# IESC Explanatory Notes Virtual Masterclass –

# Characterisation and modelling of geological fault zones

# Transcript

**Interviewer:** Good morning, everyone joining. We've got 36 people approximately joining us today. Just give you all another minute to settle in. Well, good morning, everyone. My name is Fiona Chandler. I'm with Alluvium consulting, but my job here today is to help facilitate and guide as your host today for this masterclass. That’s on the Characterisation and modelling of geological fault zones. So if that's not the topic you're expecting today, I'm sorry, but that's the focus. So what I'd like to do first and foremost is acknowledge the traditional owners. I'm joining you from Wulgurukaba and Bindal country in North Queensland. I'd actually like to pay my respects to their elders past and present. I'd also like to acknowledge all of the traditional owners of the lands our panelists are joining from today and that each of you are all joining on from today. I really do recognise their connection to country as some of the first scientists and also the work that they continue to do across Australia. Firstly, I'd like to do some hellos and welcomes. I know we've got people from across

Australia joining today, so what I'd love you to do is even do a shout out in the chat room and let us know where you're joining from today. Perhaps the country of your own

traditional owners. But firstly, I'd like to say hi to Chris Pigram, good morning, Chris.

**Interviewee 1:** Good morning Fiona.

**Interviewer:** Chris is the chair of the IESC and we'll hear a little bit more from Chris in a minute. Wendy, would you like to say good morning and who you are, where you're from?

**Interviewee 2:** Good morning, everyone. I'm Wendy Timms. So I'm professor of Environmental

Engineering at Deakin University. I'm a member of IESC with expertise in geology and hydrogeology.

I'm familiar with many of you. And I'm coming this morning from Wathaurong country in southern Victoria.

**Interviewer:** Phil, good morning.

**Interviewee 3:** Good morning. Everyone. I'm Phil Hayes, an Associate Professor of water resources in the centre of Natural Gas, University of Queensland. I'm a member of the IESC, where I work on hydrogeology and groundwater modelling.

**Interviewee 4:** I'm Joan Esterle. I'm coming from Jagera Country and I'm an Emeritus Professor at the University of Queensland. I'm a coal geologist there. I'm a former member of the IESC.

**Interviewer:** Thank you.

**Interviewee 5:** Peter Baker, Director of the Office of

Water Science based in Canberra. And our major role is to support the IESC.

**Interviewer:** Thank you all. So we've got a really great and experienced panel today. The plan for the rest of today is to go through some content this morning, but at 1130 there's an opportunity where we just get to turn all the videos and cameras and audio on and just have a really open discussion. But while we're in a webinar format, there's a couple of ways that we still want you to participate and still feel really open to ask questions. This is a knowledge sharing activity. Even though we're hearing from our panellists today, we still want to hear and draw on your own experiences. And we know we've also got a lot of experience in the session today. So at any time, if you noticed on the little zoom bar, you'll be able to ask a question. And we've made sure we've got certain times within the content today and across the next 2 hours, we will stop and look to those questions and have an answer and get the panel to respond. If we don't if we've run out of time, we'll try and leave some of those to the end as well. At any time today, you can also make a comment. add an observation in the chat room and we'll keep an eye on that as we go through as well. And as I said, 1130 hang on the line if you can. It's a just a great chance to network and have a chat, albeit virtually with each other. And we are recording the session. This is actually the fourth in a series of these masterclasses that the IESC has run over the last 1 to 2 years. The recordings of the previous masterclasses are all on the IESC website. So first of all, I'm just going to find out who's in the room. So I'm just going to stop sharing. And on your screen or going to plan, there's a couple of questions which I'd love you to all answer. So I just let us know where you're from, how much experience you've got, and this just helps us guide the conversation for the panellists and our speakers. So, just respond to those questions. Nothing too hard at this time of the morning. All right. I'm going to end that poll here

and just share those results. So it looks like the Queenslanders are here in force. Hi too, if you're from South Australia. or Western Australia. Looks like we've got a really great range of experience, which is what we thought we had, including some people who've been working for a long time. so we really look forward to you sharing your experience as well. For those, if you're new, please, There are no questions that are off line today. This is really an opportunity to talk about this particular issue. We've got some people where it’s a bit of a new issue, too, which is also great. We'll be covering quite a range of diversity. So there you go, panellists. Some great diversity in the room today. First of all, I'd actually like to now invite Dr. Chris Pigram, the chair of the IESC, just to make some opening comments and remarks. Over to you, Chris.

**Interviewee 1:** Thanks very much, Fiona, and welcome everybody. Delighted you could participate today. I didn't mention earlier in the introductions that I'm actually a lapsed geologist and I'm coming to you from Ngunnawal country. Before we get into the details of the Masterclass, I'd like to provide you with a background on the IESC and a brief overview of our role and function. And I apologise to those of you who already know this that we're going to step through it just to bring everybody up on the same page in terms of what the IESC's role and function is. So the IESC was established by the Australian Government under the EPEC Act in 2012 to address community concerns

related to coal resource development. So your primary responsibility under the Act is to provide governments with scientific advice on water related impacts to coal seam gas as a consequence of coal seam gas or large coal mine developments. This also includes the management of salt production and salinity. One of the questions I'm often asked is what defines a large coal mining development and that's defaulted to, in fact, the position of every coal mine development. We provide the Australian Government and state governments declared under the EPBC Act and the States declared under the Act are, New South Wales, Queensland, South Australia and Victoria. Advice to the Australian Government on water related impacts of coal seam gas and coal mines can also include providing advice on research priorities and research projects. So next slide, please. The committee comprises a maximum of eight members who are appointed by the Commonwealth Minister for the Environment. The current members of the committee are here with all of the names

and you'll be familiar with many of them. And let me reassure you that this is a terrific committee and these individuals are the preeminent people in their fields. And I have the next one, please. Thank you. Our primary role is to advise decision makers on the potential impacts to water resources from coal resource developments. It's important to note three things. One, our advice is scientific.

We don't, we are not the decision makers, and the advice is designed to inform statutory decision makers. Our advice is transparent. We publish our advice on projects referred under the Water Trigger on our website within ten business days of it being provided to the regulator. And you can see in the table here that we've now provided 151 pieces of advice, as of last week, and not surprisingly most of them are from New South Wales and Queensland. And finally we are independent excuse me, we are appointed as individuals and experts in our field and we do not represent any group

or organisation. Any projects which are considered to have a significant impact on water resources must be referred by the relevant, relevant regulator to the Committee for advice. The decision around significant impact is a matter for the regulators and we consider all potential impacts on water resources. It's important to understand this because it includes the effects on groundwater, surface water, water quality and quantity, ecosystems and ecological processes. At the request of an appropriate state or territory, with a written agreement of the Commonwealth Environment Minister. The IESC can also provide advice on any other matter within the expertise of the committee. So, in recent times we have provided advice in relation to a gold mine. For example, which clearly is not a large coal mine or coal seam gas development. Let me step into information guidelines and explanatory notes, if I may. So we have produced a range of resources to assist proponents in providing the information that we need to provide a robust scientific advice on a project. These resources include our information guidelines and explanatory notes. The Information guidelines were first published in 2013 and were updated in 2015 and 2018, and we are currently undertaking another review of the guidelines and we hope to have that available to you early next year. The current update proposes to build on current risk based, risk based approaches where the primary additions include further information on numerical models as decision support tools, including an emphasis on quantifying uncertainties and predictions so that management risks are not understated. Ecohydrological conceptual models, which integrate hydrological and ecological components to show likely impact pathways. And using metagenomic approaches such as environmental DNA to characterise ecological communities in surface and groundwater. It's important to recall that the information guidelines are not prescriptive. They provide guidance

to proponents on information needed in environmental assessments to enable the IESC to provide regulators with robust scientific advice on a project. Can I have the next one, please. The 2018 Information Guidelines introduced a series of explanatory notes that provide further guidance for proponents on specific components of environmental assessments. Explanatory notes are intended to assist proponents in preparing environmental impact assessments. They provide tailored guidance and describe up to date robust scientific methodologies and tools for specific components of environmental impact assessments. Explanatory notes provide guidance rather than mandatory requirements, and proponents are encouraged to refer to the issues of relevance of their particular project. So it's important to understand that this is not mandatory. It is just, what we're trying to do is give you an up to date statement of the current understanding of a particular methodology or issue. The tools and method identified in the documents are reviewed to help proponents and are reviewed to help proponents understand the range of available approaches and are designed to be utilised across a range of regulatory regimes. Explanatory notes cannot address all aspects of a topic for or for environmental impact assessments, and proponents are encouraged to refer to specialised literature and to engage with the relevant state regulator. To date, we've published four explanatory notes on our website. Uncertainty analysis: guidance for groundwater modelling with a risk management framework, and we're currently undertaking a review of the Uncertainty Analysis Explanatory Note with proposed updates open for public consultation until 18th November this year. Second one is assessing groundwater dependent ecosystems, the third deriving site specific guideline values for physicochemical parameters and toxicants and characterisation and modelling of geological faults, which we are going to take you through today in the Masterclass. In addition, we have three future explanatory notes in developments. These are one, Ecohydrological conceptual models, two subsidence associated with coal seam gas production and three, subsidence associated

with underground coal mining, which is currently open for public consultation, which closes on the 21st of October. Public consultation has been undertaken on all explanatory notes and we intended, we intend to continue engaging with stakeholders on our explanatory notes wherever possible. I would like to thank those of you who have provided submissions and feedback on our various stakeholder consultations.

