1 Territory Party Research Team

A glaring omission – identifying the true economic cost of Fracking the Northern Territory?

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About the Author

Sue Fraser - Adams has lived in the Northern Territory for more than 30 years. With her barrister husband, she has raised a family, run building and development companies and served in the Army Reserve. Prior to coming to Darwin in 1986, she worked for CSR Limited in Sydney in various capacities including marketing and economic research in the Oil and Gas Division. Her academic training included subjects in pure mathematics, statistics and macro and macro economic modeling.

Declaration of Conflicts of Interest

1. I am a founding member of a political party, namely the 1 Territory Party. I currently hold the voluntary position of Vice- President.
2. I have been a long time member of the Country Liberal Party and have held various voluntary positions in that party including Darwin Branch Chair and President.
3. It is a principal policy of 1 Territory that, on election to government, that the Hydraulic Fracturing of Unconventional Gas will be banned in the Northern Territory.
4. I have worked in the Oil and Gas Industry when employed by CSR Limited in the 1970s and 1980s undertaking marketing and research.
5. I do not expect to receive any income or material benefit from the Oil and Gas Industry in the future.
6. This paper has been put together in my own time and any expenses have been covered by me. I am not in the employ of any organisation. I work for myself and periodically as a contractor providing building inspection services.

Why am I writing this paper?

Like most Territorians, I have been following the debate and argument from both the industry and the environmentalists and others such as the pastoralists about the Fracking industry and its impact on the NT.

I am pleased to see that efforts have been made to try and quantify the economic benefits by the commissioning of sophisticated economic models. However I have become increasingly alarmed when I have examined those models in detail and noticed that there are some glaring omissions that may be presenting results that are far too optimistic. In the absence of any further work that I am aware of, I have commenced my own research and then built some small, simple models to indicate the impact of some factors, with a clear understanding of their limitations and assumptions. The "Fullbore Model" has been built to see how drilled wells remediation costs over a longer time frame will impact on the rosy economic scenarios being pressed on governments and businesses as the NT suffers one of the worst economic downturns ever. It is tempting for an economically drowning community to grab this activity.

The oil and gas wells that have already been drilled and the thousands that may be coming to the NT are going to be there long after time sweeps us all away – should we be thinking not just 5 years, not just 20 years but hundreds of years ahead so as to not create legacy issues for future generations?

A Council of Canadian Academies[15] says it all -

"(We will be) needing to monitor wells in perpetuity because, even after leaky older wells are repaired, deterioration of the cement repair itself may occur. Recognition that wells may leak several decades or longer presents a challenge for all governments responsible for regulating shale gas development. The challenge involves balancing the desires of our current society for the economic benefits of this natural resource with the ethical imperative to avoid passing on the responsibility for well maintenance and impact monitoring to future generations."

I would welcome peer review of this paper.

Sue Fraser-Adams

Abstract

1. Two economic models that have been created to assist the Scientific Inquiry into Hydraulic Fracturing in the Northern Territory[1] headed by the Hon Justice Rachel Pepper have been examined to ascertain whether gas well remediation costs now and in the future have been included.

2. The Australian Petroleum Production & Exploration Association (APPEA) commissioned Deloitte Acess Economics Report July 2014[2] does not appear to include well remediation costs. The ACIL Allen Report[3] in their "GasMark Model" does mention uncosted "Environmental Bonds" and quantifies "Well Abandonment" at $250,000 per well and "Pad Abandonment" at $100,000 per pad but these are normal shutdown costs, not well remediation costs that have to be expended when a well commences to leak in the future.

3. APPEA figures on their website (Well Integrity FAQ) quotes USA statistics indicating a .03% failure rate between 1983 -2007 in Ohio; a .01% failure rate between 1993 -2008 in Texas and .33% failure rate in Pennsylvania since 2005.

4. A general search of the literature indicates reported well failures appear to be significantly higher than these figures. The difficulties comparing statistical examinations across a large number of research papers by eminent scientists include various definitions of "well barrier failure" and "well integrity failure", the number of wells examined (difficult if the whole population of wells is not included because they are "lost"), their age and design are acknowledged, but there does appear to be considerable evidence that well failures over time greatly exceed the APPEA figures.

5. A simple model has been constructed to try and estimate the well remediation costs for the NT now and in the future. The model is called the "Fullbore Model". The model combines conservative well failure rates (reasonably increasing slowly over time), an inflation adjusted cost of well remediation per well and assumptions about the number of wells likely to be drilled and the rate at which new well are drilled each year. Two time periods have been chosen – 24 years (to align with existing published models) and 100 years.

6. The results indicate that, at a full development rate of 67,000 wells over 24 years at 6% well failure rate, the costs of well remediation could be in the order of <u>$4.5 billion</u> and at 15% failure rate, the cost could be over <u>$11 billion</u>.

7. When the model is run over 100 years with the full development rate of 67,000 wells with a slowing increasing well failure rate incraesing each 20 years of up to 20%, the total estimated cost could be over <u>$50 billion.</u>

8. All the assumptions used are very conservative and the base figures come from other qualified, researched sources.

9. It should be stressed these figures include estimated technical well remediation costs only and do not include inspection and compliance costs (either undertaken by the companies or the NT Government); any remediation of aquifers, rivers, springs etc that might be found to be contaminated by gas or other introduced chemicals: any stock or wildlife losses or environmental damage due to vehicle movements including, rigs, trucks, etc; any social or community disruption; or any damage that might incur economic or social costs to other industries such as tourism (loss of clean, green wilderness image, for example); aquaculture (loss of pristine waters, for example), agriculture and pastoral industries (contaminated production causing damage to our clean, green image, for example).

10. The Fullbore Model has tested the cost of the estimated 235 wells (exploration and production) that already appear to have been drilled in the NT to date and under the assumptions employed, could mean by the year 2024, the cost to remediate failed wells (at a failure rate of 6%) could be over $16 million and over 100 years could be over $1 billion to remediate 143 wells (60% overall failure rate).

1. Existing Models

1.1 As a result of the Scientific Inquiry into Hydraulic Fracturing in the Northern Territory[1] which was established in September 2016, at least two economic reports have been done that attempt to provide an indication of the economic impact of the development of an expanded onshore unconventional gas industry in the Northern Territory. The first Report is the APPEA commissioned Report by Deloitte Access Economics ("Economic Impact of shale and tight gas development in the NT" dated 14 July 2015)[2] and the second is the Scientific Inquiry commissioned report by ACIL Allen Consulting "The economic impacts of a potential shale gas development in the Northern Territory" dated October 2017[3].

1.2 The Background and Issues Paper issued by the Scientific Inquiry[1] did identify well integrity as a risk to Groundwater in Table 7.1 (Page 16). They identified connectivity between shale formations and overlying and underlying aquifers as well as leaking wells as risk issues. They also referred to "*well degradation over the life of a well*" but do not appear to have specifically identified any legacy issues that will arise over the decades and centuries ahead.

