Produced Water Probabilistic Risk Assessment Framework – Disposal and Legacy Wells

SOUTHWEST RESEARCH INSTITUTE®

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Produced Water

Produced Water

- "Produced water is water trapped in underground formations that is brought to the surface during oil and gas exploration and production…
  - It may include water from the reservoir, water injected into the formation, and any chemicals added during the drilling, production, and treatment processes. Produced water can also be called 'brine', 'saltwater', or 'formation water.'"

[http://aqwatec.mines.edu/produced_water/intro/pw/index.htm]

- Hydraulic fracturing flowback fluid from oil and gas wells is treated as produced water for disposal purposes.

[https://www.rrc.texas.gov/about-us/resource-center/faqs/oil-gas-faqs/faq-injection-and-disposal-wells/]

Produced Water

- National produced water volume estimates from 2009 are in the range of 15 to 20 billion barrels (bbl; 1 bbl = 42 U.S. gallons) generated each year in the United States.
  - This is equivalent to a volume of 1.7 to 2.3 billion gallons per day.

[Clark, C. E., & Veil, J. A. (2009). Produced Water Volumes and Management Practices in the United States. Argonne, IL: Argonne National Laboratory.]

- Total volume of produced water estimated for 2012 is about 21.2 billion bbl.
- Texas represented 35% of this national total in 2012 with more than 7.4 billion bbl of produced water

[John Veil, Veil Environmental LLC. (April 2015). U.S. Produced Water Volumes and Management Practices in 2012. Prepared for the Ground Water Protection Council.]

Produced Water

webapps.rrc.state.tx.us/H10/searchVolume.do?sessionId=157037545962279

RRC ONLINE SYSTEM

H10 Filing System

H10 Public Main | Public Query Help

Injection Volumes

Injection Volume Query

Return To Search

Search Criteria:
- From:2018
- To:2019
- County:DIMMIT
- Commercial:Disposal into a nonproductive zone (W-14)

Year	BBLS/MCF	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2018	BBLS	2,772,675	3,298,511	4,209,994	3,756,959	3,915,684	3,964,316	3,747,211	4,122,496	3,628,895	3,623,909	3,883,805	3,917,006
	MCF	0	0	0	0	0	0	0	0	0	0	0	0
2019	BBLS	3,557,839	3,543,049	2,932,015									
	MCF	0	0	0									

Return To Search

Produced Water Management

- Produced water is the largest volume by-product or waste stream associated with oil and gas exploration and production.
- The cost of managing such a large volume of water is a key consideration to oil and gas producers.

[Clark, C. E., & Veil, J. A. (2009). Produced Water Volumes and Management Practices in the United States. Argonne, IL: Argonne National Laboratory.]

Produced Water Management

- Produced water management practices vary widely across the United States and in some instances across a single oil and gas field.
  - Water treatment
  - Enhanced recovery
  - Deep well injection
  - Sustainable development practices
  - Water reduction (like downhole oil/water separation)
  - Beneficial uses (water with TDS 10,000 ppm or less may be employed for beneficial uses)

[Interstate Oil and Gas Compact Commission and ALL Consulting. (2006). A Guide to Practical Management of Produced Water from Onshore Oil and Gas Operations in the United States. Prepared for: U.S. Department of Energy, National Petroleum Technology Office]

Probabilistic Risk Assessment (PRA)

Probabilistic Risk Assessment (PRA)

- Probabilistic Risk Assessment (PRA) is a comprehensive, structured, and logical analysis method aimed at identifying and assessing **risks** in complex technological systems for the purpose of cost-effectively improving their **safety** and **performance**.
  - Single, low-probability and high-consequence mishap events, and
  - High-consequence scenarios resulting from occurrence of multiple high-probability and low consequence or nearly benign events.

[Stamatelatos and Dezfuli (2011). Probabilistic Risk Assessment Procedures: Guide for NASA Managers and Practitioners. Washington, DC: NASA]

PRA - Risk

- Risk includes undesirable consequences and likelihoods
- Production of probability distributions for consequences provides a detailed description of risk
- Common definition of risk is to use:
  - **Scenarios**
  - **Likelihoods**
  - **Consequences**
- Determination of risk through answers to three questions:
  - What can go wrong? (Scenarios or Hazards)
  - How likely is it? (Likelihood == Probability)
  - What are the associated consequences?

[Stamatelatos and Dezfuli (2011)]

PRA - Fault Trees

- Provide the means to answer –
  - What can go wrong? (**Scenarios** or Hazards)
  - How likely is it to occur? (**Likelihood** == Probability)
- Fault Tree Analysis (FTA) is an analysis technique where the fault, or undesired, state is specified and the entire system is analyzed to find all realistic ways in which the fault can occur.
  - Provides a graphic model of parallel and sequential combinations of multiple events that are required to produce the fault or failure.
  - Depicts the logical interrelationships of basic events that lead to the undesired event, the top event of the fault tree.
- Faults, or failures, can be events that are associated with component mechanical failures, human errors, software errors, or any other pertinent events which can lead to the undesired event.