**Interviewer:** Thanks, Chris. I just want to pause for a moment. One, to let you know the chat room is now working, so thanks Keith and others, but are there any questions if you'd like to pop them into the Q&A now? of Chris, in terms of the broader role of the IESC, you can ask now. Chris is going to stay with us for this full masterclass and also be an opportunity later on. Just give you a minute to think about that. Okay. In that case, let's get going into the fun stuff. So I'm going to introduce

Phil Hays is going to kick us off on some of the content. So Phil, over to you.

**Interviewee 3:** Okay. Thanks, Fiona. Let's just check that, well, one you can hear me, which I think that's good. And yep, so I'm going to kick off with the technical content and this is going to be split between myself and Wendy and Joan, and we're going to bounce between each of them to give ourselves a little bit of a break. We do have around 50 slides to get through, but there are some breaks in that. So what I'm going to set out just in the next 5 to 10 minutes is a little bit on the structure of the explanatory note to think about why we would actually produce and Explanatory Note on faults, and to think a little bit about our role, from the IESC, of looking at the risks to environmental values that faults can act as pathways or barriers. and exacerbate. We'll start just by quickly looking at the explanatory notes itself. This presentation is not structured that we're going to go through this sort of page by page by any means. So I'm hoping that the majority of you will have looked at this explanatory note, although I can also imagine that some of you will not have seen it in detail or not looked at in detail for quite a while. So there's five main sections in terms of faults and definitions and data sources and geometry. Then we talk through the conceptualisation and identification of risk pathways. There's information on numerical modelling systems with faults. There is a checklist of where you can look and see ‘Have you done certain work?’ So work being completed, might not be necessary, but it's there. But one of the main things that's in here is we have some work scenarios and we're actually going to use those work scenarios as we go through this presentation. So we're not going to dive into those areas in detail. The document itself is 60 pages. There's five main sections and those scenarios I mentioned, there’s 16 of those 60 pages going through those scenarios in more detail We have three pages of glossary at the back of that document. So if you hear terms today used by myself, Joan or Wendy that you don't know what they mean, just dive into the document towards the back end, you'll find a three page glossary. So in the main body of the report is about 34 pages. So it's not actually that chunky of a document overall. And three of that's the checklist. The, the thing I will really draw reference to, sorry there’s a pun there, is we have five pages of references in here and that's actually where I see quite a lot of the value in this document is that we're not trying to say absolutely everything or present everything but there are the pointers there into the literature. Some of that is scientific papers, some project reports. So there's a lot of value in that part of the part of the document. We just move on. So this is how we're going to actually structure things today. We're going to look at those scenarios and I'll go through those a little bit more in a while. But what we're going to do is take those scenarios, present them, and then use those to go on a little bit of a deeper dive into focus on a particular area. You can see those on the screen. So we'll be switching between ourselves. Okay. I think I probably said all I need to say that, so I'm going to kick off on this scene setting. Joan's going to go into a bit of more focus on geology and moving beyond just a line on the map. We're going to go through the scenarios on A2 and B. and look at aquitard integrity and tracers and the characterisation of faults and some of the techniques. Wendy will take us through that, we'll jump back to Joan a little bit on juxtaposition of faults and actually looking at flow pathways where we have windows caused by the movement of strata.

I'll then talk a little bit more about modelling before Wendy wraps up on Scenario D and looking a bit on the nation at the end of the webinar, we do have a question time, which Fiona has already pointed to, and I think will also be an opportunity for further off, off video later on. So I need to make sure I click on the correct screen. So why, why faults, what are we actually getting at? Why have we done this? So much of the IESC's technical role can be summarised as assessment of development project impacts to environmental values. That's what we are asked about. Remember that we don't just go and pick up a project and look at, we are requested by a regulator, state regulator or Federal regulator and we usually answer questions. So we get specific questions posed to us, which is typically phrased along the lines of does the IESC have confidence in the predictions of impacts from the projects to some environmental value, and that environmental value may be, maybe a creek or a river, or it might be a groundwater dependent ecosystem, it could be stygofauna. So a range of environmental impacts. And when we look at regional structures in this case, we have an example from the northern Surat Basin. This is work by OGIA, looking at the conceptualisation of the Hutton-Wallumbilla fault zone and we've got a number of aquifers there, we've got a significant throw and we know that that fault zone is not just is not one structure, we’ve got multiple, a flower structure of faults that's coming up in that area. And those are controlling the locations of springs. And you can imagine, I've not put it on here, but there are projects both on the northern side and on the southern side of this fault, which could have impact on the aquifers, that are therefore feeding the faults. Okay. So what is the impact and how is that being, how is that being assessed? So in terms of asking from a risk perspective is a fault relevant is it relevant and significant from a water asset

or groundwater dependent ecosystem, an environmental value. And that depends a lot on the scale,

the scale of the fault, the scale of the groundwater system that we're looking at, the distance between a project and a fault, there’s a lot of difference between a project that's located directly next to a fault or maybe even mining through a fault zone versus a project that's 20 or 30 kilometres away. And the scales of environmental investigation that we can do are also very scale dependent from taking plugs of rock and core drilling faults to testing hydraulically across faults to use in traces or to use in remote sensing techniques. And that's partly what we're getting at with this figure on the right hand side which is from Bense’s work. So I've mentioned scale there, but we talk about the scale and the nature and the displacement involved. So a fault could act as a pathway or a barrier or it can act as a conduit and a barrier at the same time. So the questions we need to be asking is what's the nature of a potential impact of a fault. Will it limit impact. As in, will prevent impact spreading further but that limiting the impact may end up actually intensifying impact on one side of the fault or conversely, a fault may actually allow the propagation of an impact and the nature of the rock, the host rock in which that fault zone exists will potentially change, answer to those questions. So in a crystalline rock and a competent rock, we might expect that rock to break. We end up with a fracture zone, a damage zone around the fault. We may end up with some fault gouge and we may end up with some fracture around it. In a poorly lithified sediment, we may expect to see weaker rocks to slide, to smear over each other. We also need to think around the scale of the structure and there is a reasonably proven relationship just between the actual the length of the structure and the overall displacement that we see on them and there’s a power law relating those that you can see on the right hand side. So I've said that we're going to take you through the scenarios. So I'm just going to briefly introduce those before handing over to Joan. So within those within the Explanatory Note,

we have scenarios labelled A to D, and these are kind of almost increasing levels of impact, potential and complexity. So in scenario A, we’re effectively saying that faults are unlikely to affect groundwater flow. As in, there probably aren't any or perhaps they're so distant, distant from a project that they can be ruled out relatively straightforwardly as an impact pathway. Or on scenario two, where we have a very large, thick aquitard, a competent aquitard, that we believe can't be breached by any of the structures that we see as we move through into scenario B, they're more potentially relevant on scenario C, we're saying that they are definitely relevant. They need detailed assessment and scenario C, we’re then looking at due mechanical impacts, what could happen if we got differential settlement that actually opened up flow horizons more clearly. So some of the diagrams are in there. I'm just going to ask Fiona just to move on one more slide, please. Those scenarios are summarised in the table that actually appears twice in the document, which is in the executive summary and it's in section three. So there is this summary table, this A3 table, where we try to collate everything together and to talk around the issues with those faults characterisation methods. And that's what's in that, which is probably two small for you to see on your screen. But hopefully with fitting on one side of A3 is a helpful memoir. Okay. At that point, I'm hoping I'm not taking too much time and I'm going to hand off to, to Joan.

**Interviewee 4:** Okay? Thank you Phil. And Fiona might, just let you advance the slides. So one of the impetus or an impetus of this EN a few years ago was to try and raise the bar on structural characterisation and illustration of faults. Many of the proposals that were received in the IESC just had maps with lines on them that conveyed no information about the faults nor evidence, strong evidence to often support the interpretation of these faults. That would lead to some uncertainty in the assessment of impact on groundwater assets. And so, what I provide here are just two illustrations. Improvements can be made quite simply by providing consistent annotation on fault lines with regards to the fault type to the thrower severity. The width of the potential damage zone, some sort of, in this case they're colour coded red, blue and green by the different coal seams that they actually displace. So not all strata are displaced by the same fault. The faults can actually weave their way through the stratigraphy. And then, of course, you want to know how is that that fault geometry or architecture related to, the, the aquifers and aquitards that are in the system. So this just provides an illustration from a colleague of mine, Renate Sliwa, of integrated geoscience. And in the next slide, it's just about, well, what kind of evidence do we look for, for the interpretations? Well, you know, good drilling records, seismic survey potential field surveys, mapping and modelling. And on the left is a really nice seismic line that shows different horizons have been mapped and, and, faults have been interpreted. And the point of that slide is to show that that these faults do actually migrate or displace different parts of the section. And that can be nicely illustrated by combinations of of maps and seismic sections. So in the next slide there also, when some people say, well, it's a new greenfields project, we haven't done a lot of drilling and survey, you can actually start to draw upon information that's in the, in the public domain. So there are regional studies that are put together often in house, but also by the Australian Coal Association Research Program, where people go through or in this case Sliwa et al, compiled faults in different areas and looked at the statistics of those faults and so on. So there is information provided in this case for the Bowen Basin. And in the next slide in that same report for the Surat Basin, also for the Surat Basin are reports that have been put out by the universities, by the Centre for Natural Gas, by CSIRO and various components. And also in the next slide there's a regional compilation available at least in Queensland for the Surat Basin from OGIA. And so, so we just recommend that you can contextualise your own area with respect to regional studies that that that compile not only the faults but their impact on the groundwater table. So in the next slide, also there are things that are available, you know, in publications. And so this is a study, it's one of many where Viljoen et al, from industry were able to demonstrate the sealing characteristics of the fault through a combination of hydraulic testing, pressure data observations, core examination of the the fault gouge and fracture character, and then of course seismic survey and target drilling and site assessment. And so these are all things that are available and can be brought into, into a proposal. So in the next slide, you know, in scenario A1 we say, well, nothing to see here. There are no faults that are likely to affect the, the groundwater flow. So either you have no faults or no faults with a few or negligible displacement. So what's the evidence for that? Well, a little more than three drill holes, hopefully. But you look for the strata being flat lying or underformed. You show your drilling and your seismic data, you create a series of sections perpendicular and parallel to the strike to convey the regional and local context of the structure. But another point here is to also check in the overlying strata. So just because your target seems relatively quiet or benign as this case, if you look at the the kind of the blue and the the red marker horizons that are coal seams, they're not as structurally complicated as, say, the overburden. So, you know, look up, look down, look all around and and demonstrate that your area is, in fact, benign. So I think that so that's all from me on, on A1.

