to groundwater.

This report summarizes an innovative modelling effort which aims to enhance the hydrogeological understanding of this area, with an emphasis on the springs flow mechanisms. The model was developed using FEFLOW platform due to its advance capabilities for (1) allows an unstructured grid, which increased flexibility around key areas of interest and larger cell sizes away for focus areas , (2) allows multi-level water tables, i.e., two or more phreatic aquifers, and (3) surface-subsurface interconnection.

2 BACKGROUND

2.1 SCOPE

In areas of concentrated CSG development, the impacts on water levels caused by individual CSG projects can overlap. In these situations, the Queensland Government may declare an area to be a ‘Cumulative Management Area’ (CMA). The area of concentrated CSG development in Queensland has been declared as the ‘Surat CMA’.

When a CMA is declared, the Office of Groundwater Impact Assessment (OGIA) is required to prepare a cumulative assessment of impacts of CSG water extraction. This includes regional groundwater modelling and the development of integrated management arrangements, including spring and aquifer monitoring requirements. The collective assessments and management arrangements are established in an ‘Underground Water Impact Report’ (UWIR).

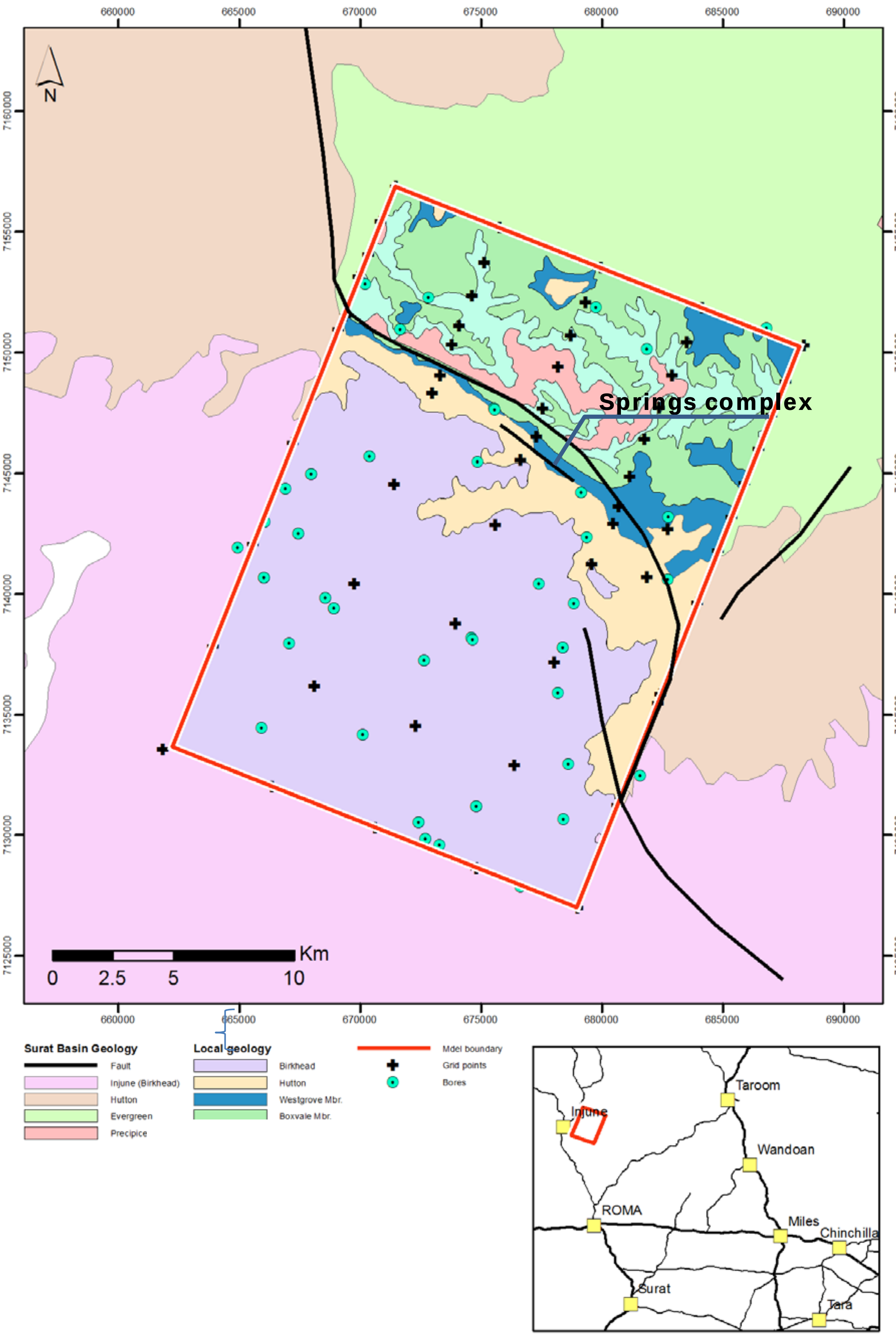


Figure 1: *Location and Geological maps*

A key component of the UWIR is the Spring Impact Management Strategy (SIMS). The SIMS relates to all potentially affected spring vents (points of discrete groundwater discharge) and watercourse springs (gaining streams). In relation to potentially affected springs, the mechanism and nature of the connection between a spring and underlying aquifers affects the susceptibility of the spring to a change in water pressure. OGIA is currently undertaking a project improve the local scale hydrogeological understanding at selected sites (OGIA, 2013). To support this research, OGIA contacted USQ to complete an innovative modelling study for the Lucky Last and Abyss spring complexes.

2.2 Data sources

Data sources for this project included previous studies (EHA, 2009; KCB, 2012a, KCB, 2012b) and data supplied exclusively for the purpose of this project by OGIA. The latter includes stratigraphic interpretation of private water bore and exploration well within the model domain.

2.3 Geology

The study area is located at the north-eastern rims of the Surat Basin. The study area is intersected by a prominent fault, which is part of the longer Hutton-Wallumbilla Fault Zone (Figure 1) and which lower the south-west part in respect to the north-east accompanied by thrust.

The outcropping sequence includes four Jurassic formations (from top to bottom): Birkhead Formation, Hutton Sandstone, Evergreen Formation and the Precipice Sandstone. In the Evergreen Formation, two members can be identified- the Westgrove Ironstone Member and the Boxvale Sandstone Member; the section above and below these sequence is termed upper zone and lower zone, respectively (Table 1). On the north-east side of the major fault only the Evergreen Formation and Precipice Sandstone are at outcrop.

Table 1: Composite geological section

Formation	Sub-units	Principle lithology
Birkhead		mud and siltstone
Hutton		sandstone
Evergreen	Upper zone	shale
	Westgrove Member	mud and siltstone
	Boxvale Member	sandstone
	Lower zone	shale
Precipice		sandstone

In principle, the Hutton Sandstone, the Precipice Sandstone and the Boxvale Sandstone Member comprise water bearing layers, the Evergreen Formation comprises shales, and Birkhead Formation and Westgrove Ironstone Member comprise mud and siltstone (Cook et al., 2013).

2.4 Hydrogeology

2.4.1 The regional system

The studied area lies within the eastern margin of the Great Artesian Basin (GAB). The GAB comprises a sequence of alternating layers of permeable sandstone aquifers and lower permeability siltstone and mudstone aquitards including the Jurassic units in the focus of this study (see Table 1). The overall recharge rate for sandstone outcrop in the area was estimated to be 1-5 mm/year (Kellett et al., 2003; QWC, 2012). The major aquifers, including Precipice and Hutton sandstones are vast, have significant water storage, and are extensively developed for groundwater use (primarily stock, domestic/town/industrial water supply). North-east of the fault, the Bandanna Formation is currently being exploited for CSG extraction, requiring de-pressurization of the formation.