[Stamatelatos, M., & Caraballo, J. (2002). Fault Tree Handbook with Aerospace Applications. Washington, DC: NASA]

PRA – Fault Trees

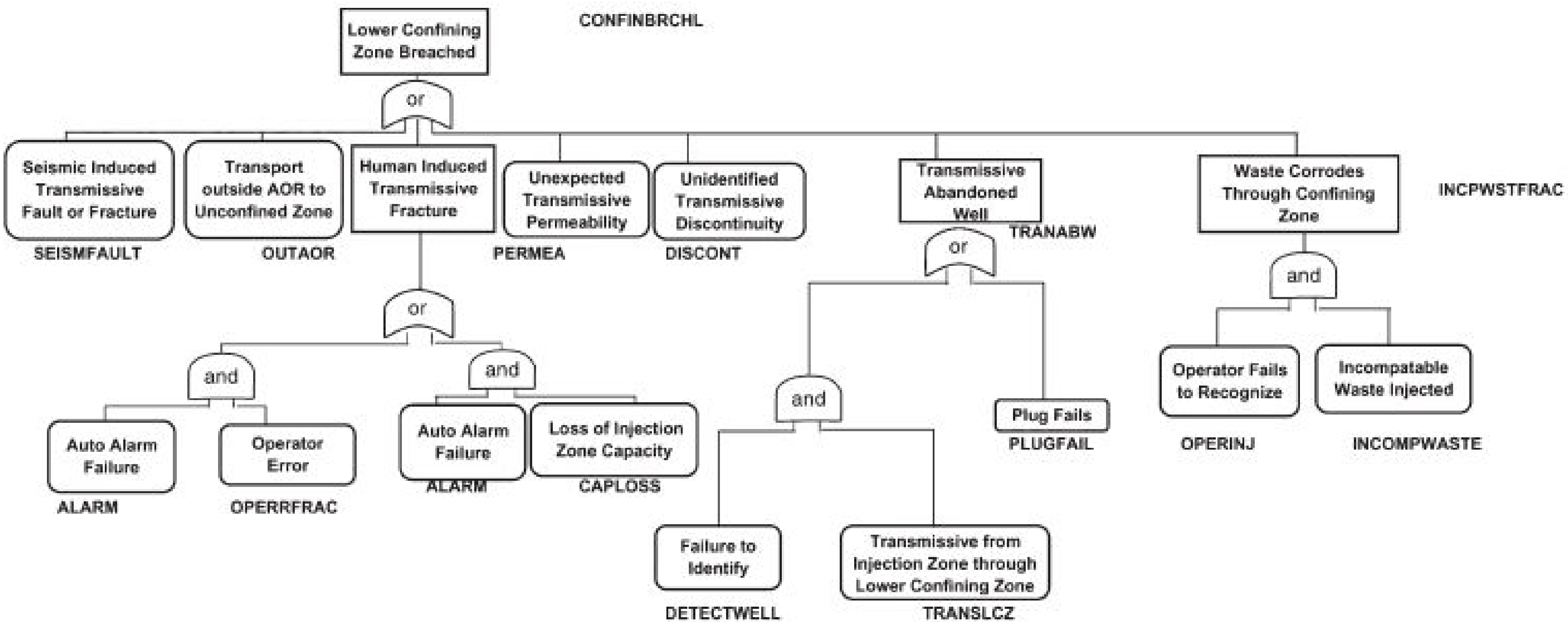


Fig. 10.4. Fault tree for a lower confining zone breach in a Class I hazardous waste injection well.

[Rish, W. R. (2005). A Probabilistic Risk Assessment of Class I Hazardous Waste Injection Wells. In C.-F. Tsang, & J. A. Apps, Underground Injection Science and Technology (pp. 93-135). Elsevier.]