1.3 Both Reports[1&2] use economic modeling and various scenarios to try and estimate in a macro sense what sort of economic impacts the development of this industry will have in the NT. Economic modeling by its very nature is only as good as the assumptions and framework on which the model is built and both Reports, to their credit, urge caution in the use of their findings. This particular industry is particularly difficult to model due to the range of unknown factors such as quantifying recoverable reserves, price fluctuations of finished product over time, taxation regimes that change over time and quantifying environmental damage that may not become evident for many years, which are only a few of the relevant factors.

1.4 It is interesting that while both Reports[1&2] set out with a similar broad aim to model the economic impacts, they did come to significantly different results (for example, the Deloitte[2] report estimates job creation could reach 6,300 FTE under their "Aspirational" scenario and 4,200 FTE under their "Success" scenario by 2040 but the ACIL Allen[3] report using five scenarios to 2043 ("Base", "Calm", "Breeze", "Wind" and "Gale") came to very different conclusions depending on the assumptions used. Some of the differences between the two reports were analysed in Chapter 13 " Economic Impacts" of the Inquiry Draft Final Report[4] so it is unproductive to cover that ground again.

1.5 Many of the Deloitte Report[2] assumptions have been challenged by other analysts or now become out of date (eg The Australian Institute "Economics of unconventional gas development" June 2017[5] and Pangaea submission to the Inquiry[6] dated 15 /2/18 – Page 5) and my own examination shows that in regard to gas pricing and possible government revenues, that these two factors alone are possibly too optimistic - the government revenues in particular are probably overstated. There is support for this proposition from the on-going Senate Economics Reference Committee Inquiry[7] indicating that the large multinational corporations involved in this industry quite legally do not pay much, if any company tax and because of the structure of the Petroleum Resource Rent Tax (PRRT) being a tax on profits, almost no tax is paid there either. The industry does not employ a lot of people directly but there would be some downstream multiplier effect locally and the Pangaea submission[6] attempts to quantify these expenditures.

1.6 The difficulties of building complex economic models to assess the realistic impact of this activity where the full extent of recoverable resources are unknown, among other factors, are appreciated and understood. The social cost of any activity can be difficult to quantify as well, but should not be ignored because of this.

2. A glaring omission

2.1 However, the glaring omission in all the sophisticated models mentioned above, is something that can be quantified. This omission is the factoring in of well barrier and integrity repair costs, not just to the years 2040 and 2043 but for the next 100, 500 or even 1,000 years, as wells will fail due to a number of reasons that are briefly examined below.

2.2 I can find no reference to well remediation cost in the Deloitte Report[2] and in fact they do say specifically the "Potential environmental and social considerations of developing these resources were outside the scope of this study" (Page 14) so have been excluded.

2.3. Similarly, I can find no mention of well remediation costs in the ACIL Allen Report[3] either. Their model assumptions used in their "GasMark Model" do mention an "Environmental Bond" in Section 5.12 "Financial Inputs and Assumptions" on Page 49 but do not say what that should be and perhaps rather ominously say that this information has come from "Stakeholder consultation". ACIL Allen do quantify well abandonment at $250,000 per well and pad abandonment at $100,000 per pad but these are normal shut down costs and there is no attempt to cost well remediation where a well fails and commences to leak anytime in the future. As this factor is not mentioned, the issue of who pays for well remediation is not canvassed either.

2.4 It appears that the "Environmental Bond" required will be left to the political process unless further information is provided and this paper attempts to put some meat on that particular bone of contention. The companies involved in the industry do not appear to want to quantify the size of this Bond; perhaps understandable because of the impact on their bottom line and the difficulty in calculating what it should be anyway, as the time period it has to cover to be effective is very long.

3. How often can we expect wells to fail?

3.1 Why is well failure an important consideration in economic analysis modeling? It is important, to my mind, because of the potential large and ongoing cost that will be borne by this and future generations. Before any political decisions are made to allow the widespead use of Unconventional Hydraulic Fracturing to extract gas and petroleum in the Northern Territory, some attempt to quantify these potential costs should be made.

3.2. So at what rate can we expect wells to fail? APPEA (www.appea.com.au) in a section called "Well integrity FAQ"[8], quotes USA statistics indicating a .03% failure rate between 1983 -2007 in Ohio; a .01% failure rate between 1993 -2008 in Texas and .33% failure rate in Pennsylvania since 2005.

3.3 However a general search of the literature indicates well failures appear to be significantly higher than these figures. Some of the papers surveyed include those mentioned below.

3.4. Notes from the research paper by Richard J Davies et al in March 2014[9] indicate the following:-

- comprehensive data examined in this study was for wells that included production, injection, idle, orphaned and abandoned, both onshore and offshore, both conventional and unconventional;

- the well failure data is highly variable from 1.9% to 75% depending on the number of wells examined, their age and design;

- the data shown on the APPEA website does appear to be inconsistent with this research that indicates of the *".....8,030 wells targeting the Marcellus shale that were inspected in Pennsylvania between 2005 and 2013, 6.3% were reported to the authorities for infringements relating to well barrier or integrity failure"*. That is a significant difference from .33% quoted by APPEA[8] above.

- Table 3 in Davies' paper[9] shows the variation of well failure rates in different countries over different time periods. (Table 3 - "Compilation of published statistics on well barrier and well integrity failure, including information on well age, number of wells included in study, well location, and terminology used to describe nature of well barrier or integrity failures" – See Appendix 1).

3.5. Notes from the research paper by Robert B Jackson published in July 2014[10] indicate the following:

- unconventional shale gas wells were 6 times more likely to show problems than conventional wells;

- for unconventional wells in Pennsylvania drilled in the period 2000- 2008, the violation rate was 9.8%; the rate was 9.1% for 2009 -2012 (quoting Ingraffea AR et al "Assessment and risk analysis of casing and cement impairment in oil and gas wells in Pennsylvania 2000-2012");

- it appears in Pennsylvania that older wells are rarely inspected, with 8,000 wells having no records at all;

- new analysis suggests there could be 280,000-970,000 abandoned wells in Pennsylvania alone.

3.6. Notes from the research paper by Anthony Ingraffea et al presented in January 2017 [11] indicate the following:

- Page 11 - "Recent Operator Performance in the Pennsylvania Marcellus Play : Results of Survey" (See Appendix 2).