Groundwater flow within this part of the GAB is generally eastward-south-eastward (Figure 2). Generally, near the recharge zones, vertical water leakage is induced by pressure differences, and tends to be downwards, with the shallow aquifers feeding the deeper artesian aquifers, and vice versa, away from the recharge zones vertical gradient is upward (Welsh, 2006).

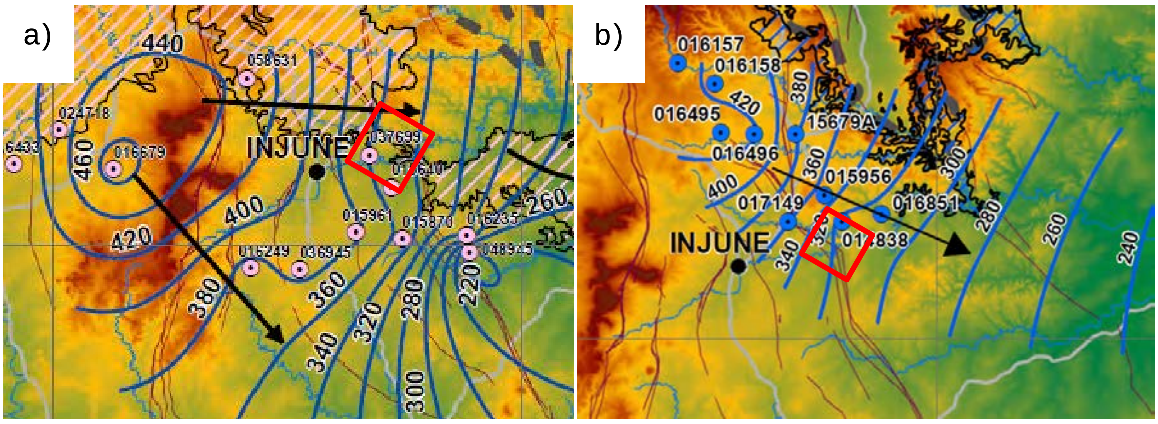


Figure 2: *Groundwater flow field in (a) Hutton Sandstone Aquifer and (b) Precipice Sandstone Aquifer (source: QWC, 2012). Model area in red for scale.*

Previous studies indicate that within the study area, heads decrease in the Hutton aquifer from ~+370 m to ~+345 - +335 m and in the precipice aquifer from +340 m to +310 m. In turn, this suggests a downward vertical gradient, as expected near the recharge zones.

2.4.2 Springs and watercourses connectivity

Within the studied area there is inter-connection between the surface water and the groundwater through several systems, including the various low discharged springs (describe below) and a ~5 km section of the Injune creek. This interconnected section runs from the Birkhead/Hutton contact line at elevation +356 m, eastward, to elevation +348 m (Figure 3).

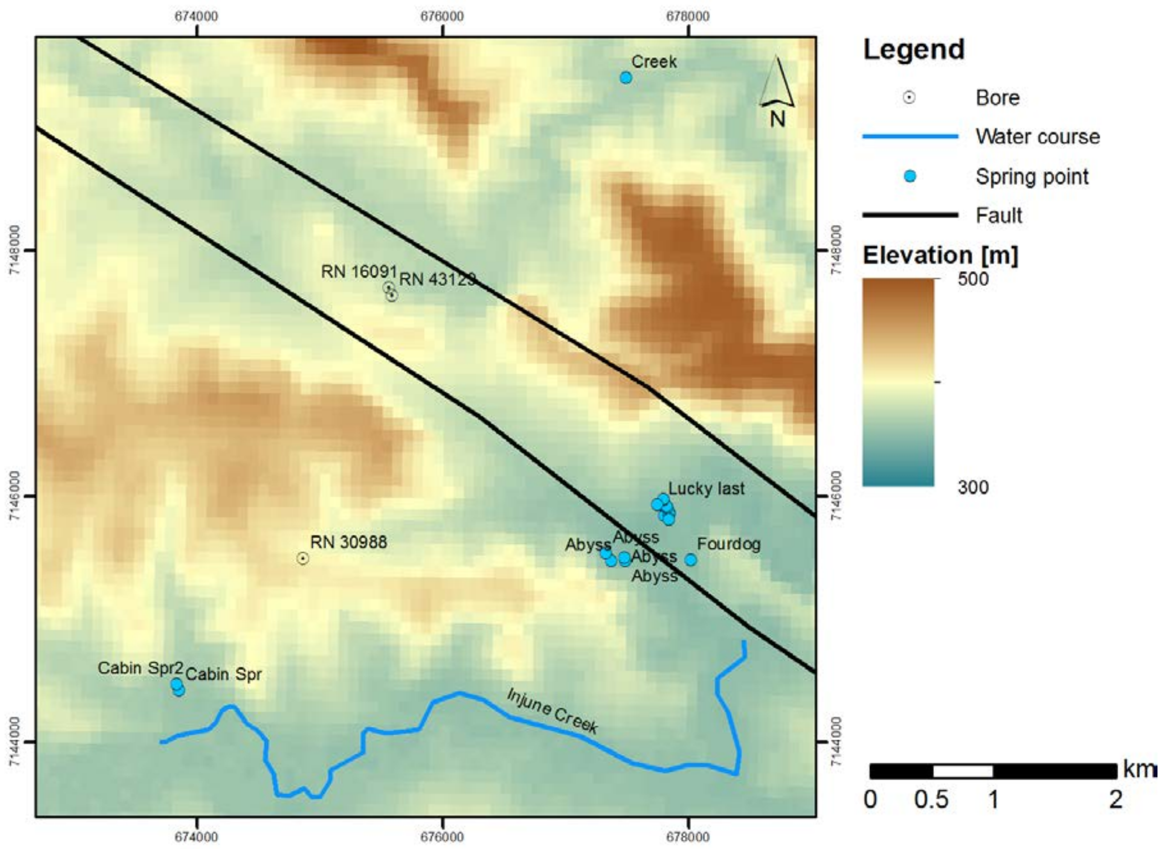


Figure 3: *Springs and Creek location*

The springs include five groups (Table 2), three of which are located in association with the fault zone, and in similar elevation. The springs are permanent, some with a significant mounding (KCB, 2012a). Nevertheless, all the springs serves only as a minor outlet for the regional aquifers.

Two hydrogeological ‘springs feeding’ mechanisms were suggested for the vents included in the studied area (Figure 4; QWC, 2012):

1. ‘Water table window’: springs are fed by phreatic water table, at places where the potential head is slightly higher than the topography. In the studied area the Hutton formation is incised and feed the Injune Creek and probably also the cabin and Abyss springs. The Evergreen Formation is probably feeding the ‘Creek’ springs and maybe also the ‘Lucky last’ and ‘Fourdog’ springs (KCB, 2012a,b).
2. ‘Artesian pressure’: springs are fed by confined aquifer, at places where a possible ‘leak’ occurs, such as near fractured fault zones. In the studies area the Precipice sandstone may feed the ‘Lucky last’ and ‘Fourdog’ springs, leaking upward through the fault zone (KCB, 2012a,b).