PRA - Consequences

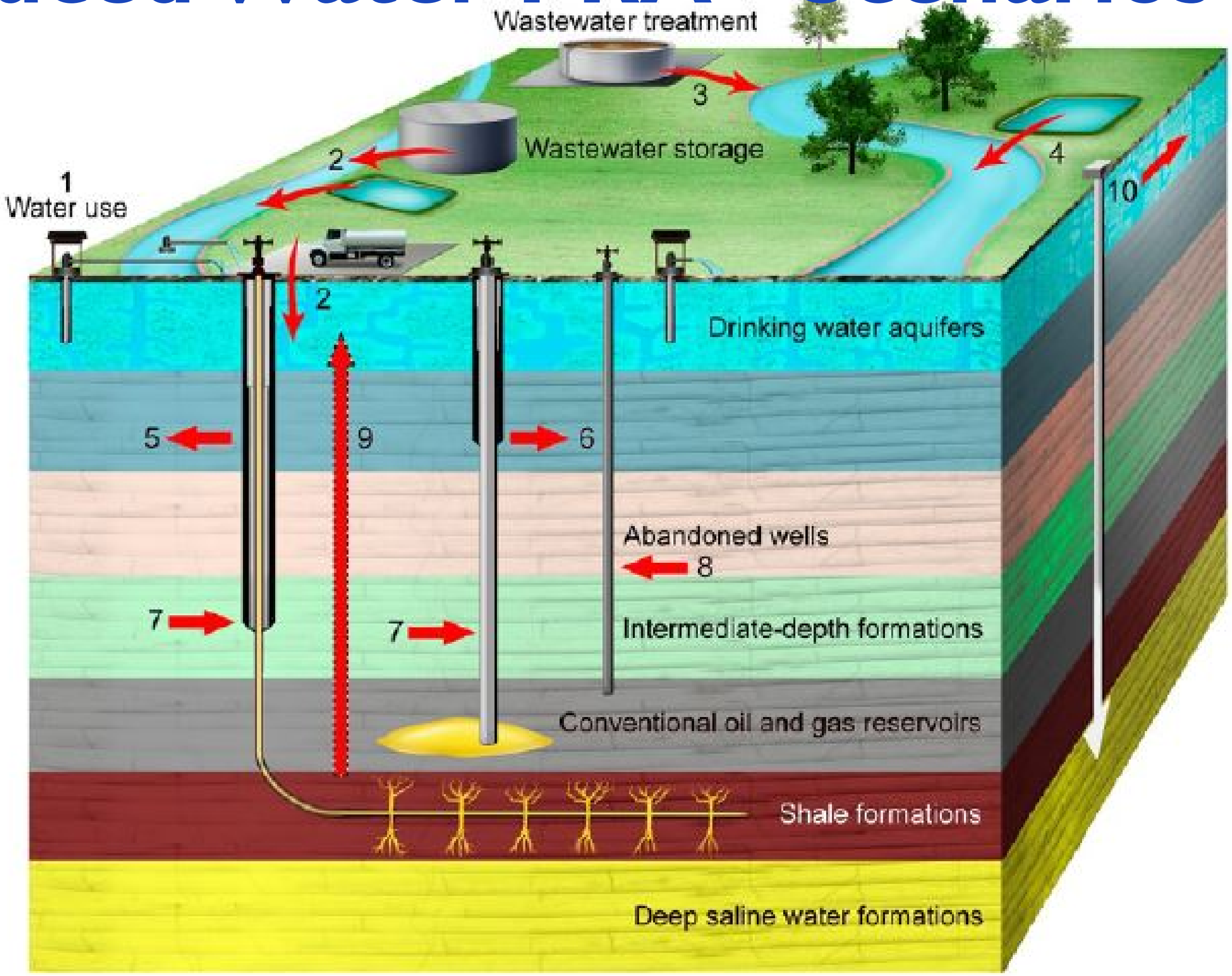
- Consequences are the undesirable outcomes that can result from faults or failures
- The goal for a PRA is to produce a probability distribution for the consequences
  - Risk management involves the prevention or at least reduction in frequency of scenarios with undesirable consequences
  - One way to compare consequences is to allocate costs and use total cost as the metric
- For produced water, engineered systems –
  - Release of produced water or partially treated water to the biosphere is the top level failure/fault
  - Consequences are the resulting contamination, toxicity and any physical damage from the discharge

Produced Water PRA

Produced Water PRA

- Project Goal: PRA for the entire produced water lifecycle – from the production well to disposal, treatment, recycling, or beneficial use
  - This project has effectively just started
  - Partial funding from SwRI internal R&D grant

Produced Water PRA - Scenarios



[Vengosh, A., Jackson, R. B., Warner, N., Darrah, T. H., & Kondash, A. (2014). A Critical Review of the Risks to Water Resources from Unconventional Shale Gas Development and Hydraulic Fracturing in the United States. Environmental Science & Technology, 48, 8334-8348.]

Produced Water PRA - Scenarios

- Vengosh et al. (2014) provide 10 shale gas development water hazards
  1. Overuse of water leading to depletion and water-quality degradation of potable water sources
  2. **Surface water and shallow groundwater contamination from spills and leaks from storage and pits**
  3. **Disposal of inadequately treated wastewater to surface water sources**
  4. **Leaks of storage ponds**

  5. - 7. Shallow aquifer contamination by stray gas and brine from production wells

  8. **Aquifer contamination via abandoned wells**
  9. Flow of gas and saline waters from deep target horizons to shallow potable water sources
  10. **Aquifer contamination through leaking of injection wells**

Produced Water PRA - Scenarios

Truck Transport and Traffic

- In the Bakken shale area, 95% of saline wastewater is piped or trucked onsite prior to injection well disposal. Spills during transport may be more likely to contaminate drinking water resources

[Shrestha, N., Chilkoor, G., Wilder, J., Gadhamshetty, V., & Stone, J. J. (2017). Potential water resource impacts of hydraulic fracturing from unconventional oil production in the Bakken shale. Water Research, 108, 1-24.]

- Trucking of produced water from production to disposal has increased truck traffic in rural areas of Texas which has led to traffic-related safety concerns

[Galbraith, K. (2013, March 29). Water for Fracking: As Fracking Proliferates, So Do Disposal Wells. Texas Tribune.]

Produced Water PRA - Scenarios

Flowlines and Pipelines

- In a four state study, 50% of produced water spills were related to storage and moving fluids via flowlines.

[Patterson et al. (2017). Unconventional Oil and Gas Spills: Risks, Mitigation Priorities, and State Reporting Requirements. Environmental Science & Technology, 51, 2563-2573.]