- Summary (quote) -

> *- Loss of wellbore integrity a well-understood and chronic problem.*
>
> *- Recent experience in PA Marcellus play no exception.*
>
> *- Methane is prevalent in water wells in PA, but at very low levels.*
>
> *- Pressing need for scientific investigation of possible links between leaking gas wells and water well contamination.*

3.7 Notes from the Submission to the NT Government Hydraulic Fracturing Inquiry (the Hawke Inquiry)[12] by the NT Branch of the International Association of Hydrogeologists[13] in May 2014 indicate the following:

- actual well remediation costs were identified for McDills No 1 (a petroleum well drilled in 1965 at a depth of 3,204 metres by Amerada Petroleum and abandoned – the operator became insolvent and the water gushed until 2002, with 2 other abandoned wells nearby at the rate of 17 ML /day since 1965). In 2002, the costs of about $500,000 remediation were paid for by the NTG and Commonwealth as the company was insolvent. (Source: Humpfreys G and Kunde B).[14]

- in Pennsylvania Cabot Oil & Gas Corporation estimated it cost $2,190,000 to properly abandon 3 vertical Marcellus Shale gas wells;

- estimates more than 67,000 wells may be drilled in the NT;

- literature searches indicate conservative failure rates of 4.6%- 8.9%;

- horizontal or inclined wells have significantly higher failure rates.

3.8 Notes from the research paper by Council of Canadian Academies in 2014[15] indicate the following:

- direct quote from this paper:

"Muehlenbachs et al. (2012) measured surface casing vent flow from wells less than five years old in the Horn River Basin using the latest technology and demonstrated that major improvements are still needed to prevent behind- the-casing gas migration."

- in Alberta alone, where almost 400,000 wells had been drilled by the end of 2012 (AESRD

2013), well failures start at 14,500 (Watson & Bachu, 2009) – 3.6%.

- In an unpublished assessment in Quebec, evidence of methane leakage (bubbles, faint hissing) was found at the surface around 18 of the 29 abandoned wells that were surveyed (BAPE, 2011b) – 62%.

3.9 Having researched the literature, one can be puzzled as to why there appears to be such a difference between what the industry claims are very low well failures and yet what is clearly evident in papers cited above (which are only a few of the many available). It does appear that there are a number of factors at play here, including what the researcher defines as a well failure; the population of wells that are being examined; the vintage of the wells (the age of wells and wine are described in a similar fashion) and other factors. The best description of this that covers some of these issues I have found is in the CSIRO submission[16] which forms Appendix 14 and quotes two older studies often quoted by industry (King and King 2013[17]) and (Kell 2011[18]) and I quote (my emphasis in bold):

"King and King estimated barrier and well failure rates using the data from Kell's study (Table 3). The barrier failure rate was 0.1-0.035% and the well failure rate was one order of magnitude lower than that. King and King defined a well barrier as "a means of containing wellbore pressure and fluids", and well failure as "all well barriers failing in sequence and a leakage pathway being created across all the well barriers."

*"The study by Kell relied on reported contamination incidents, and there may have been integrity issues in other wells that did not result in contamination of a drinking water well or were not noticed and reported. Therefore, the barrier failure rate and well failure rate in the study should be considered **a low-end estimate** of the number of well integrity issues."*

*"In Texas, no groundwater contamination incidents related to hydraulic fracturing were identified over the study period, during which large-volume, multistaged hydraulic fracturing operations for shale gas well stimulation were carried out in over 16,000 Barnett Shale wells. This may be because **the wells were characterised while they were still young, so the failure mechanisms described earlier may have not yet had a chance to develop.** Intensive, long-term monitoring of stimulated wells would be required to establish whether groundwater contamination occurs over longer timeframes. Only one shale wells was drilled in Ohio during the study period."*

3.10 In conclusion, it does appear that there is an explainable difference between what the industry would like to portray as the situation with well failure rates and what extensive other research papers have indicated. There certainly appears to be an amount of unease from those who have examined this issue in the scientific community, as future well integrity will have to be maintained for a very, very long time; well after the writers, the operators, the companies and governments have passed on. Even the scholarly Report by the CSIRO[16] acknowledges in their conclusions that the long term integrity of wells has not been addressed to date:

"Methods for ensuring the long-term integrity of wells post abandonment could also be explored, helping to reduce the uncertainty around this phase of the well life cycle. Baseline studies to characterise environmental receptors before shale gas activities start will be important to assist in any future evaluation of the environmental impact of the industry."

4. How and why do wells fail?

4.1 It is important to understand from the literature how and why gas and petroleum wells fail.

4.2 Well remediation is required when "well integrity" fails. Well integrity "*refers to the zonal isolation of liquids and gases from the target formation or from intermediate layers through which the well passes. In a practical sense, it means that a well doesn't leak.*" (Jackson[10]).

4.3 What is a leak? Davis et al[9] elaborate below:

"A leak can be catastrophic, as seen in cases such as the recent blowout of a Whiting Petroleum Corp oil well (Cherry State 31-16H) in North Dakota (North Dakota Department of Health (2014)) and rare examples of explosions in urban areas (Chillingar and Endres, 2005), or be at sufficiently low rates to be barely detectable. The fluid sources can be hydrocarbon reservoirs (e.g. Macondo, Gulf of Mexico); non-producing permeable formations (e.g. Marshall and Strahan, 2012); coal seams (e.g. Beckstrom and Boyer, 1993; Cheung et al., 2010); and biogenic or thermogenic gases from shallow rock formations (e.g. Traynor and Sladen, 1997; Jackson et al., 2013). Oil or gas emissions can seep to the surface, though leaking methane can be oxidised by processes such as bacterial sulphate reduction (e.g. Van Stempvoort et al., 2005). Well failures can potentially occur in any type of hydrocarbon borehole, whether it is being drilled, producing hydrocarbons, injecting fluid into a reservoir, or has been abandoned".

4.4 The Council of Canadian Academies[15] paper quoted earlier says:

"Natural gas leakage from improperly formed, damaged, or deteriorated cement seals is a long-recognized yet unresolved problem that continues to challenge engineers. Leaky wells due to improperly placed cement seals, damage from repeated fracturing treatments, or cement deterioration over time, have the potential to create pathways for contamination of groundwater resources and to increase GHG emissions. The issue of well integrity applies to all well types, including water and conventional gas or oil wells. Several factors make the long-term impact related to leakage greater for shale gas development than for conventional oil and gas development. These are the larger number of wells needed for shale gas extraction; the diverse chemicals used in hydraulic fracturing operations; the potential development of shale gas resources in rural and suburban areas that rely on groundwater resources; and possibly the repetitive fracturing process itself."

And further more:

"Conventional methods of monitoring gas leakage may be inaccurate, and are incomplete because leakage outside the main well casing is rarely measured. The issue of well integrity applies to all oil and gas wells, not only shale gas development wells. However, the much larger number of wells needed for shale gas extraction, and the occurrence of shale gas development in areas of substantial rural and near-urban populations relying on wells for drinking water, suggest that the consequences of leakage will be correspondingly greater than for conventional oil and gas development."