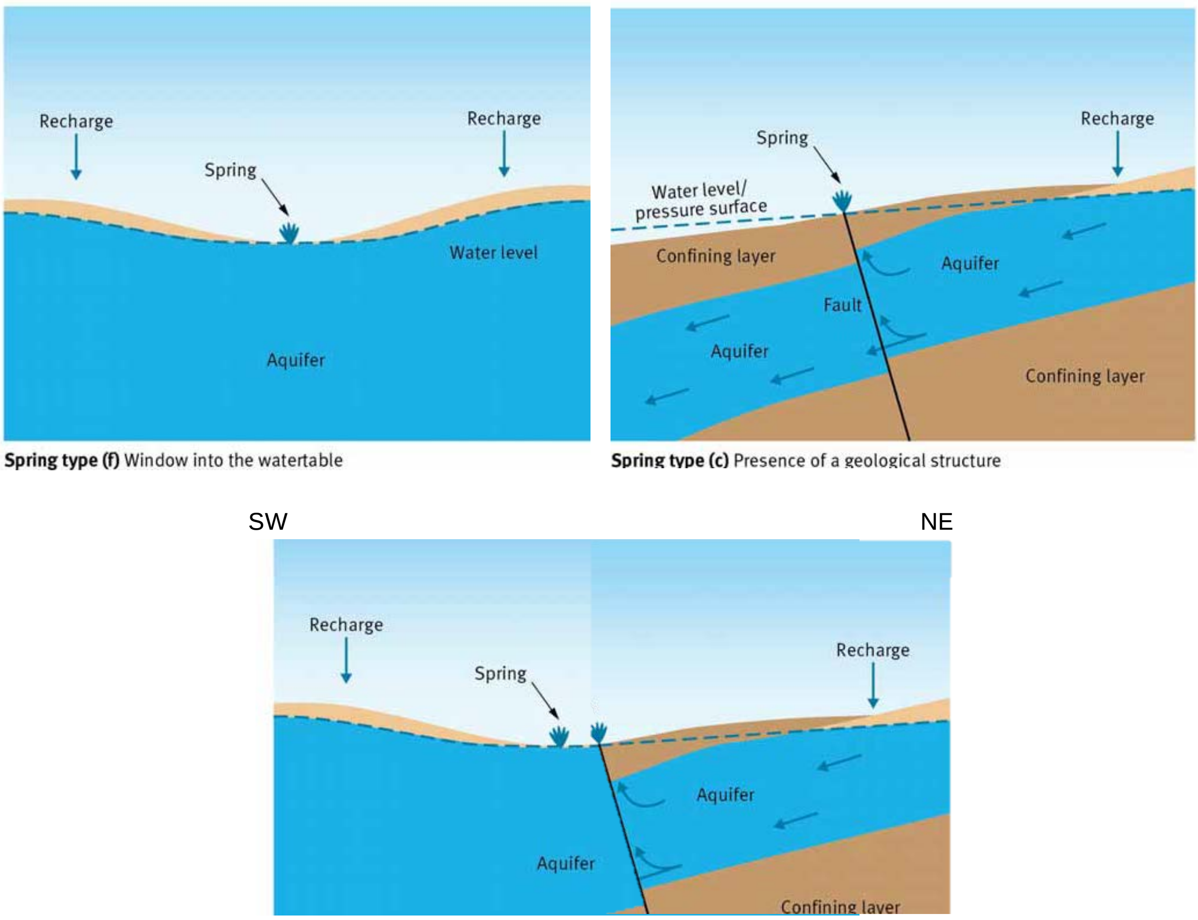


Figure 4: *Suggested Springs Emerging Mechanism. (a-b) ‘Springs types’ as appear in QWC, 2012; (c) Conceptualization of the studied area for vents 286 and 287*

Table 2: Spring groups details

Group	**Elevation [m asl]**	**Outcrop**	**Previous suggested feeding mechanism** (KCB, 2012b)
Cabin Springs (285A+B)	+355.5	Birkhead/Hutton contact line	WT/AR
Abyss Springs (286)	+348.2	Hutton/Westgrove contact line	WT/AR
Fourdog (287)	+349.5	Westgrove	WT/AR
Lucky last (340)	+349 - +350	Westgrove	WT/AR
Creek (285)	+356.8	Boxvale	WT

3 NUMERICAL MODEL SETTINGS

3.1 Conceptualization

The numerical flow model exhibits the groundwater flow in the four prominent hydrogeological units, namely Birkhead Formation (aquitard), the Hutton Sandstone (aquifer), the Evergreen Formation (aquiclude) and the Precipice Sandstone (aquifer), as well as the groundwater system interconnection with the surface water.

Further distinction to the sub-units of the Evergreen Formation was made only at the vicinity to the fault zone as (1) there are no wells to constrain such a detailed division in wider areas, (2) the outcrops of the different members of the Evergreen Formation in the NE area are not continuous, i.e, they are desiccated to discrete hills, and (3) in many places the upper sub-units are dry (i.e., the groundwater table is found below bottom of the layer). Throughout the model, the top hydrogeological units assumed to be under phreatic conditions.

The model comprises three dominant structural zones: a south-western lower zone, a mid-fault uplifted zone and a north-eastern uplifted zone (Figure 5). In between the three zones two narrow belts of elements were set to represent the fault (gauge); across these fault belts extreme elevation gradient exist.

As it comprises a very small part of the entire GAB, its boundaries do not coincide with the hydrogeological boundaries of the system; groundwater flow is assumed to derive by the differences in the assigned head. At places where groundwater - surface-water interconnections is assumed, a suitable representation of the hydrological conditions was assigned to the top layer.

The objectives of the model were to represent a low discharge through the springs, by satisfactorily reconstruct the groundwater head map through several (two) alternative conceptualization of the fault-aquifer properties. **It should be noted that only limited water level information is available within the model domain; the conceptualization and models resolution are restricted to the availability and spatial distribution of these hydrogeological data.**

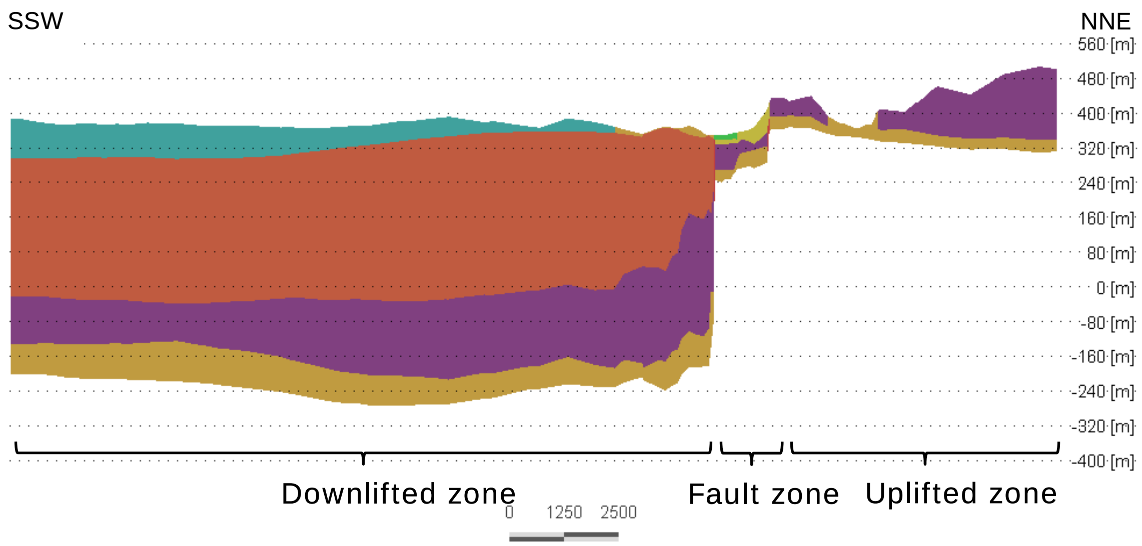


Figure 5: *SW-NE Cross-section of the model domain. See colours legend in Table 4. More cross sections are shown in the appendix.*

3.2 Interface

The numerical model was introduced using the FEFLOW code (Version 6.1) of WASY's GmbH (Diersch, 1996). FEFLOW is a commercial finite-element model which is able to address the unique specification needed for the study area including a complex topography and structure, multiply water tables and lateral shift from confined to unconfined conditions. These capabilities are aligned with the project objectives. FEFLOW solves the continuum equations for liquids (i.e. water) in porous media (Diersch, 1996). Further FEFLOW definitions within the text are italic. Complete technical definitions are listed in Table 3, below.

3.3 Model domain and Discretization

The model domain covers an area of 18 km x 25 km, which rotated about the north direction by 30 degrees, to enable better description of the boundaries. It was automatically discretise into 2836 triangular elements, to align with the following pre-defined features:

- Formation outcrops;
- The Hutton-Wallumbilla Fault;
- The local water bores;
- Spring locations;
- Spring section of the Injune creek.