- Steel pipelines carrying produced water and all steel pipe involved with produced water handling are vulnerable to corrosion.
  - High TDS in produced water thought to result in failure of corrosion inhibitors
  - High salinity in produced water can result in pitting corrosion of pipes

[Shrestha et al. (2017)]

Produced Water PRA - Consequences

Contamination and Toxicity

- Produced water spills can "foul the land, kill wildlife and threaten freshwater supplies "
- Wastewater spills can be more damaging than oil spills
  - Microbes may eventually degrade spilled oil
  - Salt-saturation causes the land to dry out, kills trees and prevents crops from growing
  - Brine spills often contain heavy metals like arsenic and mercury and there is anecdotal evidence for heavy metal tainted grass killing cattle

[Flesher, J. (2015, September 12). Drilling Boom brings rising number of harmful waste spills: Spills of salty wastewater from oil extraction have surged, leaving behind fouled land and water. Associated Press in Minneapolis Star Tribune.]

Produced Water PRA - Consequences

Contamination and Toxicity

- At least one instance of a Texas produced water disposal well contaminating an aquifer.
  - Leak from disposal well contaminated Pecos River Cenozoic Alluvium in 2005.

[Galbraith (29 March 2013)]

- Inorganic contamination associated with brine spills in North Dakota have been observed to be persistent with elevated levels of contaminants for up to four years

[Lauer, N. E., Harkness, J. S., & Vengosh, A. (2016). Brine Spills Associated with Unconventional Oil Development in North Dakota. Environmental Science & Technology, 50, 5389-5397.]

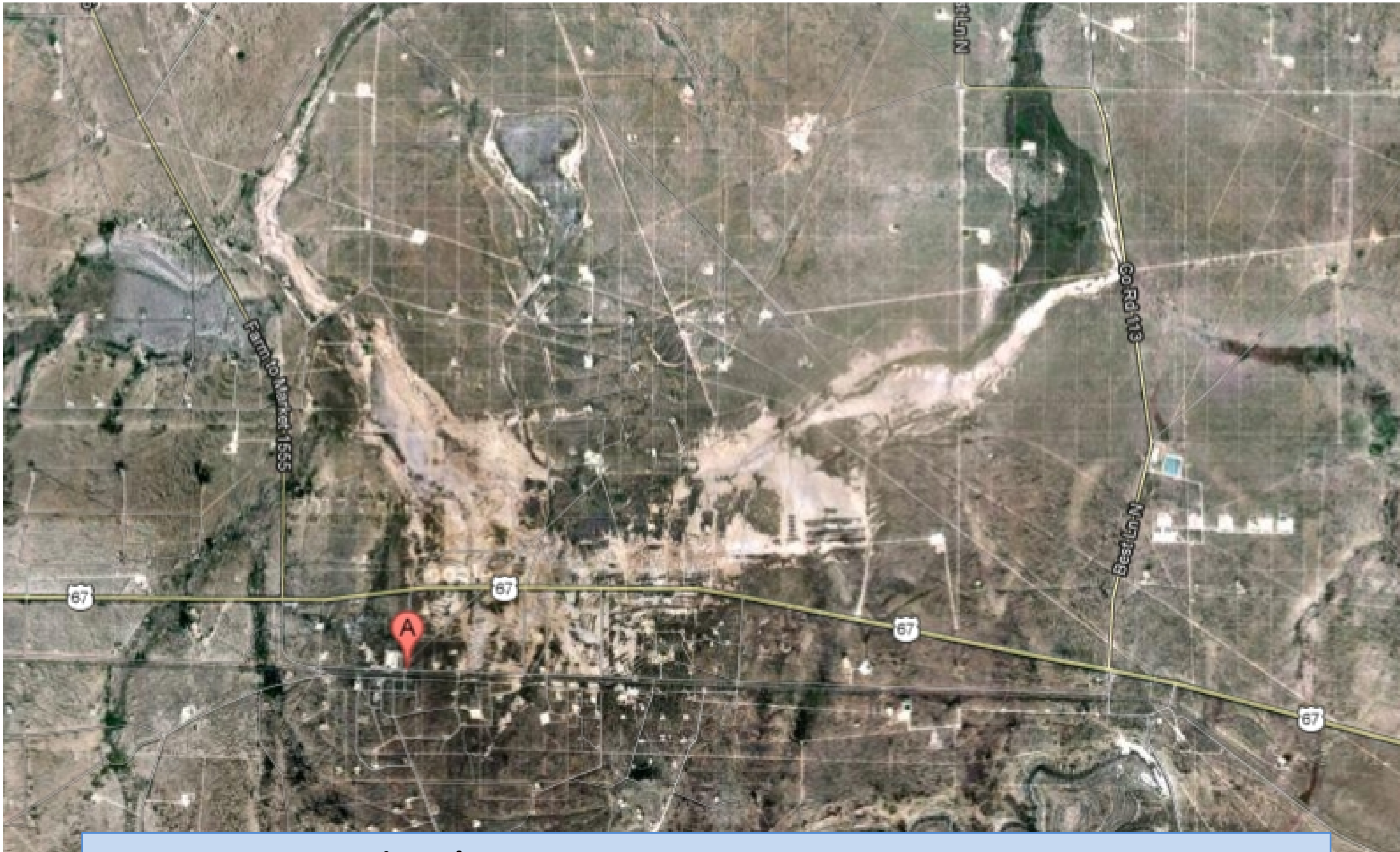
Produced Water PRA - Consequences

Contamination and Toxicity

- Anecdotal reports of salt kills and brine flowing in bar ditches from produced water which attributes these observations to unknown and unplugged, abandoned wells