**Interviewer:** Thanks Joan and Phil. Just want to take a couple of minutes just to check in with you all. Are there any questions that have already come to mind? Feel free to also put in a question there if you want, perhaps for us to look at it in the future as well. If you think of it, add it in. It’s all quiet. Okay. So I believe, Wendy, you're going to keep going if you'd like to try Wendy and grab control of the slides.

**Interviewee 3:** Yes. Let's have a go at this and let's see if we've got remote control. All right. So I think that worked. Okay, here we go. So we we're diving into a few examples around scenarios, A2, which kind of segway into scenario B, looking at around faults, aquitards and tracers, sort of the characterisation techniques that might be useful with certain scenarios. So this cartoon, that's very nicely prepared by Titus and Bill, we have here a workflow, you know, some ideas around a workflow that's not prescriptive, but it's some, some suggestions, some recommendations around what could be done where you have the regional aquitard with high integrity and that, you know, faults may not be such an issue. So of course, you've got the base date there on the left-hand side around a proposed development and it could be, as mentioned by Joan, some seismic, the grey lines being the 2D seismic. The grey box there, being some 3D more detailed seismic besides all of these these exploration holes. And I think we've gone, could we just jump back to the last one, Fiona, and then, thanks for that. We've got some in the green lines over here and starting to look at the geological makeup of the subsurface, the green lines indicating the thickness of the aquitard and of course, various faults characterised there in terms of the style of faulting the type of faulting the possible offsets. But what's new here is it's really needing a bit more evidence around the, the aquitard sides themselves and whether or not the faults are likely to be significant pathway through those faults, whether they're breaching the aquitard and so on. So. Yes. So on this next slide, an example where we do have a very thick regional aquitard, this one’s in the Otway Basin down the road from where I am here and we know the upper tertiary aquitard side, the Gellibrand Marl is very, very thick. As is shown in the Orange area so many of the embayments of this large basin onshore and then then offshore as well down into the, under the ocean. you know, we're looking at several hundred meters of thickness. Of course, it does kind of pinch out, lens out and where the structural highs locally, you know, the aquitard might be very thin or might in fact be absent. But on the regional cross section there, part of Angela Bush’s PHD. And you can see this there are a lot of faults through the Otway Basin. Many of you will be far more familiar with some of these details. But the the upper aquitard here, the upper tertiary, this pale orange colour towards the top, there's not a lot of faulting that actually penetrates through that aquitard because we know that the marl itself has a bit of plastic behaviour to defamation. And so some of the shallower aquifer systems on top here, in the carbon in the Port Campbell limestone or in the basalt flows themselves are less likely to be interacting with the deeper zones and conventional oil and gas and the possibility of coal seam gas and so forth. And so the characterisation of the aquitards or the capped rocks themselves is quite important when it comes to the relationship with faulting. Some more detailed investigations, just as a bit of an example here at the Otway International Test Centre and there was some more detailed fault zone investigations. In fact, this was more focused on the top of the Gellibrand Marl and into the Port Campbell limestone around one of the fault systems, the Brumby Fault, where it did actually penetrate through to the surface. And so there's inclined drill holes, there is downhole geophysics, core analysis, hydraulic testing, a whole range of different lines of evidence around how that fault might behave with water flow. But of course, this is a little bit of a different application to do with carbon sequestration. And there's a whole bunch of journal papers around that. But certainly in terms of the the hydraulic testing, around, within that damage side, within the aquitard zone itself and then within the fault zone, the relative vertical permeability and the relative ratios of vertical and horizontal hydraulic conductivity is is really important when it comes to potential connectivity, whether it be for groundwater or in fact, or dissolved gases or buoyant gases through that system. But I guess another example where perhaps initially you might assume that we've got a scenario A2 as well, where we've got a regional aquitard with high integrity. This comes from the Sydney Basin and an investigation right on the western side. Here South west of Sydney, near the Thirlmere Lakes. And I guess with this cross section here, there's this red line here, the Bald Hill claystone, of course, it extends right out to the coast where we've got some lovely outcrops that we can look at. And I guess the challenge being that it's not necessarily the same over that entire basin. So in the area that we were focused on just in here around Thirlmere Lakes and the assumption that, you know, that it was a self sealing barrier and that we could count on that as having high integrity once it got into a bit more detailed mapping, some field, field confirmation, part of Tim McMillan's PHD. And I guess it emerged that the story was a bit more complex than perhaps what we'd assumed. And and so, you know, in backing up some of the characterisation on aquitards, not only do we need to know that it's regionally extensive and, you know, the thicker it is, probably the less likely it is for some kind of hydraulic connection. But we also need to know, you know, with some evidence, I guess, that at local scale, in that particular part of the basin, what might be going on and whether there's integrity that's maintained through that aquitard with ground defamation. So in this case, multiple lines of evidence that in fact in this particular local area, the aquitard is pretty poor integrity, whether it's looking at downhole geophysics, whether it's looking at coring, geo-mechanical testing of rock core, very brittle defamation, there’s no evidence of any shale smear during ground movement, drill stem testing, mineralogy. In fact, there's no minerals in there that are considered swelling or where self-sealing. One of the important parts of this this work that Tim did, together with Titus, at Southern Highland Structural Geology is to reconstruct the geological cross-sections with a bunch of new data and a bunch of existing data that's available from various regional sources. And the important thing here is it's not just a pretty picture, it actually is a kinematic restoration of that strata, conserving the rock mass before and after movement along those fault zones, in this case, tectonic movement not related to mining. But it's really an important step here to do kinematic restoration. And it becomes apparent then that you've got some breakages here through the, through the aquitards juxtaposition windows where it is possible to have a hydraulic connection. And so running this through fault risk software is one of the possibilities. One of the things that, you know, if this is a potential Risk, at a site to have a look in a bit more detail here, using a range of plausible input factors such as displacement and length and some, as Phil mentioned earlier, around what is actually considered possible and plausible in terms of fault core permeability and so forth, running a whole range of probability distribution. Well, 5000 simulations in this case. And you can see the kind of possibilities here in terms what kind of area of potential flow might actually occur through a juxtaposition window based on the available information. Now, of course, going another step beyond that in terms of quantifying the groundwater flow is is quite, quite difficult, quite uncertain, we'll get to modelling it at the towards the end of this session today. But I just wanted to also quickly touch on a couple of couple of slides here around another line of evidence on the potential influence of faulting or if there's no influence at all, where you've got a tight system and that is of course environmental water traces and a recent ACARP project that's demonstrated some suitable natural traces for surface and groundwater flows, the underground coal mines. And this also builds on an earlier fact sheet, actually from the IESC, that you can find on the website around the possible examples of environmental water traces. So we've, in this ACARP project, gone a little further. And PHD student Devmi, has also published this paper, which you can freely download from Mine, Water and Environment and really looking at around some of the primary traces that you might commonly use, even simple things like EC and temperature. So some have some investigation traces that require a bit more effort, a bit more cost, and some of the advanced research kind of level, dare we say academic kind of approaches where it's perhaps not commonly used but can provide another another line of useful evidence. So whether it's underground here, I love going underground and collecting drips underground or from de-watering bores here and, you know, it can really provide some pretty useful information. One of the studies in mine water environment, is this one from South Africa, where it was really useful to actually identify which bores which groundwater samples were sourced primarily or partly via movement through faults zones into a deeper water aquifer. So we know also that some of the more advanced traces that can, radioisotopes, tritium, can also give us quite a distinctive distribution of age traces. It's not just one number but these can be used to be, you know, pretty useful in terms of providing indications of preferential flow paths through faults and fracture zones over a range of different, different ages. Potentially a bit of a gap here with some argon that's going to be coming on line, I think probably a bit more commonly in the future around some of the dissolved noble gases as well. But look, there's lots of lots of details and opportunities there that we don't have time to go into here. But some I guess, some, you know, in thinking around the scenarios around the potential interactions of faults and aquitards, clearly there's a lot of cases where we have a really nice aquitard, it's got high integrity and the fault is is may be tight more acting like a barrier. But then on on some sites where we look a bit more closely and look at many different lines of evidence and certainly that last example around the western side, around Thirlmere Lakes, where we're potentially then moving into a scenario B, where we've got potential flow paths here both along strike. So I indicated here by the little red crosses and also potentially up, upwards and downwards along some of these fault structures. And through these these juxtaposition windows. So I think at this point we're back to questions. So.