4.5 The Australian Council of Learned Academies (ACOLA) Report in 2013 is quoted by the Canadian Report[15] above when it noted the ACOLA[19] observations:

- *"Cement and steel do not have very long-term integrity in geological materials".*

- that there is a lack of adequate data and analysis to define what constitutes a failed well and states that:

"well abandonment is not just a regulatory issue but is also an issue that requires more research and development in areas such as the very long-term behaviour of cements and extended monitoring under hostile subsurface conditions [...]. The very long-term integrity of a cemented and abandoned well (beyond 50 years) is a topic where more information will be essential".

4.6 So there are many factors that cause a well to "fail". Some failures are fairly minor but others are catastrophic, where explosions have occurred and people killed.

4.7 Trying to model these variables is very difficult but essential because well failure should be factored into any economic models as somebody in the future will have to pay for well remediation.

5. How many wells will be drilled in the NT if Unconventional Gas is allowed?

5.1 The calculation of the number of wells is not a simple one. It is hard to work out the number of wells that would actually be drilled in the NT because of the uncertainly of reserves and classification. An example of the complexity is the following extract from the NTG publication "Petroleum geology and potential of the onshore Northern Territory" [20] in 2014:

"Summary of onshore petroleum resources and production

Although the onshore NT is very prospective for both conventional and unconventional petroleum, exploration programs are at relatively early stages, or are still to commence in most basins. Petroleum resources and/ or reserves have been determined for only four basins(Amadeus, McArthur, Georgina and onshore Bonaparte),and the only production has been from the Mereenie and Palm Valley fields in the Amadeus Basin. This section tabulates the current estimates of discovered and undiscovered petroleum in the NT, from industry and academic sources"

"Resources classification system

*Petroleum resources are generally classified and reported according to Petroleum Resource Management System guidelines provided by the Society of Petroleum Engineers Oil and Gas Reserves Committee. These guidelines (SPE 2011) provide a basis for the classification and categorisation of all petroleum reserves and resources within a basin. Although the system encompasses the entire resource base, it is focused primarily on estimated recoverable sales quantities. Resources are classified according to the maturity or status of the exploration program (broadly corresponding to the chance of commerciality) using three main classes, with the option to subdivide further using subclasses. The three classes are Reserves, Contingent Resources and Prospective Resources (**Figure 5**). Reserves are quantities of petroleum accumulations that are anticipated to be commercially recoverable from developed or soon-to-be developed projects. Contingent Resources are quantities of petroleum anticipated to be commercially recoverable from known accumulations from projects that are not yet mature enough to be considered commercial. Prospective Resources are those petroleum resources that might be recovered from undiscovered accumulations in future projects.*

*The range of uncertainty for each class of resource is categorised based on the principle of capturing at least three estimates (low, best, and high) of the potential outcome. If all the criteria for defining Reserves are satisfied, the low, best, and high estimates are designated as Proved (1P), Proved plus Probable (2P), and Proved plus Probable plus Possible (3P), respectively. The equivalent terms for Contingent Resources are 1C, 2C and 3C, and the terms 'low estimate', 'best estimate' and 'high estimate' are used for Prospective Resources. The three estimates may be calculated using either a 'deterministic' or a 'probabilistic' method. **Figure 6** illustrates the relationship between the two methods. The deterministic method combines a single set of discrete parameter estimates (gross rock volume, average porosity etc) to input into an appropriate equation, to obtain a single, specific estimate of recoverable quantities, and is expressed in the 1P, 2P, 3P terminology."*

5.2 It is difficult from perusal of industry literature and reports to obtain a clear picture of the number of wells that could be drilled in the NT. Perhaps it just very difficult to quantify given the uncertainty identified above. I cannot find any total well numbers for the NT in the APPEA commissioned Deloitte Report or in a perusal of industry literature about the NT– this information may be there but I could not find it in the time available to me. I am more than happy to put any any industry figures into my simple model if they were available.

5.3 Fortunately I have found 2 figures in the Hydrogeologists Report[13] cited above (extracted from Page 5) – a broad estimate of 67,000 wells and a more specific figure possible in the four most prospective Basins of 55,725.

Basin	**Basin Area (km2)**	**No of shale gas wells**
Amadeus	133,110	10,399
Georgina	228,120	17,849
McArthur	196,288	15,351
Wiso	154,310	12,126

5.4 The ACIL Allen "GasMark" model, to its credit, does quote well numbers but it is a little unclear how these figures were obtained. The surprising feature is that the well numbers quoted in "GasMark" are very low in its three scenarios compared to the predictions of thousands of wells drilled in the Hydrogeologists Report. I cannot reconcile these differences and have to just accept them.

6. A statistical model to estimate well remediation costs

6.1 As the number of wells figure is a vital component of any cost calculation of well remediation costs, I am forced to use the Hydrogeologists[13] figure of 67,000.

6.2 Another figure (which again was not easy to obtain) to input into the model is the existing wells all ready drilled in the NT. Through various CORE[21] publications produced by the NT Government, I have estimated there are at least 235 wells (exploration and production) that already appear to have been drilled in the NT to date.

6.3 Therefore these two figures will form the basis of one of the input parameters into the statistical model to try and predict well remediation costs over time which I have called the "Full Bore Model".

7. The "Full Bore Model" - 24 years and 100 years

7.1 <u>24 year Model Assumptions:</u>

7.1.1 The cost of well remediation is assumed to be an average of $756,300 per well. This figure is based on the actual cost in 2002 of $500,000 of the McDills well remediation (Humphreys G and Kunde B)[14] which has been brought to 2018 value assuming an inflation rate of 3% / year for the past 16 years. In the future, depending on the seriousness of the well failure, this figure could be a lot higher or lower in each individual case. I have assumed it is an average figure.

7.1.2 The well cost remediation as identified in 7.1.1 above is adjusted for the rate of inflation, assumed to be a conservative, consistent rate of 3% over the 24 years to 2042 in Table 1 and the same rate in Table 2 over the 100 year time span. It could reasonably expected that the rate of inflation in Australia would at times be a lot higher than 3% over the next 24 and 100 years and this adds an element of conservatism into the analysis.

7.1.3 The time period chosen for the first run is 2019- 2042 (24 years) to conform to the time period of the ACIL Allen model. The second analysis in Table 2 has been made to show the likely cost of well remediation over 100 years and runs from 2019 to 2119.

7.1.4 The well failure rate is assumed to be a snapshot of two scenarios - a rate of 6% and a rate 15% for the first 24 years, which is very conservative according to the literature outlined above. I have accepted the broad interpretation of "well failure" and not the narrow interpretation that the industry prefers to quote.

7.1.5 The total number of wells drilled in the NT is assumed to be 67,000, which was estimated in the Hydrogeologists[13] report above. I have accepted the figure of 67,000 wells being a complete utilization of gas recovery attempts in the whole of the Northern Territory across all Basins but it is indicative of the potential size of the well remediation problem the NT will face if mass Unconventional Hydraulic Fracturing is allowed to proceed.