Elements dimensions varied according; particularly small elements are located along the fault line, vent line and around the springs.

Table 3: FEFLOW option for mesh generation and problem summary

Problem Summary		
General	Description:	Separate flow process
	Type:	Saturated
	Time class:	Steady flow
Surfaces	Projection:	3D phreatic aquifer (fixed mesh)
	Free surface constrains:	unconstrained when touching the top surface
		unconstrained when falling dry
Numeric	Anisotropy settings	Axis-parralel anisotropy
	Velocity approximation	improved
	Solver type	Preconditioned conjugate gradient PCG
Mesh	Element type:	Triangular prisms
	Number of layers:	4
	Number of elements:	11,344 (2,836 per slice)

3.4 Layers

The models mesh represents the local geological structure and comprises of four layers (Table 4, Figure 6). These four layers are bounded by 5 slices, the upper most of which is the topographic surface (1sec DEM, supplied by OGIA). The other four slices were constructed in GIS (ArcView) based on interpolation of a point data supplied by OGIA (see 'grid points' in Figure 1). All the point data were interpolated using the IDW method, with the two faults strand defined as barriers. The GIS layers were imported in to the FEFLOW project and elevation data for each of the layers were attributed to the mesh nodes. In vicinity to the fault zone, architecture was amended manually to fit a different division into Westgroup member (thickness of 10-15 m, and trimming NE), Boxvale member (15 m), lower Evergreen (60 m) and Precipice (25-35 m).

Table 4: Grids Layers

South-west			North-East	
Layer	**Geological unit#**	**Top surface**	**Top surface**	**Geological unit#**
#1	Birkhead*	Topography	Topography	Evergreen*
#2	Hutton	Top Hutton	Top Precipice	Precipice
#3	Evergreen	Top Evergreen	Top Precipice-10m	Precipice
#4	Precipice	Top Precipice	Top Precipice-20m	Precipice
		Bottom Precipice	Bottom Precipice	

Notes:

Colours are the same as in Figure 6.

* In places where the uppermost geological formation is eroded, cells were set to represent the 2nd geological formation.

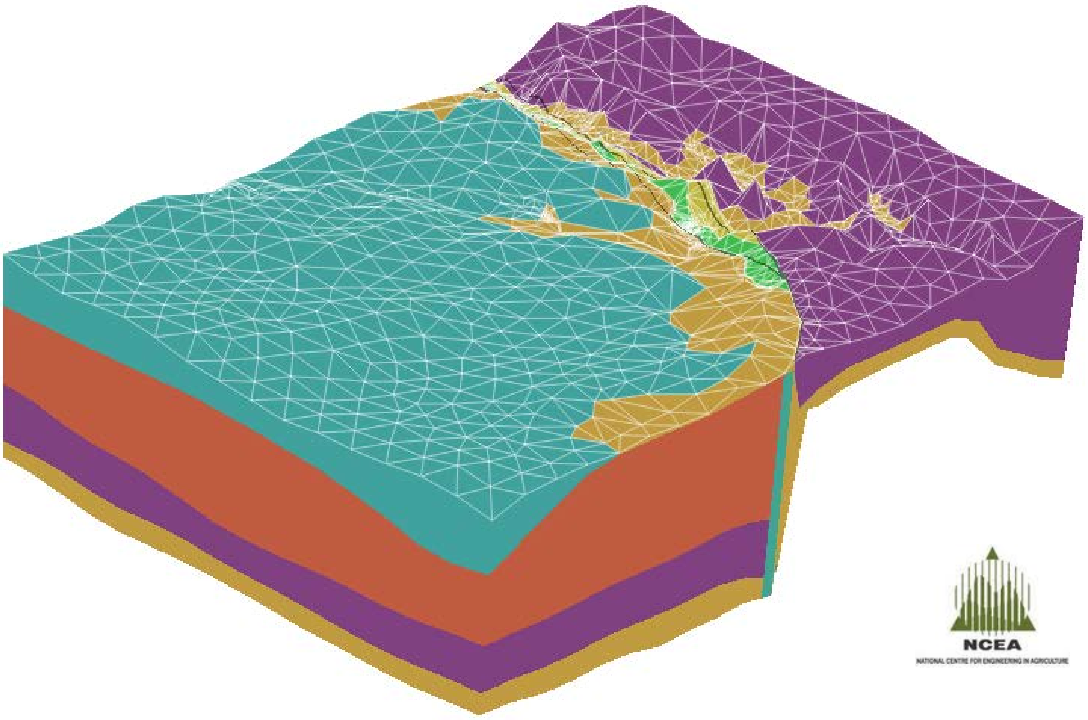


Figure 6: *Oblique view of the model domain from the south-east. Colours represent vertical conductivities, and set to exhibit the layered structure.*

3.5 Parameterization

The various layers were set with a singular horizontal ($K_h=K_x=K_y$) and vertical ($K_v=K_z$) hydraulic conductivities (Table 5). Representative values for each layer, were extracted from the GHD (2012) model; this information was supplied by the OGIA as a digital GIS Raster. It should be noted that different horizontal hydraulic conductivities for all formation in the realm of the Surat basin were documented and used in previous researches; these may range upon several orders of magnitude. For example, the Hutton aquifers was ascribed 0.05–1.25 m/d and the Precipice aquifer was ascribed 0.1-4 m/d, while in the present work both ascribe 1 m/d (based on local GHD (2012) values). Changes of the flow regime in respect to changes in the conductivities may be tested using a sensitivity analysis.

In the base scenario, the fault cells were set to $K_h=K_v=0.0001$ m/d. These values are equivalent to siltstone properties, as it is assumed that the fault serves as a barrier to the groundwater flow, and that the horizontal conductivity of the fault was downgraded due to the slick on the fault.

Table 5: Hydraulic properties of geological layers

<table>
<tr><th rowspan="2">Formation</th><th rowspan="2">Sub-units</th><th rowspan="2">Principle lithology</th><th colspan="4">Hydraulic Conductivity [m/d]</th></tr>
<tr><th colspan="2">Horizontal</th><th colspan="2">Vertical</th></tr>
<tr><td colspan="2">Birkhead</td><td>mud and siltstone</td><td colspan="2">0.05</td><td colspan="2">$7x10e^{-5}$</td></tr>
<tr><td colspan="2">Hutton</td><td>sandstone</td><td colspan="2">1</td><td colspan="2">0.5</td></tr>
<tr><td rowspan="4">Evergreen</td><td>Upper zone*</td><td>shale</td><td rowspan="4">$6x10e^{-5}$</td><td></td><td rowspan="4">1e-7</td><td></td></tr>
<tr><td>Westgrove Member</td><td>mud and siltstone</td><td>0.001</td><td>0.001</td></tr>
<tr><td>Boxvale Member</td><td>sandstone</td><td>0.1</td><td>0.05</td></tr>
<tr><td>Lower zone</td><td>shale</td><td>$6x10e^{-5}$</td><td>1e-7</td></tr>
<tr><td colspan="2">Precipice</td><td>sandstone</td><td colspan="2">1</td><td colspan="2">0.1</td></tr>
</table>

* missing

3.6 Boundary conditions

The northwest and the southeast boundaries of the model were set as first type boundary conditions (Dirichlet type) with a fixed head. Initially, the heads were extracted from the GHD model (GHD, 2012); this information was supplied by the OGIA as a digital GIS Raster. Basically, heads at the NW were higher than in the SE and derive groundwater flow through the domain. Following preliminary simulations, the values were slightly adjusted.

The five spring complexes and the spring water course were represented by a third type boundary condition (Couchy type) (Table 5). This boundary condition defines the discharge (Q) as a function of head differences between a given spring threshold and the aquifer, and a transfer rate parameter (ϕ) :

$$Q = A * \Phi * (h_{aquifer} - h_{spring}) \qquad | \ h_{aquifer} > h_{spring}$$

As default, ϕ was set to 1 day^{-1} for all the springs. Table 5 also listed the calculated discharge in the base scenario.