**Interviewer:** Thanks, Wendy. Just going to pause and have a quick check of the Q&A and the chat room while we're waiting for people to perhaps think of some other questions. Wendy, you mentioned a few places in Australia during your slides where there are known issues, where are some of the other regions in Australia that are possibly more susceptible for people?

**Interviewee 2:** Oh well, there's a tricky question right to kick off with, isn't it. Yeah. Look. I, I think when I first started looking at the structural geology, I guess in the lower Hunter Valley where not so much on the flood plains with some of the big open cuts, but some perhaps on the edges there where you've got some, perhaps more topographic relief and a combination of crystalline rocks and quite a lot of complex earth movement going on, it tends to be a bit more complicated. Remember, one of my first projects actually as a graduate geologist looking at trying to map some of the geological structures from the high country and through the alluvial colluvial slopes from upland country down into the to the Hunter Valley itself. But look, yeah, I think particularly where there's where there's that, where there's terrains, where you've got complex incised gorges and the potential for really complex geology. But I think, I think, I’ll also defer and throw here to, to Joan and Phil as to what they, there thoughts might be.

**Interviewer:** Phil, other areas that you've come across?

**Interviewee 3:** Well, I suppose I would probably step away actually from the CSG and large coal mining and just think around metalliferous oil bodies. Very typically those, the reason they are in place in the first place is through hydrothermal activity and that's often related to that tectonic activity. So faulting is a is a very major component when looking beyond CSG and coal mining. If we do think of the CSG basins that we work in, certainly in Surat, I’ve already used an example of a large regional bulk fault system there and perhaps, perhaps there's another question that we could think of here, which is, in terms of data, I mean, I mean I work a lot with with oil and gas companies that have access to seismic, they have probably have slightly larger exploration budgets than some other, other proponents. So how can how can people illustrate that there are no faults? Well, we can't say there aren't any. It's more a case of that we can look to see the range of structures that are in a basin or surrounding a project and start to look at the scale of those, the investigation that's gone on. And then if we think back, what Wendy’s has just been through in terms of aquitard thickness integrity,

what is the likelihood that there are structures that are large enough to have significant enough displacement, to actually juxtapose units through a thick aquitard? So there's that sort of line of evidence. Okay. You can't clearly show that there are no faults. There are some sub seismic faults that have been missed. But we can actually start to develop lines of evidence that say, well, it's actually really pretty unlikely, given that, say, the seismic coverage or an area that we have that there can be faults that are significant, large enough to be significant enough to this project assessment. So it’s about start trying to piece things together and to and to provide a justification or a line of evidence that says, no, we think we've done, there's been enough investigation in an area and that it's really rather unlikely that we have missed a 20 kilometre regional structure with 100 meters of throw in the middle of it. Thats a different question. I’m just wondering if other people have got areas that, you know about, maybe just share them in the chat room, if there’s other particular sites that you've worked on, that would be really interesting to see where else you've been working.

**Interviewer:** Well, let's keep going, Joan. I think you've got another scenario now that you're going to take us through.

**Interviewee 4:** Yes, well Phil will start off and then I'll jump in.

**Interviewee 2:** Okay. So we've said that we're going to move through from the simpler scenarios

to more complex scenarios. So in scenario C, we've got a project in the map on the. Yeah. Thank you. Thank you. Fiona. I’ve not even attempted to take control at this point. I'll just leave you to do the slide transitions, if that's okay. So if you leave it on that slide for now. Thank you. So in the map here in the, in the top left, what we've got there is a number of, a number of structures either side of the proposed longwall coal mine development and rather close to a large dam. I can’t think where this example may be akin to. In cross-section below that, we've got a fairly complex flat yet faulted geology. And over on the right hand side, we've got some arrows showing potential flow pathways through there. Sorry, do you just move on to the next slide. Sorry, Fiona. There we go, that's better. So we've got multiple aquifers and aquitard builds that truncated adjacent to a proposed project in an environmental value. So we've got the potential of juxtaposition windows, where we may get flow, and we may get depressurisation propagating along and upwards through, through those, and we may get flow pathways that are a mixture of mechanisms. We might get matrix flow through the aquifers, across the faults or we may get some fracture flow along fault damage zones. Okay. Some of the aquifers may end up actually isolated. That could exacerbate the actual depressurisation within that aquifer, due to their juxtaposition against aquitard to load permeability units and the nature of flow that we might see maybe heavily influenced by the nature of the material actually within the fault itself. Okay. So what we're going to do now is Joan's going to take you through a few techniques that are mentioned in the in the Explanatory Note. And in some ways, I think this is probably the hardest thing to present and explain. So over to you, Joan.

**Interviewee 4:** Thanks. I'll go ahead and request control and see how we, how we go. So, I think one of the issues is that currently we have very sophisticated geological and reservoir modelling packages that can illustrate quite complex faulting relative to the stratigraphy and visualise the displacement and juxtaposition of stratigraphy to search for these risk areas where we might have aquitard breach or communication pathways to groundwater assets. But not every proponent has access to to these modelling packages. and a lot of the packages are based on concepts relatively early ones, work by this guy called Allan and in the late 80's to map areas where he had hydrocarbon migration and entrapment. And so one of the suggestions by Titus Murray in putting this together was the concept of, of revisiting Allan diagrams. And so I think I should be advancing. There we go. And so when we talk about what is an Allan diagram, it's a juxtaposition diagram. And in this case, faults are assumed to have neither leaking nor sealing properties, and the potential for communication is determined by the juxtaposition of the stratigraphy along the fault boundaries. So in this example, that's in the EN you have aquifers kind of in a yellow or an orange aquitard and in green and we're just going to talk about a single reference horizon, which is this B horizon. It's the top of the the, the B aquifer. So often you represent these aquifers without the background, as in the footwall, so A and B, and then have some sort of displacement of the fault. And so in essence, all an Allan diagram is, is a projection of the aquifers and aquitards in the footwall and those in the hanging wall projected onto the fault plane. And the fault plane isn't always vertical. The faults themselves will have variable displacement going often from from zero displacement on their their edges to quite a bit of throw in the centre of the fault so they can become more and more complex. And I'm just going to provide a simple example of a single reference horizon. And so in essence, you know, in the next step, you know, you could represent this by a series of, of cross-sections across and parallel to the fault zone or a whole series of maps of different horizons. But what the Allan diagram attempts to do is to project all of these displacements either onto a single fault plane or into a map of the of the reference horizon or the footwall. And so in this case, you know, we have a normal fault and we drop down and we've got the A aquifer and we can see that it intersects both A and B along different horizons. And then you can actually start to map out the juxtaposition of some of your aquifers and aquitards. In this case, there's sort of no real communication between A and B along this particular position or in this particular position on the other side of the fault. You, you are starting to connect a bit with with B to A, and then you can start to map the intersection along that of the juxtaposition of of A and B in the footwall and then you can start to map that. And in this case it's just a simple hand-drawn diagram of reference Horizon B that shows the elevated area in the footwall the down drop part of that of the the hanging wall. There's a nice normal fault. You can see that the displacement increases towards the centre of the fault and declines away. And then you just map that potential communication area. It's projected into the footwall. And so it's a fairly straightforward way to do it for a single horizon. But in Allan's paper, he actually goes to, to varying degrees of increasing complexity and starts to map multiple aquifers or multiple juxtapositions on cross-sections and, and, and maps. So I can recommend that paper to you. So I put together kind of a, an amusing diagram to just start to say, well, here we have our example, where we have the dam, we have a series of normal faults which is placed down to the to the east, and we have this planned underground mine or longwall panels that are mapped in the footwall. So how do we actually think about the communication of these different aquifers into the foot wall where the mine's planned? And so we have our aquifers A and B and C, and we're going to just quickly animate a bit of down drop on fault F3. and F4, because they're so closely spaced and so we can start to drop these down and look for juxtaposition, you say that's a mess, what am I going to do with that particular diagram? And so one of the challenges in, in doing these juxtaposition diagrams in cross section, is how to colour code them. And so in this case, what, what has been done is that Aquifer A is shown in the darker blue and in the in the footwall, and then the aquifer in the hanging wall is in the the lighter aqua zone. And then the juxtaposition window is shown in yellow. And so in a in kind of a simpler diagram, you can start to look just by the juxtaposition and not even thinking about the nature of the faults and the damage zones and whether they're their ceiling or conduit. We just assume juxtaposition. Then they're a whole series of pathways that start to communicate between these aquifers. And if we're then thinking about putting a long wall into into the into the footwall, and there's a lot of potential for communication and then Wendy's going to go through, you know, reactivation of these faults and then also the fractured zone up into the goaf. So if nothing else, I would start to alert you to areas that might need a little more sophisticated monitoring and, and modelling. Thanks.

**Interviewer:** Just, just before we go on, Joan, can you just confirm that scenario C you've just talked about Is that an actual project or is that a hypothetical situation?