- Observed high TDS hot spots in groundwater conservation district (GCD) monitoring that are thought to be related to abandoned wells (either failed plug or no plug) in conjunction with produced water disposal
  - TDS elevated beyond drinking water standards

Produced Water PRA - Consequences



Texon Scar near Big Lake, TX [https://gardap.wordpress.com/2012/08/08/texon-scar-near-big-lake-tx/]

Produced Water Disposal PRA

Produced Water PRA – Disposal PRA

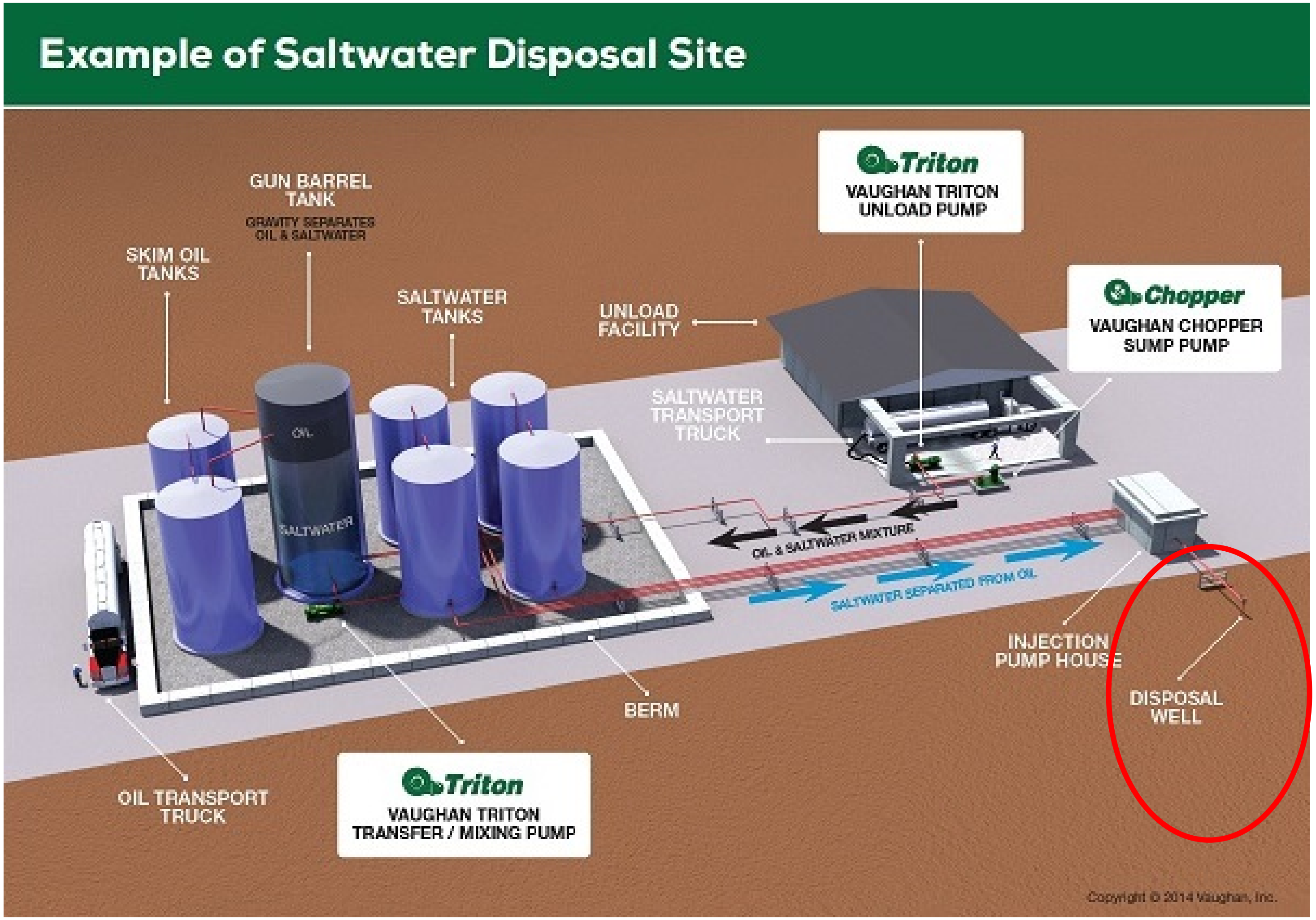
- Project Goal: PRA for the entire produced water lifecycle – from the production well to disposal, treatment, recycling, or beneficial use
- Step I: PRA for produced water disposal
  - Template: an existing PRA for hazardous waste disposal using deep injection wells

[Rish, W. R. (2005). A Probabilistic Risk Assessment of Class I Hazardous Waste Injection Wells. In C.-F. Tsang, & J. A. Apps, Underground Injection Science and Technology (pp. 93-135). Elsevier.]