7.1.6 It is assumed, unrealistically I know, that the wells are drilled at an even rate of 2,792 (67,000 divided by 24) a year when the reality is that they would come on stream at a slower rate in the early years as the industry was gearing up and the speed up as the industry matured and more fields were discovered and gas fields are proved up. This has been done for simplicity in the absence of actual industry intentions that have not been made public.

7.1.7 I stress the cost figures used are only the technical well remediation costs and do not include:

- inspection and compliance costs (either undertaken by the companies or the NT Government);

- any remediation of aquifers, rivers, springs etc that might be found to be contaminated by gas or other introduced chemicals;

- any stock or wildlife losses or environmental damage due to vehicle movements including, rigs, trucks etc;

- any social or community disruption;

- any damage that might incur economic or social costs to other industries such as tourism (loss of clean, green wilderness image, for example); aquaculture (loss of pristine waters, for example), agriculture and pastoral industries (contaminated water causing damage to our clean, green image, for example).

TABLE 1 - "FULL BORE" MODEL – WELL REMEDIATION COSTS 2019 – 2042

(Please see attachment APPENDIX 3)

7.2 <u>100 year Model Assumptions:</u>

7.2.1 On the 100 year table, the following assumptions are made:

- that 67,000 wells are drilled over the 100 years at the consistent rate of 670 / year;

- that the well failure rate is as follows for the following time periods: 2019- 2042 (6%); 2043 – 2062 (9%); 2063 – 2082 (12%); 2083 – 2102 (15%); 2103 – 2119 (20%).

7.2.2 The increasing failure rate as time passes could be expected as wells deteriorate and again is not inconsistent with the research papers discussed above. In fact I would argue they are very conservative.

TABLE 2 - "FULL BORE" MODEL – WELL REMEDIATION COSTS 2019 - 2119

(Please see attachment APPENDIX 4)

8. The Existing Wells in the NT - 24 years and 100 years

8.1 The same assumptions are applied as per Sections 7.1 and 7.2 above

TABLE 3 - "FULL BORE" MODEL – WELL REMEDIATION COSTS – EXISTING WELLS NT - 2019 - 2119

(Please see attachment APPENDIX 5)

9. Results

9.1 The results from the Fullbore Model indicate that, at a full development rate of 67,000 wells over 24 years at 6% well failure rate, the costs of well remediation could be in the order of **<u>$4.5 billion</u>** and at 15% failure rate, the cost could be over **<u>$11 billion</u>**.

9.2. When the Fullbore model is run over 100 years with the full development rate of 67,000 wells with a slowing increasing well failure rate of up to 20%, the total estimated cost could be over **<u>$50 billion.</u>**

9.3 The Fullbore Model has tested the cost of the estimated 235 wells (exploration and production) that already appear to have been drilled in the NT to date and under the assumptions employed, could mean by the year 2024, the cost to remediate failed wells (at a failure rate of 6%) could be over **$16 million** and over 100 years could be over **$1 billion** dollars to remediate 143 wells (60% overall failure rate).

10. Conclusion

10.1 The failure rate of unconventional gas wells at all stages of construction, operation and abandonment appears to be a lot higher than the industry published figures.

10.2 The cost of repair, remediation or graveyard security to ensure no leaking of gas or materials or linking of aquifers is significant and should be incorporated into any economic models, either as a direct cost to the companies (but they could go broke and not be around to meet this obligation) or more preferably as a direct cost against government revenues as ultimately taxpayers could very likely be picking up the bill.

10.3 The models should run to at least 100 years, well after the expected life per well of 20-30 years to more accurately assess the total cost to government and to the community.

10.4 The cost of well failure in the NT over the next 24 years 2019-2042 could be significant. According to the "Fullbore Model", the well remediation costs could be in the range of almost **$4.5 billion** (very conservative - assuming 67,000 wells with a failure rate of 6% @ $. 756 million / per well adjusted for inflation) to more than **$11 billion** (assuming 67,000 wells with a failure rate of 15% @ $.756 million / well adjusted for inflation).

10.5 Taking a longer time span over 100 years, assuming the 67,000 wells are drilled over the 100 years to 2119, the well remediation costs could be more than **$50 billion.** This may be a more realistic scenario. It is a very conservative estimate of costs and may be considered a more realistic well drilling program over the longer time period. The assumptions are 67,000 wells are drilled over 100 years at the rate of new 670 wells drilled each year, with a failure rate of 6% in the first 24 years, then 9% in the next 20 years, then 12% in the next 20 years, the 15% in the next 20 years, and then the balance of the time at 20% failure @ a cost of $. 756 million / per well adjusted for inflation over 100 years.

10.6 These figures do not account for the possible damage done to other industries such as tourism, pastoral or agricultural or remote communities if water is contaminated by gases or linking up of aquifers and do not include the cost of cleaning up a contaminated aquifer, assuming this is technically feasible.

10.7 Further work that needs to be done in this field includes the impact on the estimated revenue streams to government in the future; in addition the run should be done to 500 years; and I would like to use the Fullbore Model to test the ACIL Allen "Gasmark Model" figures.

10.8 Perhaps the final word should be left to the Council of Canadian Academies:

"10.2 A FINAL WORD

The lessons provided by the history of science and technology concerning all major energy sources and many other industrial initiatives show that substantial environmental impacts were typically not anticipated. What is perhaps more alarming is that where substantial adverse impacts were anticipated, these concerns were dismissed or ignored by those who embraced the expected positive benefits of the economic activities that produced those impacts (EEA,2001, 2013). Many of these adverse impacts could have been lessened, if not entirely avoided, if appropriate management measures, including monitoring programs, had been put in place from the beginning."

ATTACHMENTS:

Appendix 1 – Copy of Page 246 from Davies RJ et al.

Appendix 2 – Copy of Page 11 from Ingraffea A et al.

Appendix 3 – Raw Excel Computations – Table 1 Fullbore Model 2019 -2042

Appendix 4 – Raw Excel Computations – Table 2 Fullbore Model 2019 -2119

Appendix 5 – Raw Excel Computations – Table 3 Fullbore Model – Existing NT Wells 2019 -2119

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Appendix 1 – Copy of Page 246 from Davies RJ et al.

Table 3
Compilation of published statistics on well barrier and well integrity failure, including information on well age, number of wells included in study, well location, and terminology used to describe nature of well barrier or integrity failures.