Table 6: Springs element boundary conditions

Complex	No. of Elements	Bounding head [m] (h_{spring})	Calculated discharge [l/s]
Cabin (285A+B)	3	+355.6	0.04
Abyss (286)	4	+347-348	6.36
Lucky last (340)	1	+348.5	0.05
Fourdog (287)	16	+349	0.05
Spring rock (285)	1	+356	0.36
Injune Creek	15	355-348	---

4 NUMERICAL SIMULATIONS

4.1 Calibration

The model was fitted to meet groundwater heads in the relevant hydrogeological units by changing the hydraulic conductivity, bounding heads, and the storage parameter of the springs.

The NE zone was calibrated by altering the boundary conditions to fit the measured hydraulic heads at bores RN16794 and RN17568, while allowing small seepage in spring 285. Heads along the NW and SE boundaries were +387 m and +335 m, respectively.

Heads for the Hutton aquifer in the SW zone were calibrated to fit most of the measured data in RN48884, RN31940, RN37712, RN37699, RN15640, RN123238 and RN38223. The measured heads at RN37698 and RN24893 were substantially lower than any other well in their vicinity by 14-24 m and 10-15 m, respectively, thus these wells do not account in the calibration process. The measured head at RN36742 was higher than expected in its position and was not calibrated as well. Heads along the NW and SE boundaries were around +370 m and +345 m, respectively. This values are in agreement with previous studies (Figure 2a).

There is only one measuring point (RN30988) which can be serve to calibrate the head boundaries for the Precipice aquifer. Heads along the NW and SE boundaries for this aquifer were set between +370 m - +356 m and +335 m, respectively. In any case, the Hutton aquifer head exceed the Precipice aquifer head by at least 2 m.

4.2 Groundwater flow

There is very little head data of bores in the model domain, which makes the compilation of a reliable groundwater flow map complex task. However, the numerical model allows drawing such maps, once establishing some assumptions along the boundaries. Compiled groundwater head maps for the Hutton and Precipice aquifers are shown in Figure 7. Generally, the flow is from NW to SE, as induced by the boundary conditions. The head at the Hutton aquifer is higher by 5-10 m from the Precipice aquifer in the same spot. This vertical gradient is expected at and near the recharge areas.

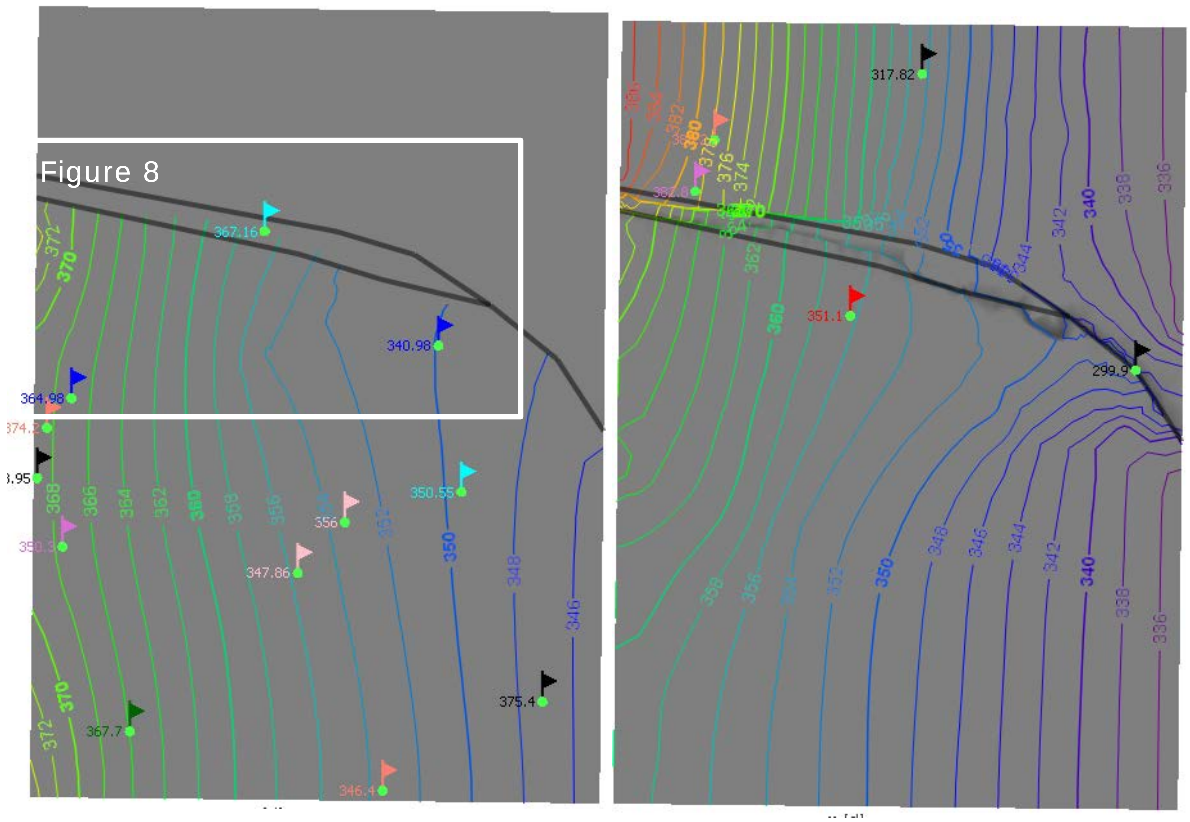


Figure 7: *Groundwater heads at (a) Hutton Formation and (b) Precipice Formation*

4.3 Water balance

Overall, there is a balance between water inflow and outflow (Table 6). The total inflows are 117 l/s; however, much more water flow in the SW zone than the NE zone (107 l/s and 10 l/s) and much more water flow through the Hutton aquifer than the Precipice aquifer (88 l/s and 29 l/s, respectively).

25% of the water entering the domain is discharge through the surface water outlets. A large portion of this component (19%) is through the Injune Creek and a smaller component (6%) is through the springs.

Table 7: Water balance [Ml/yr]

In		**Out**	
NW boundary	3,654	**SE boundary**	2,734
		Springs*	216
		Stream	704

* Outflow through each of the springs is detailed in Table 5.

4.4 Flow system

The various springs are fed by up-gradient component (Figure 8); this result is expected where the flow field is dictated by the boundary conditions.