  - Modify this template to represent produced water disposal wells
  - Add failure trees for "surface facilities" or everything that is not the disposal well

FUTURE WORK

Produced Water Disposal PRA



[http://www.chopperpumps.com/applications/salt-water-disposal/]

Saltwater Disposal Well (SDW) PRA

Saltwater Disposal Well (SDW) PRA

- Project Goal: PRA for the entire produced water lifecycle – from the production well to disposal, treatment, recycling, or beneficial use
- Step I: PRA for produced water disposal
  - Template: an existing PRA for hazardous waste disposal using Class I deep injection wells

[Rish, W. R. (2005)

  - Modify this template to represent produced water disposal wells
  - This modified PRA is the saltwater disposal well (SDW) PRA

Class I Injection Wells

- Safe Drinking Water Act (SDWA) was passed in 1974
  - Class I: inject hazardous and non-hazardous fluids below any underground sources of drinking water (USDW)
  - Class II: SDWs - inject brine fluids associated with oil and gas production
- Class I and II differentiated because large volume "special wastes" from exploration and production, including produced water, are lower in toxicity
  - "The exemption does not mean these wastes could not present a hazard to human health and the environment if improperly managed. p 5"

[U.S. Environmental Protection Agency (EPA). (2002). Exemption of Oil and Gas Exploration and Production Wastes from Federal Hazardous Waste Regulation. Washington, DC: U.S. EPA.]

Class I Injection Wells

- Class I underground injection wells are considered safe and reliable.
- Rish (2005) produced a PRA for Class I underground injection wells.
  - "Because of the conservative assumptions used for failure event probabilities and the explicit treatment given to uncertainties in this analysis, we believe that the risk of loss of waste isolation from Class IH wells is less than 10−6.
  - The low risk is due in large measure to the use of redundant engineered systems and geology to provide multiple and diverse barriers to prevent release of waste to the accessible environment. P. 120"

[Rish, W. R. (2005). A Probabilistic Risk Assessment of Class I Hazardous Waste Injection Wells. In C.-F. Tsang, & J. A. Apps, Underground Injection Science and Technology (pp. 93-135). Elsevier.]

SDW PRA

- How do produced water disposal wells, or saltwater disposal wells (SDW), compare to Class I injection wells?
  - Overall technical standards are similar
  - Technical differences:
    - Class I injection wells have continuous and automated pressure monitoring with alarms and in Texas operators of SDW wells have to report monthly maximum pressures, annually
    - In Texas, disposal interval needs to be sealed above and below by unbroken, impermeable rock layers; Class I injection location needs to be separated by a minimum of two (2) extensive confining units from USDW
  - Permitting standards are similar between Class I and Class II wells as a result of EPA delegation of permitting authority to state entities

SDW PRA – Scenarios and Event Trees

- Class I Injection Well PRA has seven initiating events or event trees that can culminate in a failure. Each event tree may include events that are described with a fault tree.
  - Class I injection wells are highly engineered systems with redundant safety systems which is why event trees are used

1. Packer leak
2. Major packer failure
3. Injection tube leak
4. Major injection tube failure
5. Cement microannulus leak
6. Confining zones breach — SDW PRA Focus
7. Inadvertent injection zone extraction

[Rish, W. R. (2005)

SDW PRA - Scenarios

- Disposal well portion of the site includes these water hazards:

  8. Aquifer contamination via abandoned wells

  – **This has to be extended include surface releases**

  10. Aquifer contamination through leaking of injection wells

- Leaking of the injection wells is assumed to be the lesser risk
- Texas has a surplus of abandoned wells
  - There are at least 5,987 improperly abandoned orphan wells that lack a responsible owner

  [Jackson, R. B., Vengosh, A., Carey, J. W., Davies, R. J., Darrah, T. H., O'Sullivan, F., et al. (2014). The Environmental Costs and Benefits of Fracking. Annual Review of Environment and Resources, 39, 327-362.]