Country	Location	No. Wells studied	% Wells with barrier failure or well integrity failure	Additional information	Published source
USA	ONSHORE Operational wells in the Santa Fe Springs Oilfield (discovered ~1921), California, USA	>50	75	Well Integrity failures. Leakage based on the 'observation of gas bubbles seeping to the surface along well casing'.	Chillingar and Endres (2005)
USA	ONSHORE Ann Mag Field, South Texas, USA (wells drilled 1998–2011)	18	61	Wells drilled 1998–2011. Well barrier failures mainly in shale zones.	Yuan et al. (2013)
USA	OFFSHORE Gulf of Mexico (wells drilled ~1973–2003)	15,500	43	Wells drilled ~1973–2003. Barrier failure. 26.2% in surface casing.	Brufato et al. (2003)
Offshore Norway	OFFSHORE Norway, 8 Companies, Abandoned Wells (wells drilled 1970–2011)	193	38	Wells drilled 1970–2011. Well integrity and barrier failure. 2 wells with likely leak to surface.	Vignes (2011)
China	ONSHORE Kenxi Resevoir, China (dates unknown)	160	31.3	Well barrier failure	Peng et al. (2007)
China	ONSHORE Gudao Resevoir, China (wells drilled 1978–1999)	3461	30.4	Wells drilled 1978–1999. Barrier failure in oil-bearing layer.	Peng et al. (2007)
Offshore Norway	OFFSHORE Norway, 8 Fields (dates unknown)	217	25	Wells monitored 1998–2007. Well integrity and barrier failure. 32% leaks occurred at well head.	Randhol and Carlsen (2007)
Canada	ONSHORE Saskatchewan, Canada (dates unknown)	435	22	Wells monitored 1987–1993. Well integrity failure: SCVF and GM	Erno and Schmitz (1996)
Offshore Norway	OFFSHORE Internal Audit, Location Unknown (dates unknown)	711	20	Barrier failure	Nilsen (2007)
Offshore Norway	OFFSHORE Norway, 12 Offshore Facilities (wells drilled 1977–2006)	406	18	Wells drilled 1977–2006. Well integrity and barrier failure. 1% had well head failure.	Vignes and Aadnøy (2010)
China	ONSHORE Daqing Field, China (wells drilled ~1980–1999)	6860	16.3	Wells drilled ~1980–1999. Barrier failure	Zhongxiao et al. (2000)
Bahrain	ONSHORE Bahrain (wells drilled 1932–2004)	750	13.1	Wells drilled 1932–2004. Failure of surface casing with some leaks to surface	Sivakumar and Janahi (2004)
Netherlands	ONSHORE Netherlands (dates unknown)	31	13	Barrier failure	Vignes (2011)
UK	OFFSHORE UK Continental Shelf (dates unknown)	6137	10	Well integrity and barrier failure.	Burton (2005)
USA	ONSHORE Marcellus Shale, Pennsylvania, USA (wells drilled 1958–2013)	8030	6.26	Well reports 2005–2013. Well integrity and barrier failure. 1.27% leak to surface.	This study
China	ONSHORE Gunan Reservoir, China (dates unknown)	132	6.1	Barrier failure	Peng et al. (2007)
USA	ONSHORE Nationwide Gas Storage Facilities (<1965–1988)	6953	6.1	Wells drilled <1965–1988. Well integrity and barrier failure.	Marlow, 1989
China	ONSHORE Hetan Reservoir, China (dates unknown)	128	5.5	Barrier failure	Peng et al. (2007)
USA	ONSHORE Marcellus Shale, Pennsylvania, USA (wells drilled 2010–2012)	4602	4.8	Wells drilled 2010–2012. Well barrier and integrity failure.	Ingraffea (2012)
Canada	ONSHORE Alberta, Canada (wells drilled 1910–2004)	316,439	4.6	Wells drilled 1910–2004. Monitored 1970–2004. Well integrity failure: SCVF and GM	Watson and Bachu (2009)
Indonesia	ON/OFFSHORE Malacca Strait (wells drilled ~1980–2004)	164	4.3	Wells drilled ~1980–2010. Both well integrity and barrier failures. Further 41.4% of wells identified as high risk of failure.	Calosa and Sadarta (2010)
USA	ONSHORE Pennsylvania, USA (wells drilled 2008–2013)	6466	3.4	Wells drilled 2005–2012. Well integrity and barrier issues. Leak to surface in 0.24% wells.	Vidic et al. (2013)
China	ONSHORE Kenli Resevoir, China (dates unknown)	173	2.9	Barrier failure	Peng et al. (2007)
USA	ONSHORE Marcellus Shale, Pennsylvania, USA (wells drilled 2008–2011)	3533	2.58	Wells drilled 2008–2011. Well integrity and barrier failure	Considine et al. (2013)
USA	ONSHORE Nationwide CCS/Natural Gas Storage Facilities (dates unknown)	470	1.9	Well integrity failure. Described as significant gas loss.	IPCC (2005)

Appendix 2 – Copy of Page 11 <u>from Ingraffea A et al.</u>

Recent Operator Performance in the Pennsylvania Marcellus Play: Results of Survey

1,609 wells drilled in 2010.
97 well failures.
6% rate of failure.

1,972 wells drilled in 2011.
140 well failures.
7.1% rate of failure.

1,346 wells drilled in 2012
120 well failures.
8.9% rate of failure.

Consistent with previous industry data, and not improving.

Appendix 3 – Raw Excel Computations – Table 1 Fullbore Model 2019 -2042

Year	Year	Base cost of Individu well remediation	Well cost adjust $ for inflation	Assume 6% wells Fail (6% × 2792) Number of wells	Total cost 6% Fail (C x D) $	Assume 15% fail (15% x 2792) Number of Wells	Total cost at 15% fail (F x C)
2019	**2019**	756,300	778,989	168	130,496,237	419	326,240,593
2020	**2020**	756,300	802,359	168	134,411,124	419	336,027,811
2021	**2021**	756,300	826,429	168	138,443,458	419	346,108,645
2022	**2022**	756,300	851,222	168	142,596,762	419	356,491,905
2023	**2023**	756,300	876,759	168	146,874,665	419	367,186,662
2024	**2024**	756,300	903,062	168	151,280,905	419	378,202,262
2025	**2025**	756,300	930,154	168	155,819,332	419	389,548,330
2026	**2026**	756,300	958,058	168	160,493,912	419	401,234,779
2027	**2027**	756,300	986,800	168	165,308,729	419	413,271,823
2028	**2028**	756,300	1,016,404	168	170,267,991	419	425,669,977
2029	**2029**	756,300	1,046,896	168	175,376,031	419	438,440,077
2030	**2030**	756,300	1,078,303	168	180,637,312	419	451,593,279
2031	**2031**	756,300	1,110,652	168	186,056,431	419	465,141,077
2032	**2032**	756,300	1,143,972	168	191,638,124	419	479,095,310
2033	**2033**	756,300	1,178,291	168	197,387,268	419	493,468,169
2034	**2034**	756,300	1,213,639	168	203,308,886	419	508,272,214
2035	**2035**	756,300	1,250,049	168	209,408,152	419	523,520,381
2036	**2036**	756,300	1,287,550	168	215,690,397	419	539,225,992
2037	**2037**	756,300	1,326,177	168	222,161,109	419	555,402,772
2038	**2038**	756,300	1,365,962	168	228,825,942	419	572,064,855
2039	**2039**	756,300	1,406,941	168	235,690,720	419	589,226,801
2040	**2040**	756,300	1,449,149	168	242,761,442	419	606,903,605
2041	**2041**	756,300	1,492,623	168	250,044,285	419	625,110,713
2042	**2042**	756,300	1,537,402	168	257,545,614	419	643,864,034
	TOTAL			**4,020**	**4,492,524,826**	**10,051**	**11,231,312,065**