**Interviewee 4:** I think that, that all of these are hypothetical situations that are based on maybe an amalgam of different projects that have come in to the IESC or just areas that people have worked on.

**Interviewer:** Okay, Keith, if you've got another question about that, maybe in the next break, happy for you to ask a bit more. Okay. Thanks, Joan. Thanks. Thank you. So, Phil, you going to continue on?

**Interviewee 3:** Yeah, I will try and take tight control. We've had no questions, but anyway. Okay. So I'm going to say a little bit more in terms of, in terms of representation of faults in models. and we may be doing that for a couple of reasons. One, we may be trying to test scenarios and Wendy's already shown a probabilistic assessment of juxtaposition window using some specialist software developed for the oil and gas industry or it may be that we're trying to. Sorry, I've lost my train of thought then, that's fine. I'll just carry on from where we're at. Actually, the, in terms of modelling, what is requiring representation. Okay, we have a project, we have some environmental values that have been identified around that, could be other groundwater wells, creeks, rivers, a dam in the case of scenario C or ground-water dependent ecosystems. But the, the question from modelling perspective is, what we need to actually put in there, what we need to represent and what are we trying to do with that? are we after quantification, or are we after an assessment of the likelihood that this, this structure may, might be an impact pathway if we like. So that's going to be net defined by scales, which I touched on earlier, particularly the scale all regional structures and the distance between a project and those structures. You know, very different between scenario C, where we're adjacent to an environmental value to if we're 50 kilometres away. But it's also defined by the the nature of the host rock and the faults themselves. Been through that a little bit already. And what are the flow mechanisms that we're looking to simulate? Are we looking to simulate a juxtaposition window? that Joan's just taken us through, techniques to to look at areas of, and identification of or are we looking to represent matrixed flow from one aquifer to another through a juxtaposition window, across a fault? Is there a damage zone there that we feel may impede flow? Or conversely, is that damage zone, potentially a conduit of flow that may connect other horizons? Or can we actually have that mixed mode where we have a fault core that's actually conductive, that's surrounded by a damage zone that's less conductive with clay smear etc. and the tools we've got available as modellers, I would say have actually advanced enormously over the last, the last ten years, and I suppose I use ten years there, really, probably a key, a key advance for modellers was the release of the unstructured grid version of MODFLOW and the extra flexibility that, that gave us, not only in the shape of our grids, the move away from being constrained by rectilinear grids, but into other ways of connecting flow through our models. So let's go through a little bit of, a little bit of that. Lets see, it's actually working again. So the first thing I'm going to talk about is actually just the simplest thing, which is where we actually believe or we have good evidence, that a fault is acting as a barrier. But this is this is fairly banal. How can we represent a barrier in a groundwater flow model? Well, the first thing we can do is simply use a number of nodes to contrast hydraulic parameters. So we just put lower hydraulic conductivity in a zone and that's what I'm trying to illustrate on this diagram. On the left-hand side, that little box where we've got the darker coloured cells, we just say those are low, low hydraulic conductivity. The next step from that and again, this is pretty banal. This is a boundary condition that's been available in MODFLOW since, since I used it first in around 93, is horizontal flow barriers. And what that's doing is not actually using contrasting hydraulic parameters, but it's just adjusting the inter block transitivity before the matrix equations are solved. Okay, so MODFLOW goes through the setup routine, setting up the coefficients and then prior to solving equations it's just going to tweak them. So we can define along connections between nodes that we wish to adjust the hydraulic connectivity. None of that will be news to the modellers here on this call. But of course that, that, that ability is being taken through into the latest version of MODFLOW and through into MODFLOW 6. So I'll just give you a couple of examples of representation of faults. And in choosing these examples, I actually I've deliberately gone to not choose examples from IESC work, so I'm not trying to present particular consultant's work here or a particular project that's been in front of the IESC, OK that means I've fallen back on work I've been involved in. So this is an example . from the southern Eromanga Basin, so the limit of the Great Artesian Basin. There is a well field down on this limit and that's in an area of mountain springs. So in this case we have faults which are controlling and limiting the spread of drawdown in a north east south west direction is limited and it's being propagated more in the north west, south, east direction. Okay. And the way these faults are being represented is that we've not got the juxtaposition. We're not using the fancy methods. So some advanced methods come on to. These fault zones relatively broad and these have been parameterised with pilot points, with, where we are putting the variogram between these pilot points, pointing along these structures. So we're giving instructions towards PEST that we think there's something different here, but then we have the observations to enable PEST to go and parameterise and to estimate the degree to which these fault zones influence the connectivity, across the faults and to actually parameterise it. And that's what I've got down in the right hand side. So it's really the parameter field is being informed by these, these prior observations that we know where the faults are and the orientation of the structures. But we actually don't have hard information investigating those fault zones. But we do have history matching or calibration information that we can use. And that's how it's been used in this case. Do you want to just flick on to the next one Fiona. Thank you. This is another example and more where faults are acting as potential conduits. So this is on the The Darling floodplain in New South Wales at Menindee Lakes. So this is work that was conducted primarily by Geoscience Australia looking at the potential of managed aquifer recharge schemes in this area and utilising the system. Were the system has a special aquifer because it's relatively poor quality an aquitard layer the Blanchetown clay, which is actually was not tremendously thick, is actually very, very tight formation. And beneath that we have an aquifer where we have connectivity to the fresh water that's flowing in the Darling or in Lakes We have bodies of fresher water that have formed and in this case, Geoscience Australia have done a lot of a lot of field work, a lot of airborne electromagnetics. And from that they could discern the the structures so that this, Menindee itself is where two large regional structures meet, if you were to look at it on the map. On a map in the Darling River, we'd see that the Darling River is flowing and in a south westerly direction, until it gets to Menindee and then it turns 45 degrees and heads south to meet, to meet the Murray. So in this area, those, that, those two regional structures have given rise to a system of faults that have propagated up into the, into the near surface and have actually produced faults that go through some pretty poorly lithified, so these are not hard sediments, but we've got that connectivity due to displacement. So we've got many relatively small structures that have been mapped because the Blanchetown Clay is relatively thin, those structures offer the potential for connectivity across them, the way they were integrated with. Again, we don't how hard evidence on exactly which structures have sufficient throw and which structures actually do permit lower salinity water to get into the aquifer beneath. But what we could do here is to actually assess from the fault length, the likely levels of connectivity, and that's what's on the middle, the middle map here is in terms of the the maximum throw across the structures. And on the right hand side, again, we have a permeability field where using the information that we have in terms of the electrical resistivity of the groundwater in the aquifer at depth, we could look through historical simulations to see how much flow we can get through those structures. And from there , again parameterise, again with PEST in terms of setting the connectivity across across those structures. These were not represented in a particularly elegant manner. These were represented a fairly simplistic manner, that simply manipulated the vertical hydraulic conductivity through to the aquitard cells to enable that flow between. So we've not actually got the representation of all of these offsets. So there's levels of complexability, complexity, that we can bring into, into the modelling. Okay. Just advance it another one, Fiona. Since it works for you. Again, this is an example from FEFLOW. Another frequently applying modelling tool. This is actually just from their documentation. This isn't one of my examples, this is theirs and what they've got here is illustrating the use of their discrete element method. We've got a equivalent porous media aquifer in purple in the background. They, there is flow entering on the left-hand side and exiting on the right hand side of this model domain. And you can see that these metric head contours on here concentrated around a pumping well that's just off to the lower left of that model domain. The superimposed on that, they're using these discrete finite element nodes to add additional permeability along structures We've got a fairly complex pattern of connections through here, so we've got much more permeability along these narrow features, and then they're introducing the solutes on that left-hand boundary. And what we're actually seeing in purple is a background concentration of zero and in red, a higher concentration of 100 milligrams per litre. And we can see how that contaminant has flowed along these preferential flow pathways through to the, to the pump well and actually, I should say that that contaminant mass is only introduced at the four locations where those discrete elements meet the left-hand boundary here. So there being focused in flowing along those those elements so there within FEFLOW is another tool as advanced, well certainly advanced its graphical user interface that they've also got features in there that enable to, to, to get this final resolution Can you move on to the next slide, Fiona. So I've just got one slide really going through the unstructured grids. So, MODFLOW advanced a very long way since, with the release of USG in 2013, enables us to refine our meshes down through many orders of magnitude. I'm sure many people on the call have done this it gives us the flexibility to take to take meshes down to that fault scale. Also within USG, we have the ability to use connecting linear networks to allow flow between nodes which are not adjacent. And on the left-hand side here, I've just got a, just a diagram from the unstructured grid manual where it's just actually really talking more around node numbering, but it's actually useful to talk around. We've got a fault in there that's in the dark brown colour, and if we have this, we would probably be looking to to connect. I don’t know Fiona, if I can, No, I knew that would happen. I don't think anybody can see my cursor, unfortunately, but in the top, in the top left where we've got the above and below is darker brown material, which I'm taking as an aquitard. And we can see we've got a juxtaposition all the lighter tan. Ohh you can see the cursor. Thanks Keith, that's helpful. I can't actually see that my cursor's there. So we've got a juxtaposition here and that's really where these non-negative connections in USG can really come into their own. What I've also put on here is some work that was being done out of Flinders by James McCallum and the other authors on on here, which is really quite a detailed look at simulating groundwater flow using unstructured grids. And it's comparing the different methods that are in that code. Now that was a document that I actually wasn't that familiar with until I was involved in the, in this Explanatory Note. But I'd really, if you've not seen that document I'd point you towards it, it goes through these different methods of using connected linear networks of doing non-neighbouring connections and also this other method I've forgotten the author of it, but effectively it's a method that used in the oil and gas industry in terms of transmissibility modifiers, and that's the bottom diagram here. So yeah, so simulating ground flow dynamics of fault zones in MODFLOW unstructured grids, comparison methods I'd highly recommend that you search that out if you've not, if you've not already seen that. Okay, Just a few more slides to go on the modelling. So if you just advance one Fiona, please. So this is just an example. This is from OGIA's work in the Surat Basin and we've actually moved down into the southeast part of the basin here and looking at the Horrane Fault, near Cecil Plains in Dalby and No, no I've not, no, no. I've got no, I'm sorry, I have changed my, I changed my mind here. I didn't use the Horrane Fault because Joan's already used that, I've gone back to the Hutton-Wallumbilla Fault but both are represented in the same way using the same mechanism within USG and within OGIA's underground water impact modelling. Okay. So what we've got here on the left-hand side is actually an illustration of those non-neighbour connections. So this is an ability that we can take a relatively complex lithology we can include the offsets, but we can then go back into MODFLOW and add additional connections between nodes, across faults so we can simulate and we can ensure that we can simulate those those connections, control those connections, feed the parameterisation of those connections through to a to PEST. And that's exactly what OGIA do. So it's a reasonable amount of detail in their documentation, particularly from 2019. That I think these diagrams are from, ,that describes the process they've been through. Now, I would say that that's still not a particularly, it's a it's a non-trivial exercise. This is having to get relatively deep down into the setup of MODFLOW files to add those additional connectivity in there. I'm just going to just move on one further. Just a couple of more slides to wrap up on the modelling. I'll give it a go. Fiona. Okay. So a couple of slides here. The models I've talked about so far are the traditional tools of whilst we have connected linear networks or discrete finite elements that we can put into MODFLOW and FEFLOW.