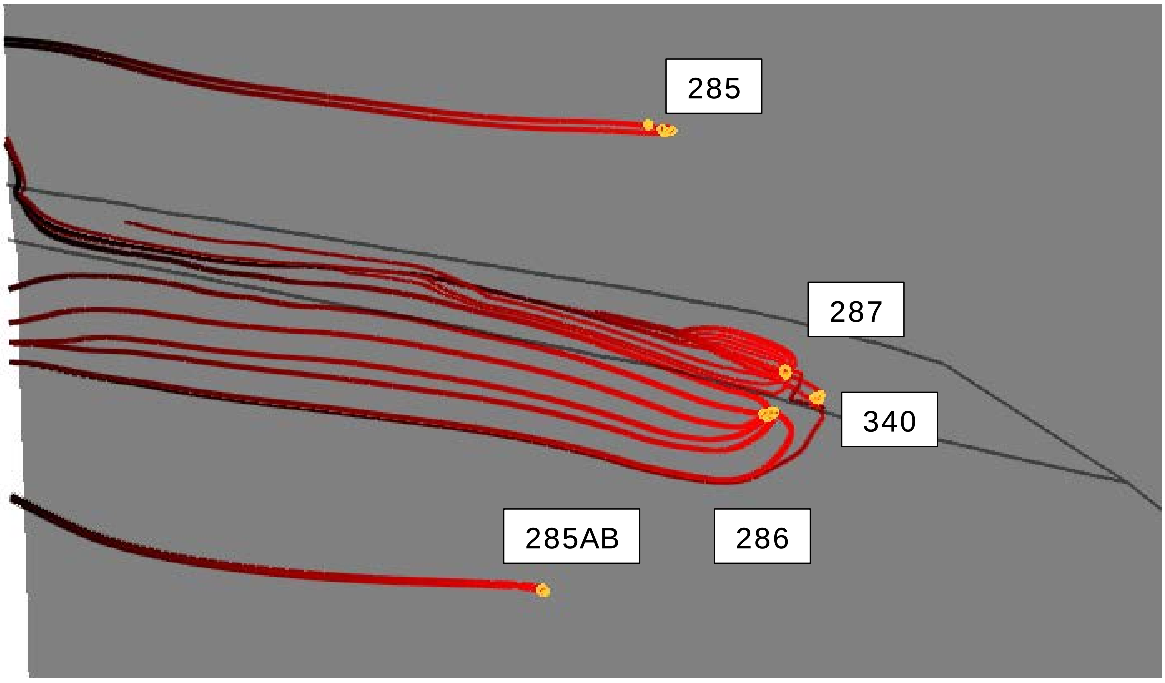


Figure 8: *Groundwater flow path toward the springs (map view, see inset in Figure 7)*

Springs 285 and 285AB are a typical water table springs. They run from the boundary, at the same elevation and gain an upward vertical component only near the springs. Flow paths directing toward spring 285AB runs at Hutton Formation and those directing towards spring 285 runs in the Precipice Formation.

Flow paths towards spring 286 runs parallel and south of the southern fault. They origin and run in the Hutton Formation, nevertheless, at varied depths.

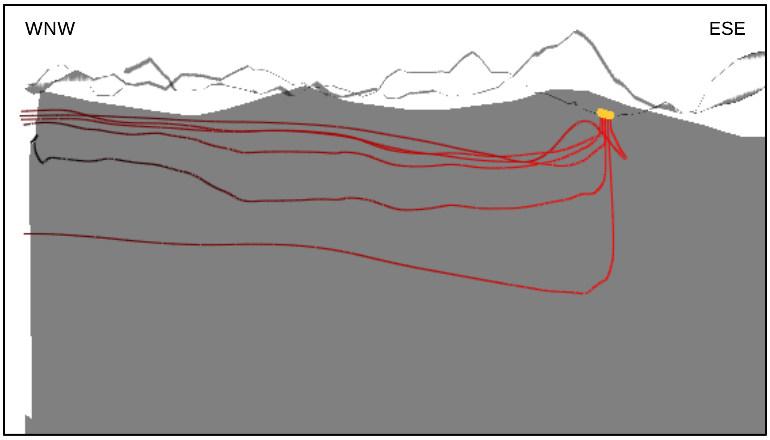


Figure 9: *Groundwater flow path toward spring 286 (vertical plain, generally parallel to the fault)*

Most of the flow paths towards springs 287 run within the faulted zone, along the Precipice Formation and gain vertical component in vicinity of the spring (Figure 10). Additional flow path occurs parallel to the southern fault from the Hutton Formation.

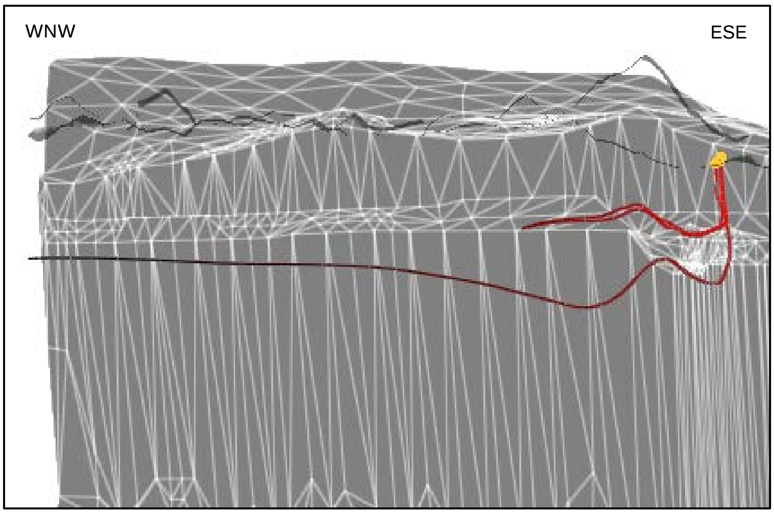


Figure 10: *Groundwater flow path toward spring 287 (vertical plain, generally parallel to the fault)*

Flow paths towards springs 340 can be divided into 3 groups: the first component origins at the WNW boundary, and runs parallel to the southern fault, at either sides of it; this component corresponds with the regional flow in the Precipice Formation. The second component originates some 1km up-gradient from the spring, in shallow depths; this component probably corresponds to lateral flow from the Hutton formation. The third component is a vertical flow path, origin at the Precipice Formation in vicinity to the springs.

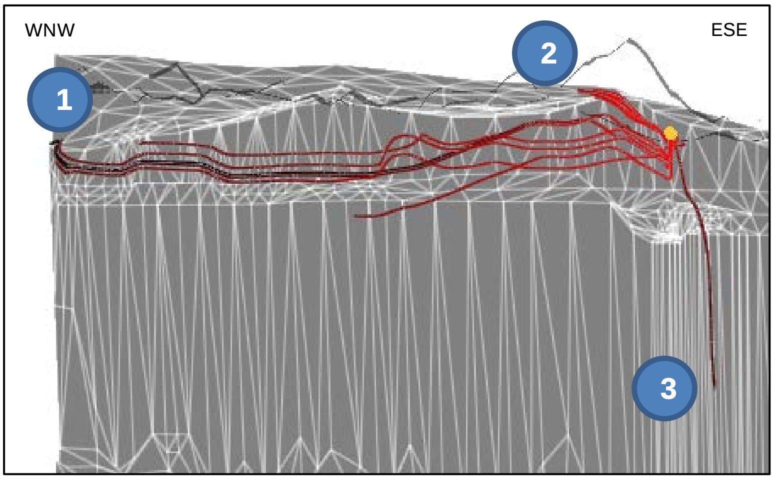


Figure 11: *Groundwater flow path toward spring 340 (vertical plain, generally parallel to the fault)*

5 SUMMARY

A 3D geological mesh, including four formations and complex faulting geology, was built for the studied area. The 3D model have been attributed boundary conditions and estimated hydraulic parameters. Flow at the relevant hydrogeological units has been set to driven by the head differences across the NW-SE boundaries, while feeding some interconnected surface water spring complexes. The preliminary results suggest all springs are fed by up-gradient component, with springs along the fault fed also by vertical component. Sensitivity of the result to parameterization and the plausible of different springs feeding mechanisms should be further investigated.

6 REFERENCES

Cook A.G., Bryan S.E. and Draper J.J., 2013. Post-orogenic Mesozoic basins and magmatism. In: Jell P.A. (Ed.): Geology of Queensland. Geological Survey of Queensland. 970p.

Diersch H.J.G., 1996. FEFLOW - Reference manual. DHI-WASY GmBH, Berlin.

EHA, 2009. Identification of source aquifers to significant springs dependent on groundwater flow from the Great Artesian Basin. Submitted to Department of Environmental and Resources Management, December 2009.

GHD, 2012. Surat Cumulative management area - groundwater model report. Rep. QWC17-10 stage 2.

Herczeg A.L., Torgersen T., Chivas A.R. and Habermehl M.A., 1991. Geochemistry of groundwater from the Great Artesian Basin, Australia. *Journal of Hydrology*, 126: 225-245.

KCB, 2012a. Hydrogeological attributes associated with springs in the Surat Cumulative Management Area. Submitted to Queensland Water Commission, Jan 2012.

KCB, 2012b. Desktop assessment of the source aquifer for springs in the Surat Cumulative Management Area. Submitted to Queensland Water Commission, May 2012.