Appendix 4 – Raw Excel Computations – Table 2 Fullbore Model 2019 -2119

Year	Base cost of Individ well remediation $	Well cost adjusted for inflation	Assume 6% of wells Fail (6% × 670) Number of wells	Total cost at 6% fail (C x D) $
2019	756,300	778,989	40	31,315,358
2020	756,300	802,359	40	32,254,819
2021	756,300	826,429	40	33,222,463
2022	756,300	851,222	40	34,219,137
2023	756,300	876,759	40	35,245,711
2024	756,300	903,062	40	36,303,082
2025	756,300	930,154	40	37,392,175
2026	756,300	958,058	40	38,513,940
2027	756,300	986,800	40	39,669,358
2028	756,300	1,016,404	40	40,859,439
2029	756,300	1,046,896	40	42,085,222
2030	756,300	1,078,303	40	43,347,779
2031	756,300	1,110,652	40	44,648,212
2032	756,300	1,143,972	40	45,987,659
2033	756,300	1,178,291	40	47,367,288
2034	756,300	1,213,639	40	48,788,307
2035	756,300	1,250,049	40	50,251,956
2036	756,300	1,287,550	40	51,759,515
2037	756,300	1,326,177	40	53,312,300
2038	756,300	1,365,962	40	54,911,669
2039	756,300	1,406,941	40	56,559,020
2040	756,300	1,449,149	40	58,255,790
2041	756,300	1,492,623	40	60,003,464
2042	756,300	1,537,402	40	61,803,568
TOTAL			965	1,078,077,233

	Base cost of Individ well remediation $	Well cost adjusted for inflation	Assume 9% of wells Fail (9% × 670) Number of wells	Total cost at 9% fail (C x D)
2043	756,300	1,583,524	60	95,486,512
2044	756,300	1,631,030	60	98,351,108
2045	756,300	1,679,961	60	101,301,641
2046	756,300	1,730,360	60	104,340,690
2047	756,300	1,782,270	60	107,470,911
2048	756,300	1,835,739	60	110,695,038
2049	756,300	1,890,811	60	114,015,889
2050	756,300	1,947,535	60	117,436,366
2051	756,300	2,005,961	60	120,959,457
2052	756,300	2,066,140	60	124,588,240
2053	756,300	2,128,124	60	128,325,888
2054	756,300	2,191,968	60	132,175,664
2055	756,300	2,257,727	60	136,140,934
2056	756,300	2,325,459	60	140,225,162
2057	756,300	2,395,223	60	144,431,917
2058	756,300	2,467,079	60	148,764,875
2059	756,300	2,541,092	60	153,227,821

(2)

2060	756,300	2,617,324	60	157,824,656
2061	756,300	2,695,844	60	162,559,395
2062	756,300	2,776,719	60	167,436,177
TOTAL			**1,206**	**2,565,758,341**

	Base cost of Individ well remediation	**Well cost adjusted $ for inflation**	**Assume 12% of wells Fail (12% × 670)**	**Total cost at 12% fail (C x D)**
	$	**$**	**Number of wells**	**$**
2063	756,300	2,860,021	80	229,945,683
2064	756,300	2,945,822	80	236,844,054
2065	756,300	3,034,196	80	243,949,375
2066	756,300	3,125,222	80	251,267,857
2067	756,300	3,218,979	80	258,805,892
2068	756,300	3,315,548	80	266,570,069
2069	756,300	3,415,015	80	274,567,171
2070	756,300	3,517,465	80	282,804,186
2071	756,300	3,622,989	80	291,288,312
2072	756,300	3,731,679	80	300,026,961
2073	756,300	3,843,629	80	309,027,770
2074	756,300	3,958,938	80	318,298,603
2075	756,300	4,077,706	80	327,847,561
2076	756,300	4,200,037	80	337,682,988
2077	756,300	4,326,038	80	347,813,478
2078	756,300	4,455,819	80	358,247,882
2079	756,300	4,589,494	80	368,995,318
2080	756,300	4,727,179	80	380,065,178
2081	756,300	4,868,994	80	391,467,133
2082	756,300	5,015,064	80	403,211,147
TOTAL			**1,608**	**6,178,726,619**

	Base cost of Individ well remediation	**Well cost adjusted for inflation**	**Assume 15% of wells Fail (15% × 670)**	**Total cost at 15% fail (C x D)**
	$	**$**	**Number of wells**	**$**
2083	756,300	5,165,516	101	519,134,352
2084	756,300	5,320,481	101	534,708,383
2085	756,300	5,480,096	101	550,749,634
2086	756,300	5,644,499	101	567,272,123
2087	756,300	5,813,834	101	584,290,287
2088	756,300	5,988,249	101	601,818,996
2089	756,300	6,167,896	101	619,873,565
2090	756,300	6,352,933	101	638,469,772
2091	756,300	6,543,521	101	657,623,866
2092	756,300	6,739,827	101	677,352,582
2093	756,300	6,942,021	101	697,673,159
2094	756,300	7,150,282	101	718,603,354
2095	756,300	7,364,791	101	740,161,454
2096	756,300	7,585,734	101	762,366,298
2097	756,300	7,813,306	101	785,237,287
2098	756,300	8,047,706	101	808,794,406
2099	756,300	8,289,137	101	833,058,238
2100	756,300	8,537,811	101	858,049,985
2101	756,300	8,793,945	101	883,791,484
2102	756,300	9,057,763	101	910,305,229

(3)

TOTAL			2,010	13,949,334,453

	Base cost of Individu well remediation $	Well cost adjusted for inflation $	Assume 20% of wells Fail (20% × 670) Number of wells	Total cost at 20% fail (C x D) $
2103	756,300	9,329,496	134	1,250,152,514
2104	756,300	9,609,381	134	1,287,657,090
2105	756,300	9,897,663	134	1,326,286,803
2106	756,300	10,194,593	134	1,366,075,407
2107	756,300	10,500,430	134	1,407,057,669
2108	756,300	10,815,443	134	1,449,269,399
2109	756,300	11,139,907	134	1,492,747,481
2110	756,300	11,474,104	134	1,537,529,905
2111	756,300	11,818,327	134	1,583,655,802
2112	756,300	12,172,877	134	1,631,165,476
2113	756,300	12,538,063	134	1,680,100,441
2114	756,300	12,914,205	134	1,730,503,454
2115	756,300	13,301,631	134	1,782,418,558
2116	756,300	13,700,680	134	1,835,891,114
2117	756,300	14,111,700	134	1,890,967,848
2118	756,300	14,535,051	134	1,947,696,883
2119	756,300	14,971,103	134	2,006,127,790
TOTAL			2,278	**27,205,303,633**
GRAND TOTAL			8,067	50,977,200,279