There are also other tools, so tools like HydroGeoSphere or from the oil and gas industry, Eclipse or or CMG. We can also look at faults and fractures in more detail using discrete fracture network approach and the example on your screen here is using the FracMan software from from Golder. Actually, what this is doing is not really so much looking at faults, but actually looking at individual fractures within a well to understand more about the level of fracturing in a formation, how connected those fractures are. And in this case, actually looking at which fractures are flowing, of which fractures are likely to be sealed and to link, linking that through to the geomechanical stress,

this is actually looking at an oil industry test, the DFIT, diagnostic formation integrity test, also known as a mini frac test, where we're actually putting pressure between packers and actually waiting for fractures to move. And from that, we're getting huge amount of information around the stress state, more information about the stress state in the rock and the questions there could be posed in terms of, OK which, here which fractures may inflate. But also if we're putting fluid in or taking fluid out and changing that stress state, where might we see movement? Where might we be expecting to see changes from that movement in terms of permeability along a longer structure? And just to move on to the final slide, which I've gone past, and here is a similar application in this case asking questions where we know a fault has been intersected by a well and in terms of the questions being, what happens if fluid, there is an exchange of fluid along that fault or fluid is is removed or put into that fault, what may that do in terms of the geomechanics and actually, then the link through into the into the the permeability, represented by that, by that feature. Okay. So there are other more advanced tools out there, beyond just the standard groundwater tools, certainly not appropriate for all projects but one or two niche applications, they may be necessary. Okay. And I think that's me.

**Interviewer:** Thanks Phil. Yep. We've got a question for you Phil. Just in the Q&A box. Whilst CLNs seem like a good option, numerical stability is often compromised by their use.

**Interviewee 3:** Yeah, I'm not sure that's really a question. That's actually more of a statement. And I think, look, I'd agree we, we've had great advances. We've also had some advances in our ability to solve really hot problems. I mean, we don't we don't struggle in the same way that we used to to get convergence. But certainly once we start introducing connected linear networks, probably putting more nonlinearity into our models, then certainly that's where the solvers may may struggle more. James McCallum's work actually does does point to to some of this and provides a little bit of advice, but yeah I mean yeah, connected lin, it's not a it's not an absolute panacea by any means. Using the node corrections is probably in my experience a little bit, a little bit more stable. So yeah, there is a downside to this. It's not that we can do everything we'd like to. We can't simulate things at every single scale and yet it's not, it's not perfect. And particularly if we've been trying to put those through into, into a tool such as PEST. We end up with greater run times and that, instabilities exceptionally unhelpful if we're trying to use parameter estimation or uncertainty technique. So I'd agree. I don't think it's really a question. It's a is it a known limitation. We're still limited in what we could do.

**Interviewer:** Phil, while you've got the floor. This is the modelling, really generated some good thought, thinking. So what, to what extent do some of the techniques hardwire a specific conceptual model into the assessment tool?

**Interviewee 3:** Well, I think that's perhaps where I lost my train of thought, was really in trying to say, are we doing this to quantify? As in we are trying to assess a level of impact, as in get a numerical result out, or are we actually going to use our models to test, to test different scenarios. So, so we have our conceptualisation and this as Wendy showed from fault seal. You know. We don't, some of this there is still a degree of arm waiving. And we don't know that the, the area I think on Wendy's example it might have been 80,000 square meters of contact where it was the most probable. I can't actually remember but let's let's say 80,000 meters there's a distribution around that and that distribution has come around because we expect that our information is not perfect. We may be out by an order of magnitude in some parameters, and that's effectively what Fault Seal doing is taking some of our uncertainties. It might be a factor of two in this and a factor of ten in something else and putting those together and running them in a stochastic way to come up with a probability density function of how much of what that cross-sectional area may be. That doesn't actually tell us what the permeability of that fault zone is. So it really depends on, on the question where we can use our modelling tools to help us test conceptualisations, possibly to rule some, some conceptualisations out. It may, you know, Wendy has been through some of the investigative techniques where we've got different lines of evidence. Perhaps we have some some tracer data, perhaps we've done some pressure testing. You know. What, what is plausible and what can we rule out. So it may be we have different conceptualisations, test with a model and then perhaps we still need to go forward with two or three different representations of a bulk. If it's a a key impact pathway, if it's 50 kilometres away, perhaps, we don't need to look at it in that much detail. If 500 meters away from project area, then we may well need to look at it in that much detail. So I hope that answers the question.

**Interviewer:** Just give us a shout out in the chat room if you don't. Phil, let's just keep on this topic for a bit longer. There are lots of examples where, from normal faults. If there is such a thing or very steep reverse faults, how do these packages actually deal with low angle thrust faults? And I'll open this up to other panel members as well as I'd like to comment.

**Interviewee 3:** I think we have to open it up. I actually, that's actually scenario I don't think I've ever myself modelled. That in some ways I'd almost open it upto the community that we that we have on the call. I'd be surprised if there isn't somebody out there who's, who's got experience of that. I'm also struggling myself to see the chat. I actually can't see any of these questions coming in. Is that deliberate? You're fielding everything?

**Interviewer:** No, no. You should be able to see it if you click on the Q&A button. Joan, did you want to add any other comments to your experience in that area?

**Interviewee 4:** No. So, that, that the question sort of came from me because what are the the issues in a lot of the geological modelling software packages is that when you start having low angle thrust faults, they they struggle to, to represent them, sometimes faithfully or if at all. And so what happens is everybody starts to visualise all faults as as normal faults. And, and so, you know, if you kind of take that from just, just simple geological static modelling and start to move that into a dynamic place, it's you know, it becomes kind of an issue. And, and often when we think about thrust faults, we think about them being compressing with lots of sharing and lots of gouge and that they're quite sealing.

But I'm just, just curious if any, if there have been any proposals that have come through that, that looked at that the thrust versus reverse, because even in the Hutton-Wallumbilla we, we model it as a normal fault. It's got quite a bit of reverse movement on it. It just happens to be steep because it's a reactivated early normal fault. So, I was just curious.

**Interviewer:** Another question, is DJF, in DFN there is no constraint on fault geometry, So James, thanks for clarifying that. Again, we might open that up for discussion later on, after we finished some of the content, we could have a bit more of a a chat about that. That sounds like, okay, there's some good discussion coming, keep it going. It's just a matter of what it's relevant to, if you've thought of something that we've talked about earlier. Just hold on to it and where I can, I'll certainly hand the mike over to you. You can interact directly the panelists in a minute. Okay. Well, look, let's keep going. I think this is sort of getting towards the last section of some of the technical content. So, who's going to kick us off now? Wendy, over to you.