Kellett J.R., Ransley T.R., Coram J., Jaycock J., Barclay D.F., McMahon G.A., Foster L.M. and Hillier J.R., 2003. Groundwater Recharge in the Great Artesian Basin Intake Beds, Queensland. NHT Project #982713, Bureau of Rural Science, Natural Resources and Mines, Queensland.

Office of Groundwater Impact Assessment (OGIA), 2013. Hydrogeological conceptualisation of springs in the Surat CMA, preliminary conceptualisation and progress report (Version 1.0, Draft October 2013). Department of Natural Resources and Mines, Brisbane.

QWC, 2012. Underground Water Impact Report – Surat Cumulative Management Area (Final), July 2012.

Welsh W.D., 2006. Great Artesian Basin - transient groundwater model. Bureau of Rural Sciences. ISBN 1 921192 00 3.

Appendix – geological cross-sections

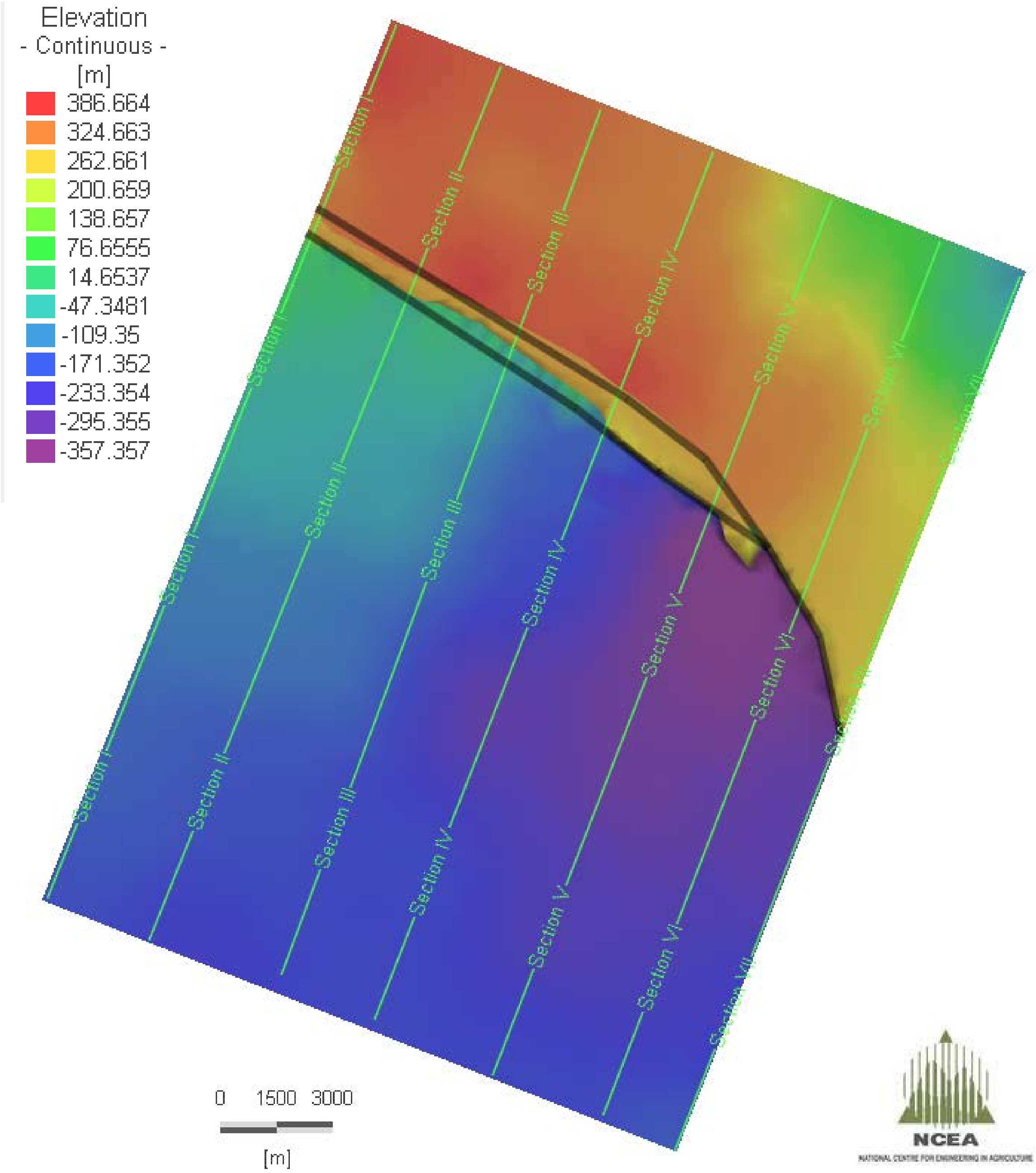
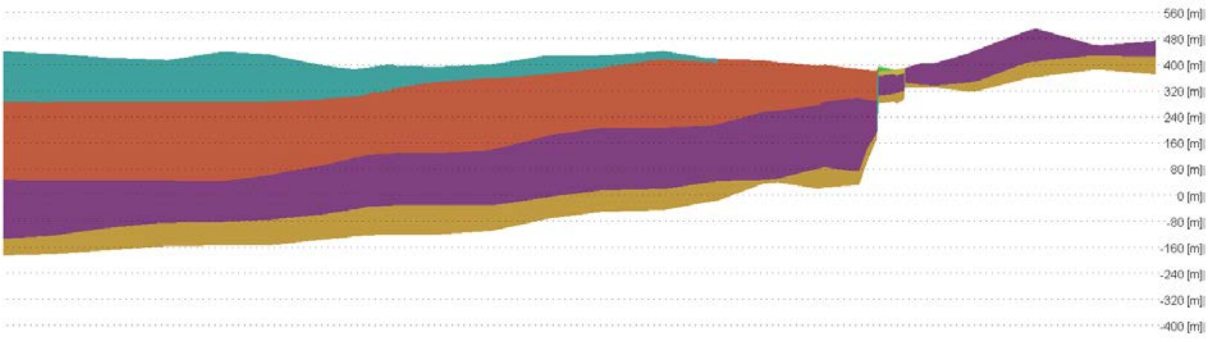


Figure A-0: Cross-sections location. Background colours represent topography (elevation) of base Precipice.

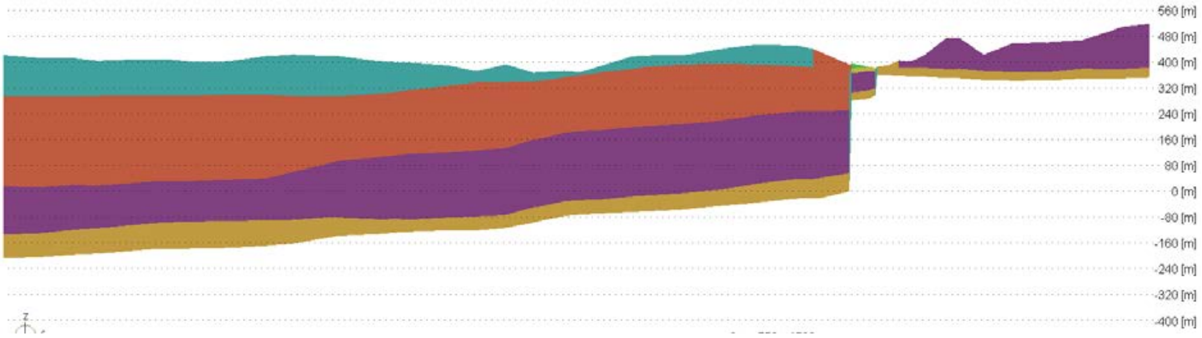
- All cross-sections have a x7 vertical exaggeration.
- All cross-sections run from SSW (left) to NNE (right).

Cross-section I.