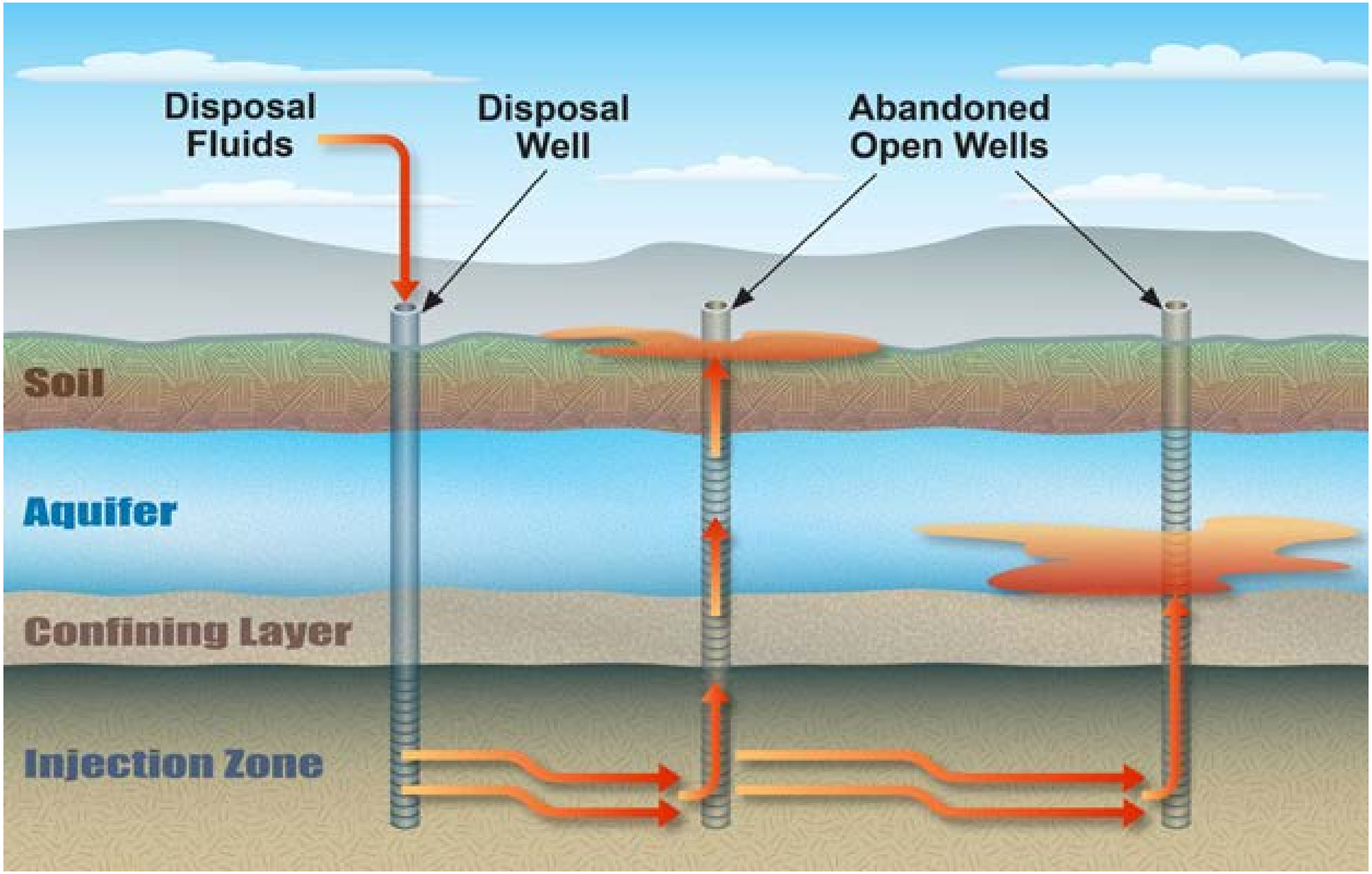
  - No guarantee that locations of all abandoned wells are known

SDW PRA Scenarios – Abandoned Wells

- RRC's 2018 oil field cleanup report:
  - More than 13,700 inactive and unplugged wells as of Aug. 2018
  - More than 4,600 inactive and unplugged wells in Eagle Ford
- RRC spent $34.9 million to plug 1,700 abandoned oil and gas wells during 9/2018 – 8/2019
  - Plugging of 1,700 up from 1,300 plugged in previous one year period
  - Plugging of 1,700 also exceeded the goal of 979 set by Texas Legislature
- "There are also an unknown number of abandoned wells for which the state has no records."

[Corso, J. (2019, September 23). Texas spent millions closing abandoned wells during recent fiscal year. San Antonio Business Journal.]

SDW PRA Scenarios – Abandoned Wells



SDW PRA – Event Trees

- SDW not typically continuous annulus pressure monitoring with automated alarms
- SDW only one impermeable confining zone required above the injection zone between injection zone and lowermost USDW
  - No buffer zone for monitoring