**Interviewee 2:** Yes, thanks. We are getting pretty much on the home, home straight here now. So we've just set half a dozen or more, roughly, half a dozen slides now to go and then. So we'll definitely have quite a quite a good chance for question and discussion and really to, to gain from the experience from everybody who's here as part of the webinar. So this last section then is on scenario D. And, this is around reactivation of faults and new flow pathways that that may occur. I guess associated with mining induced stressors. And so it's really, I guess, a bit more of a, an unusual scenario perhaps, and probably it's not as not as common as the earlier scenarios. As we've said, kind of each of these hypothetical scenarios and combining experience in these, these scenarios, the cartoons, the suggested ideas for some of the workflows some of the evidence that could be gathered. It's really, as Joan said, it's an amalgamation of a whole bunch of different projects that the IESC have been requested to look at and to provide advice on. So this scenario, the diagnostic really that makes it a little bit different from, from some of the earlier ones is around this differential movement this ground deformation that can occur. The new, the new fracture pathways deformation zones that can open up in previously either, unfaulted or perhaps unfractured strata or perhaps disturbing some of that fault gouge. It's a scenario that's probably more likely to apply in a few of the the underground mines, certainly not everyone, certainly not everywhere. But I guess it could also occur in in perhaps some of the open cut mining and, CSG type development proposals. So what we're really looking at here is, is I guess potentially some fairly rapid things that can, can occur certainly more rapidly than the typical geological timeframe that we like to think in. So, you know, something that's that's really a bit anomalous really. Now what we've done here is, is kind of jump back to, to table one in the Explanatory Note, and because it's kind of in pretty small text when we presented it earlier, this is, I guess, to try and pull out some of the the potential workflow possibilities that might help to to flesh out, to, to examine this kind of scenario. So in the first column there, some of the site based evidence and geological products to justify the choice of this scenario. And, you know, you can see quite a lot of common things from some of the earlier scenarios. But on the right there, the suggested approaches for characterisation of uncertainty, for risks and of course, as Phil kind of highlighted right at the beginning of this webinar, you know, all of this needs to be done in a in a risk based framework where the work flow, the level of effort, the level of expense and so forth, is very much commensurate with the risks that, that could occur, that the likelihood and the consequences. And I guess what's probably a bit different here then is, is really the combined geomechanical and groundwater hydrogeology approach. So these last points here. And so just to kind of flesh that out a bit more. Next slide. So just waiting for that to come through, here we go. So, we're really looking at some anomalous subsidence where this kind of reactivation could occur. It's not following necessarily some of the accepted normal systematic grand behaviour models. And this little diagram on here on the right, which I think is really useful, it's one that's quite recently been been developed by Professor Bruce Hebblewhite and the team as part of the new Explanatory Note around subsidence associated with underground coal mining. And as noted earlier, that's available for download from our website there, as a consultation draft. But there's been a bit of confusing terminology and, and it's often quite difficult for us to kind of see the, see a consistent picture sometimes across some of the documentation with these proposals and from perhaps the main reports, to some of the specialist reports around development proposals and particularly when it comes to subsidence. I guess this is a, this is quite a complex kind of topic. It's quite challenging, but I think to try and clear up some of the the terminology here, making quite a distinction here between anomalous subsidence and systematic subsidence. So systematic then being conventional, non-conventional. You can read more about it in that consultation draft. But the anonymous part of the point here is that it can be quite a discrete behavioural event, often around geological structures and very localised. So, there may be only a few meters, a few tens of meters at a particular spot rather than a kind of a more systematic substance that is able to be predicted. And the reason why it's anomalous is, is very much this interaction of the ground movement with a geological structure and whatever type of fault or perhaps even other lineaments that could be involved. And so in that Explanatory Note, there's also some, I guess, consideration from a mining engineering perspective around what could be, what could be the possible approaches to to look at this kind of scenario. And geomechanical modelling is, is, is one of the tools, I guess, in the toolbox, but it's, it's not something that would be ever done. Well, I shouldn't say ever, but it's not something that's, that's really feasible to do at this point on a three dimensional regional scale, as per, say, a MODFLOW or a FEFLOW model. What we have seen is just a few examples now of project proposals where there has been some work done looking at in-situ stresses, looking at what kind of changes could be induced by extraction of coal and some attempt to look at using 2D vertical plane strain type models such as, such as, UDEC is one of the common ones. It could be a useful starting point. They do allow for some representation of different types of discontinuity and what can happen with different orientations of, of panel extraction or across, across different fault orientations and so forth. So it's, it's as I said, it's it's not something that is is commensurate with the risk of many of the sites that we look at. So this this kind of scenario, though, is I think it's important to recognise that. And we, we do, it is possible to to see potential impacts that occur due to horizontal movement, quite a distance outside of the actual footprint or within an angle of draw of a longwall panel. So, you know, if you've got offsets, if you've got fault splays, if you've got more complex geological structures that could be say, fault propagation folds and so forth, and you've got a significant change of stress that occurs and some interaction with significant vertical subsidence and upsidence and perhaps valley closure, that this all starts get quite complex and difficult to, to predict. And in that sense it is very much anomalous. So, in this example from a, from a coal seam, you can see some minor displacement here in some of the the marker horizons within this particular coal ply. But one of the other tools that that could be useful is some three dimensional time series analysis where you've got high intensive, high intensity, geotechnical and groundwater data, particularly extensometers, for example, that might be in the roof of a coal extraction layer and, and piezometer data and, you know, at the seam level we we see these hazards around the fault zones in terms of things like rock bursts. But at the surface and I can't say this in time series three dimensions but for those who were at the the Future Mining Conference in this presentation by Peter Corbett and his team, seeing this in three dimensions, is, and in real time and in time, time series, this is actually really, really illuminating because you can see in this, in this example where we've got some of the panel layout there and in black and grey with the panels along here, we've got various sets of lineaments in pink and in blue and in brown, some cross-cutting lineaments. So there are various ages and styles of geological lineaments. These little red vertical bars here are the indicators of stressors, of movement in the roof of the extraction level, indicating in-situ stresses. Okay. And then, we kind of can't see it quite yet here. But on the surface in this next one, we've also got some, sorry the third one here, an indication in, in green and in pink where the water assets are on the ground surface and these little vertical bars here in grey, pink and red, the groundwater levels and piezometers in those shallow systems in here. And if you were to see this in time series, as a little movie or whatever, as the longwall panel advances, say, with this line here going across, you would see, you see this snapshot in time here of an increase in stresses, these vertical red bars. And you can, it's it's really quite illuminating to see that as, as some of these structures are undermined, that you see patterns of stress changes propagating along strike. And then we've seen it also along strike and then into a cross-cutting lineaments with some groundwater level responses occurring within, you know, hours and days and weeks at a place that you would almost least expect it. So having that kind of monitoring data in-situ and understanding of what kind of stressors are the pre mining with roadway development and then with extraction of a panel as the face advances, provides a much more information than, say, this conventional substance line, which is shown here in black, with a conventional substance being picked up through here with that line. So, I guess just to sneak in a photo here of a of a water assets and a GDE in this case didn't end well for this particular crayfish. Now, I mean, obviously there's a lot of multiple stressors. It's a super complex kind of issue because some of these kind of water assets, whether they be upland swamps or creek lines, rivers, there's there's a lot of stressors on these kind of systems. So whether it be bushfires, it be climate change and long term drying, which can be quite difficult

to differentiate from perhaps mining induced impacts. In some cases even, you know, some of four wheel drive damage through some of these swamps. Look, I mean, I think we acknowledge that there's a lot of multiple stressors, but what we do see is there is evidence at a number of locations where there has been long term and possibly permanent consequence for shallow aquifers, creeks, peat swamps and surprise or anomalous impacts that were not predicted, particularly associated with those fault zones. So we know that it can be not just near field and within the angle of draw, but it could also possibly, under a pretty special, in a ways, set of circumstances you know, propagate quite some, some distance. And this is, this is documented by some of the New South Wales independent monitoring panel advices and some of the subsequent some papers that have been presented at industry, industry work. So, just to I guess, a final highlights on another one of the possible tools that we can we can deploy is around high resolution, pore pressure measurements. And by that high resolution we mean vertically very sensitive, far more so than perhaps regular groundwater level monitoring with, you know, quite precise millimetre sub centimetre kind of resolution, but also high resolution in the sense of it being frequent, say hourly measurements rather than perhaps daily or quarterly. And a terrific example of this, this paper by Allegre where he use these kind of techniques along a fault zone, at various locations in these boreholes, both control boreholes and then along shear zone and then along some of the finer grained aquitard units and through a pumping well. And I think to, some of these installations, if you go to the detail in the paper, inclined boreholes as well, designed to capture the, the damaged zone, but with this kind of high resolution data and comparing the different response times during, during active pumping perhaps or hydraulic testing, but also during passive times when there's nothing else happening, there's no active extraction, there's no active pumping to to to actually determine different responses that are occurring depending on where you are in that fault system. And, and looking at potential connectivity pathways both vertically and horizontally. And, you know, we've we've been using and advancing even some of these these techniques. The researchers just moved quite a bit since 2016. And we know by by some of the combined analysis of these passive responses to earth tides and barometric pressure, it is possible to, not in all boreholes, but certainly in those that are giving suitable data to, to, to estimate several hydro-geomechanical properties. So, not just specific storage, storage parameters, but also porosity, bulk modulus, Young's modulus, hydraulic conductivity (horizontal). So a whole range of moralistic result, results. And you can see some of the examples here in a recent, recent paper. But, so we've used this technique in at least one of the new field fault zone locations here in Australia. So certainly very good examples moving on from from Allegre work in faults zones elsewhere. So that's pretty much it in terms of some of the technical content that we've, we've put together for you today and I really want to give acknowledgments and a huge thanks to everyone who's behind this supporting it. Thank you Fiona. Terrific. I know we've now to to, to work got some more through in terms of questions and discussion but just to thank you at this point and also our IESC Secretariat, Office of Water Science. A lot of people working behind the scenes, thanks to Peter and his team and Ben behind the scenes. But look, we also want to give a huge acknowledgment to Titus Murray, to Will Power, as the, the authors. There's many contributors to this Explanatory Note, and I really encourage you to ask lots of questions and let's dive into the discussion hey. Back to, back to you, Fiona.