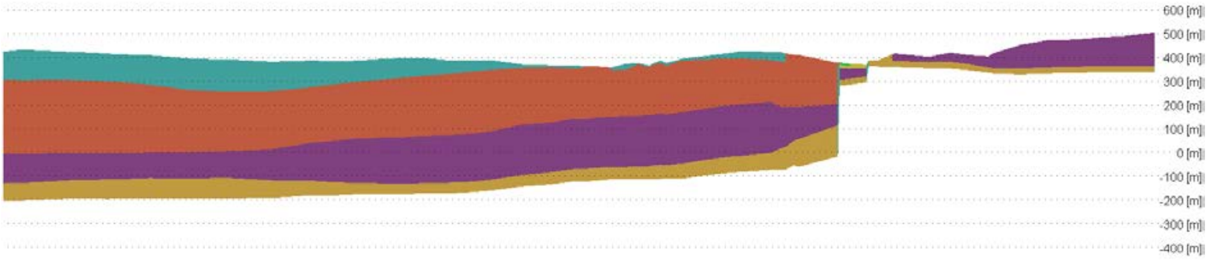
Notes: Birkhead Formation thins out, while Hutton Formation outcrops. Faulting take place along two strands- the southern is the major and the northern have only minor faulting.

Cross-section II



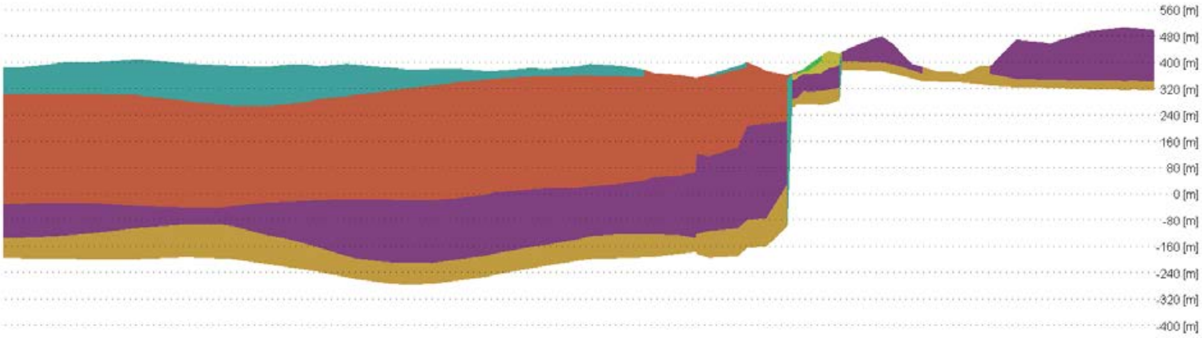
Notes: Birkhead Formation almost reaches the southern fault strand. Faulting take place along two strands- the southern is the major and the northern have only minor faulting.

Cross-section III



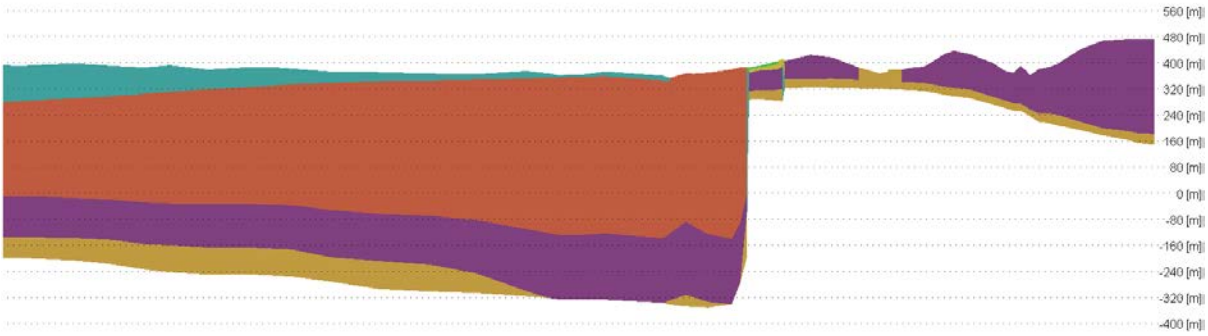
Notes: Birkhead Formation almost reaches the southern fault strand, and is very thin along low areas (creeks). Faulting take place along two strands- the southern is the major and the northern have only minor faulting.

Cross-section IV



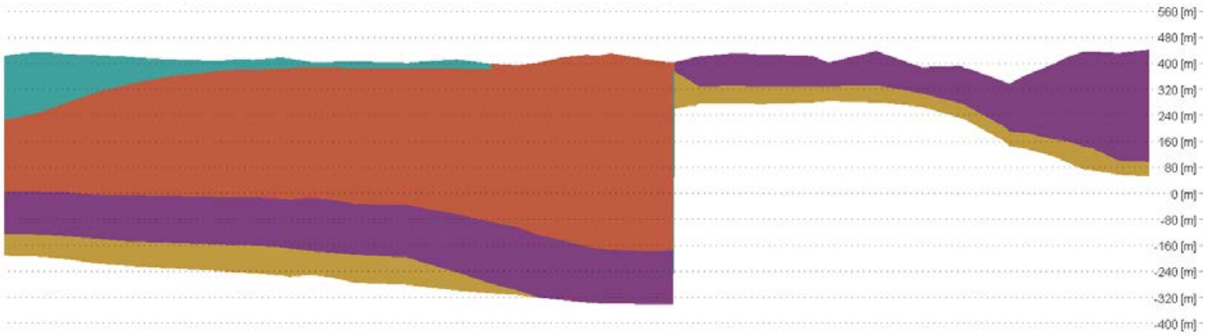
Notes: Birkhead Formation almost reaches the southern fault strand, and is very thin along low areas (creeks). Hutton Formation is thickening toward the SE (compare to thickness in sections I, II, III). Precipice Formation outcrops in the NE in low area (creek). Faulting take place along two strands- the southern is the major and the northern have only minor faulting.

Cross-section V



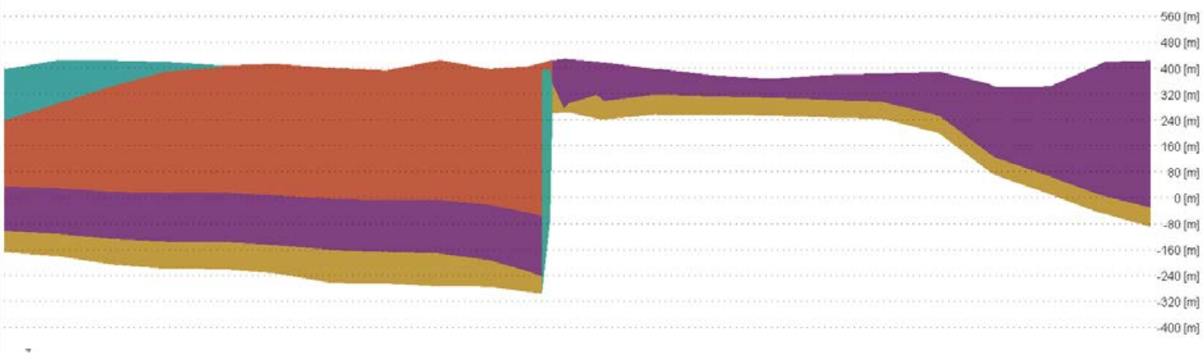
Notes: Birkhead Formation almost reaches the southern fault strand, and is very thin along low areas (creeks). Hutton Formation is thickening toward the SE (compare to thickness in previous sections). Precipice Formation outcrops in the NE in low area (creek). Faulting take place along two strands- the southern is the major and the northern have only minor faulting.

Cross-section VI



Notes: Birkhead Formation thins out, as the Hutton Formation outcrops. Hutton Formation is in its thickest section (compare to thickness in previous sections). Faulting take place along one strand only.

Cross-section VII



Notes: Birkhead Formation thins out, as the Hutton Formation outcrops. Hutton Formation is slightly thinner than section VI. Faulting take place along one strand only.