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Appendix 5 – Raw Excel Computations – Table 3 Fullbore Model – Existing NT Wells 2019 -2119

⑦

Year	Base cost of Individu well remediation $	Well cost adjusted for inflation	Assume 6% of wells Fail (6% × 235) Number of wells	Total cost at 6% fail (C x D) $
2019	756,300	778,989	1	778,989
2020	756,300	802,359	-	-
2021	756,300	826,429	1	826,429
2022	756,300	851,222	-	-
2023	756,300	876,759	1	876,759
2024	756,300	903,062	-	-
2025	756,300	930,154	1	930,154
2026	756,300	958,058	-	-
2027	756,300	986,800	1	986,800
2028	756,300	1,016,404	-	-
2029	756,300	1,046,896	1	1,046,896
2030	756,300	1,078,303	-	-
2031	756,300	1,110,652	1	1,110,652
2032	756,300	1,143,972	-	-
2033	756,300	1,178,291	1	1,178,291
2034	756,300	1,213,639	-	-
2035	756,300	1,250,049	1	1,250,049
2036	756,300	1,287,550	-	-
2037	756,300	1,326,177	1	1,326,177
2038	756,300	1,365,962	-	-
2039	756,300	1,406,941	1	1,406,941
2040	756,300	1,449,149	1	1,449,149
2041	756,300	1,492,623	1	1,492,623
2042	756,300	1,537,402	1	1,537,402
TOTAL			14	**16,197,311**

	Base cost of Individu well remediation $	Well cost adjusted for inflation	Assume 9 % of wells Fail (9% ×235) Number of wells	Total cost at 9% fail (C x D)
2043	756,300	1,583,524	1	1,583,524
2044	756,300	1,631,030	1	1,631,030
2045	756,300	1,679,961	1	1,679,961
2046	756,300	1,730,360	1	1,730,360
2047	756,300	1,782,270	1	1,782,270
2048	756,300	1,835,739	1	1,835,739
2049	756,300	1,890,811	1	1,890,811
2050	756,300	1,947,535	1	1,947,535
2051	756,300	2,005,961	1	2,005,961
2052	756,300	2,066,140	1	2,066,140
2053	756,300	2,128,124	1	2,128,124
2054	756,300	2,191,968	1	2,191,968
2055	756,300	2,257,727	1	2,257,727
2056	756,300	2,325,459	1	2,325,459
2057	756,300	2,395,223	1	2,395,223
2058	756,300	2,467,079	1	2,467,079
2059	756,300	2,541,092	1	2,541,092

2

2060	756,300	2,617,324	1	2,617,324
2061	756,300	2,695,844	1	2,695,844
2062	756,300	2,776,719	1	2,776,719
TOTAL			**20**	**42,549,890**

	Base cost of Individu well remediation $	**Well cost adjusted $ for inflation $**	**Assume 12% of wells Fail (12% × 235) Number of wells**	**Total cost at 12% fail (C x D) $**
2063	756,300	2,860,021		2,860,021
2064	756,300	2,945,822	1	2,945,822
2065	756,300	3,034,196	1	3,034,196
2066	756,300	3,125,222	1	3,125,222
2067	756,300	3,218,979	1	6,437,958
2068	756,300	3,315,548	2	3,315,548
2069	756,300	3,415,015	1	6,830,029
2070	756,300	3,517,465	2	3,517,465
2071	756,300	3,622,989	1	7,245,978
2072	756,300	3,731,679	2	3,731,679
2073	756,300	3,843,629	1	7,687,258
2074	756,300	3,958,938	2	3,958,938
2075	756,300	4,077,706	1	8,155,412
2076	756,300	4,200,037	2	4,200,037
2077	756,300	4,326,038	1	8,652,077
2078	756,300	4,455,819	2	4,455,819
2079	756,300	4,589,494	1	9,178,988
2080	756,300	4,727,179	2	9,454,358
2081	756,300	4,868,994	2	9,737,988
2082	756,300	5,015,064	2	10,030,128
TOTAL			**28**	**118,554,920**

	Base cost of Individu well remediation $	**Well cost adjusted for inflation $**	**Assume 15% of wells Fail (15% × 235) Number of wells**	**Total cost at 15% fail (C x D) $**
2083	756,300	5,165,516	1	5,165,516
2084	756,300	5,320,481	1	5,320,481
2085	756,300	5,480,096	1	5,480,096
2086	756,300	5,644,499	1	5,644,499
2087	756,300	5,813,834	1	5,813,834
2088	756,300	5,988,249	1	5,988,249
2089	756,300	6,167,896	2	12,335,792
2090	756,300	6,352,933	2	12,705,866
2091	756,300	6,543,521	2	13,087,042
2092	756,300	6,739,827	2	13,479,653
2093	756,300	6,942,021	2	13,884,043
2094	756,300	7,150,282	2	14,300,564
2095	756,300	7,364,791	2	14,729,581
2096	756,300	7,585,734	2	15,171,469
2097	756,300	7,813,306	2	15,626,613
2098	756,300	8,047,706	2	16,095,411
2099	756,300	8,289,137	2	16,578,273
2100	756,300	8,537,811	2	17,075,622
2101	756,300	8,793,945	2	17,587,890
2102	756,300	9,057,763	2	18,115,527

(3)

TOTAL			34	**244,186,021**

	Base cost of Individu well remediation $	Well cost adjusted for inflation $	Assume 20% of wells Fail (20% × 235) Number of wells	**Total cost at 20% fail** (C x D) $
2103	756,300	9,329,496	2	18,658,993
2104	756,300	9,609,381	2	19,218,763
2105	756,300	9,897,663	2	19,795,325
2106	756,300	10,194,593	2	20,389,185
2107	756,300	10,500,430	2	21,000,861
2108	756,300	10,815,443	2	21,630,887
2109	756,300	11,139,907	2	22,279,813
2110	756,300	11,474,104	3	34,422,311
2111	756,300	11,818,327	3	35,454,981
2112	756,300	12,172,877	3	36,518,630
2113	756,300	12,538,063	3	37,614,189
2114	756,300	12,914,205	3	38,742,615
2115	756,300	13,301,631	3	39,904,893
2116	756,300	13,700,680	3	41,102,040
2117	756,300	14,111,700	4	56,446,801
2118	756,300	14,535,051	4	58,140,205
2119	756,300	14,971,103	4	59,884,412
TOTAL			**47**	**581,204,903**

GRAND TOTAL			143	1,002,693,045

(60% fail over 100 yrs)