**Interviewer:** Thanks, Wendy. And we do have a bit of discussion and comments and questions coming through. What I'd like to do first, there was a question, Peter, if you wanted to respond to initially, and I think that's about information and working with clients in particular.

**Interviewee 5:** Is that in regards to the seismic? Fiona

**Interviewer:** Yes, that's it.

**Interviewee 5:** Yeah, it, it's been a while. Can I just say that? But, and it obviously depends on terrain and how much seismic you're getting done, but I don't think you'd get much change under $5,000 per kilometres I would think. The seismic is that, is that, that was James's question I was answering there, I beleive. Yeah. So I'd budget 5000 James and if it comes in cheaper, well and good.

**Interviewer:** Just while we're looking at some of these other questions Phil, do you want to just, while we're just going through some of these questions and there's a great one in the chat room that I'll just ask panelists to read. Yeah. But Phil, do you want to just kind of go back to where we started from?

**Interviewee 3:** We're actually bouncing back to a slide, which due to my impatience I think on slide transitions and waiting for them to come through, I, I breezed through and didn't see and didn't go through, but I thought it's worth just pausing and going back. So we do have a little bit of time. And in terms of why did we do an Explanatory Note on faults and yep, they're common in the advice that the IESC provide. So that they're often a feature of the environment around projects and may actually be a specific question that's coming from, from regulators. And if we were to wind the clock back perhaps more than ten years, it would push you back into the early 2000s. What was acceptable then and the levels of data and the the investigation techniques that we had available, probably isn't going to wash today. The expectation, the expectation from the community in terms of the level of the assessment has increased. And I can think of times in my career where with relatively little evidence and conceptualisation, perhaps as a fault, as a barrier, as, as an assumptions been made. And yes, I've gone and implemented that in a groundwater model. So we've not really taken it. We've taken a structural map. We've taken a line off that map and gone straight through. In terms of this Exploratory Note, really what we're trying to do is we're trying to just raise, raise the quality of assessment that's done and to bring together information, to help in that. Right. So we really do wish to reiterate that we do not see these as standard and we do not see these as a guideline. This is not shall must, you shall do, this is, there is information in here that may be useful. So it's a compilation of knowledge. It's collating, particularly cross-disciplinary information. So this isn't really an area where many of the people on the call and the people presenting, we're not absolute experts in the impact that can be propagated along faults because that's a combination of structural geology. It can be, can be actually reservoir, petroleum engineering reservoir engineering. It's hydrogeology as well. So we're bringing disciplines together and areas which have advanced further, again typically because they've got more money available than in hydrogeological investigations. Some of the software that's been presented has come out of the radioactive waste industry and also out of the petroleum industry. So what we're trying to do is show what has been done and what can be done with pointers to these examples and the conceptualisation. Okay, so you have a panel. We don't have all the answers, but please let's carry on with the questions. Thanks Fiona.

**Interviewer:** Thanks, Phil. Just before we wrap up formally, and there's some great discussion that we want to continue to have with you, if you can hang on the line however, there's a lot of new events that are starting to be discussed by the IESC. If you don't subscribe already, I suggest you get on and do that. The link to the other Masterclass series and the Explanatory Notes are just left to that QR code there. But just before we wrap up, it's really important that we get a little bit more feedback from you before we go into a more general discussion. And I'll let people turn on their videos and microphones. But if you just want to think of some other questions, just have a look at these three last questions I'd like to ask of you as participants. And this just gives us and the team a little bit of feedback. While we're doing that, Phil, there was a bit to your last point of Explanatory Notes. Claire asked a really great question about triaging, and I'll just get you to think about a response for that while people just finished this poll for me, and I appreciate that some people may need to go and this recording will be available in the near future. And we will let you know

as those people that registered. And James, thanks for inviting your friends along. you get the award for the most, most attended and I'll just give you a bit of a flavour, how we've done. So I'll just share these results. Phil, do you want to just respond to Claire and then I'm going to stop recording after this question and get people to call on.

**Interviewee 3:** Thanks, Claire, for quite a long and detailed explanation. So, I think the question which is at the bottom end of this, is that consideration of initial recommendations for an approval application, having a certain level of assumptions and complexity with conditions to refine it much more detailed later on. Claire, I'm going to sort of second guess where this is really coming from, which is consultants are often brought in slightly later in the piece. We need to, we need to work during, or partway through an EIS, your doing the hydrogeology and some modelling, some impact impact prediction, at which point I think the ability to actually get out into the field and gather new information is perhaps, perhaps getting harder and perhaps alludes to. I think, it would be very difficult for us to give specific recommendations because every site and every project is, is different. But I think the the important question to have in mind, and I know this is one of many, is as you begin an assessment, is do we have, what is the evidence of faulting, what is, what may structures mean in terms of pathways and what is the evidence, the structures from the project going out to the environmental values. So one, one thing perhaps to, if there's one little bit of advice I might might give, which is perhaps to rather than just focus on structures to start with and actually on the project, let's focus on the environmental values in an area. Let's get those maped and then let's work inwards towards the project and then be thinking, okay, we've got our various pathways for impact propagation, where do structures, where the faults come into that. That's probably as best that I can do in answering that question.

**Interviewer:** Thanks, Phil. Other comments from the panel on that one of Claire's dilemma, that I'm sure is shared by many consultants.

**Interviewee 2:** Yeah, I could, I could jump in here. I think that's yeah, we really appreciate this. It's kind of what, what comes first? What's can be triaged and it's quite, it's it's, really quite a tricky thing and there's no really super easy answer to this is there? But I guess yeah, in addition to to Phil's comments on that you know really being clear around what are the environmental assets, what are the, what are the water assets here that are potentially at risk and going from there. But I guess I would say that, you know, a lot of time and pain could probably be avoided by really investing early in some of these studies where there is a potential for geological structures to fault to to be a bit an issue, you know, saving time later on in an assessment project process by getting in there. I mean I know a lot of drilling exploration holes for example, it could be an opportunity to test for a few more things or to get some, some groundwater information as and and and also that I guess what seems to be lacking a lot of the time is, is a step in the EIS pulling together the different studies. As you say they're all on a sort of different timeline here and and different priorities at different points in the project approval process or pre-feasibility studies or invest, you know, leading to an investment decision or what have you. But but the thing is, we're often missing that integration of the different specialist studies. And there needs to be, I would suggest, a bit more of an attempt there to kind of try and bring these multidisciplinary things together at some point before the, you know, the the EIS goes in. Or what have you. I mean, sometimes, I guess, I guess we're starting to see on occasion with projects that perhaps do have a bit more around the structural geology going on in that area, that we see a specialist report around structural geology. That's not warranted for every project. But you know, where it is we're starting to see that and that, that I think helps. So yeah, Joan, maybe you've got some additional things as well. But yeah, look, it's, it's not easy.

**Interviewee 4:** I think, you know, most of my experience has been around kind of geotech and geomechanics and making sure that, that people are under a safe environment and looking for mining conditions that that are conducive or not conducive to that. And then, you know, added on to that, a lot of the similar to goemechanical work that's going on now for interaction with the aquifers, the groundwater systems kind of, you know, lends itself to to go that one step further. So from the that goemechanical modelling stage, at least from an underground point of view, you know, stepping up into, to looking at impact on groundwater assets as is a likely way to go early.

**Interviewer:** Thanks, Joan and the panel. Just before we kind of sign off formally, I guess, question may be to start with you, Chris, is what are these really core elements that the IESC are looking for and that are really critical to allow you to make strong decisions? Can you just reiterate some of those really critical aspects? And then technically we can go to the other members as well.

**Interviewee 1:** So Fiona, my question to that is very high level. My answer to that sorry, that question, is very high level and it's a common theme throughout all of the advices that we receive, is the lack of evidence to prove that the assumptions or the assertions that are being made in relation to a whole range of attributes, not just faults, but other things, are in fact true. So it's the summary that's in the presentation around characterising the faults and understanding whether or not they're behaving the way that's been assumed in the model is always a key part of our consideration. So quite often we will just be presented with an assumption and we won't have the evidence that demonstrates that the use of, that the modelling of the the fault in a particular groundwater model is well based. So it again, it's, it's having the information that gives us confidence that the model will, is robust and will, will withstand further scrutiny if you like, and that it will in fact behave the way the model is predicting so that we can be confident about the, about impacts. I think that's the fundamental question other members might want, the fundamental issue, other might want to comment, but that for me, watching or chairing it for now, over five years, now chairing the committee for over five years, that is the fundamental issue. Is it, have we got the evidence that means we can be confident that the impacts that we are attempting to understand are well characterised.

**Interviewer:** Thanks, Chris. Okay. So at this point, I'd actually like to thank all of our panellists as members of the IESC, also to the Office of Water Science. We going to stop recording now. So thank you to all the participants who have joined us today. Please watch out for the recording and stay online. We'll turn your videos on and your microphones and we'll just have a bit of an open chat. James, I know you've got some great contributions as well as we've been going through, so thank you and we'll see you next time.

END OF TRANSCRIPT