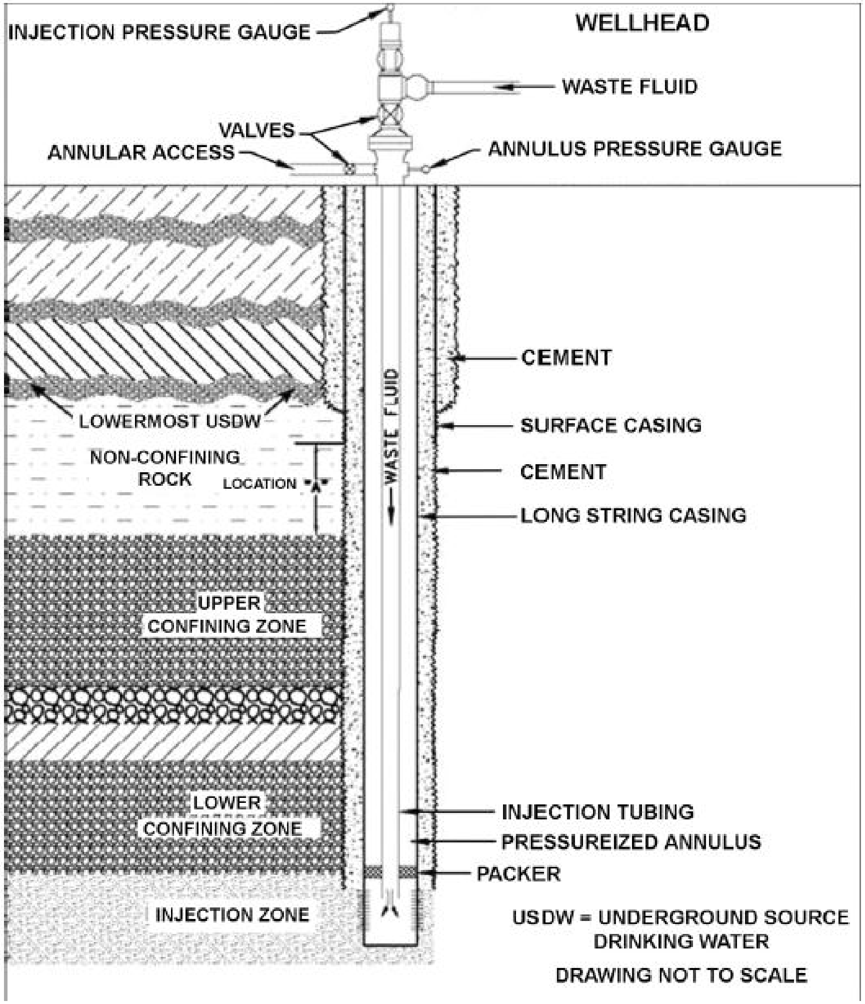


Fig. 10.1. Simplified Class I injection well system assumed for PRA.

[Rish, W. R. (2005)

SDW PRA – Event Trees

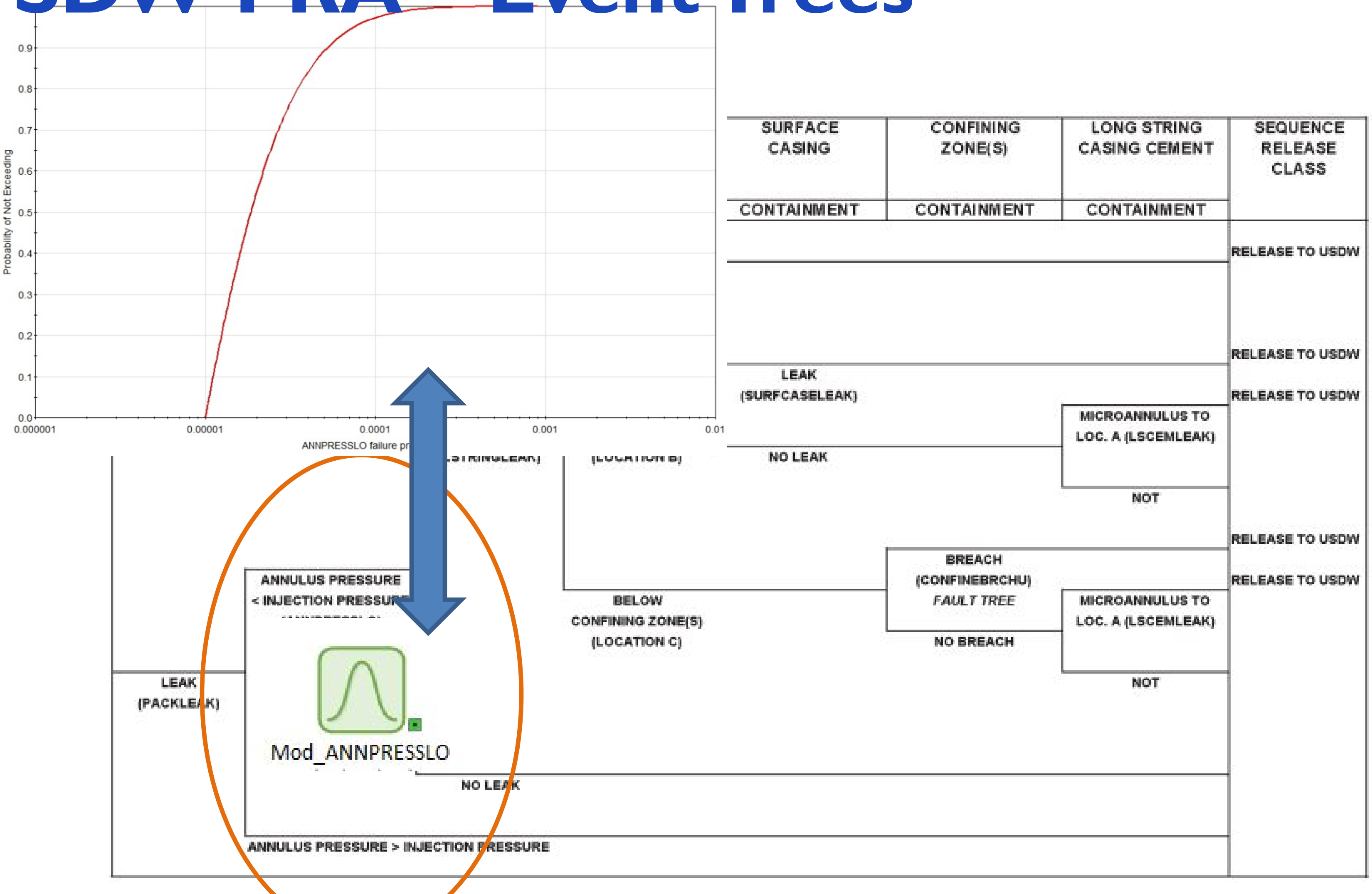


Fig. 10.6. Event tree for an injection tube failure in a Class I hazardous waste injection well.

1. Packer leak event tree from Rish (2005) modified for different annulus pressure

SDW PRA – Event Trees

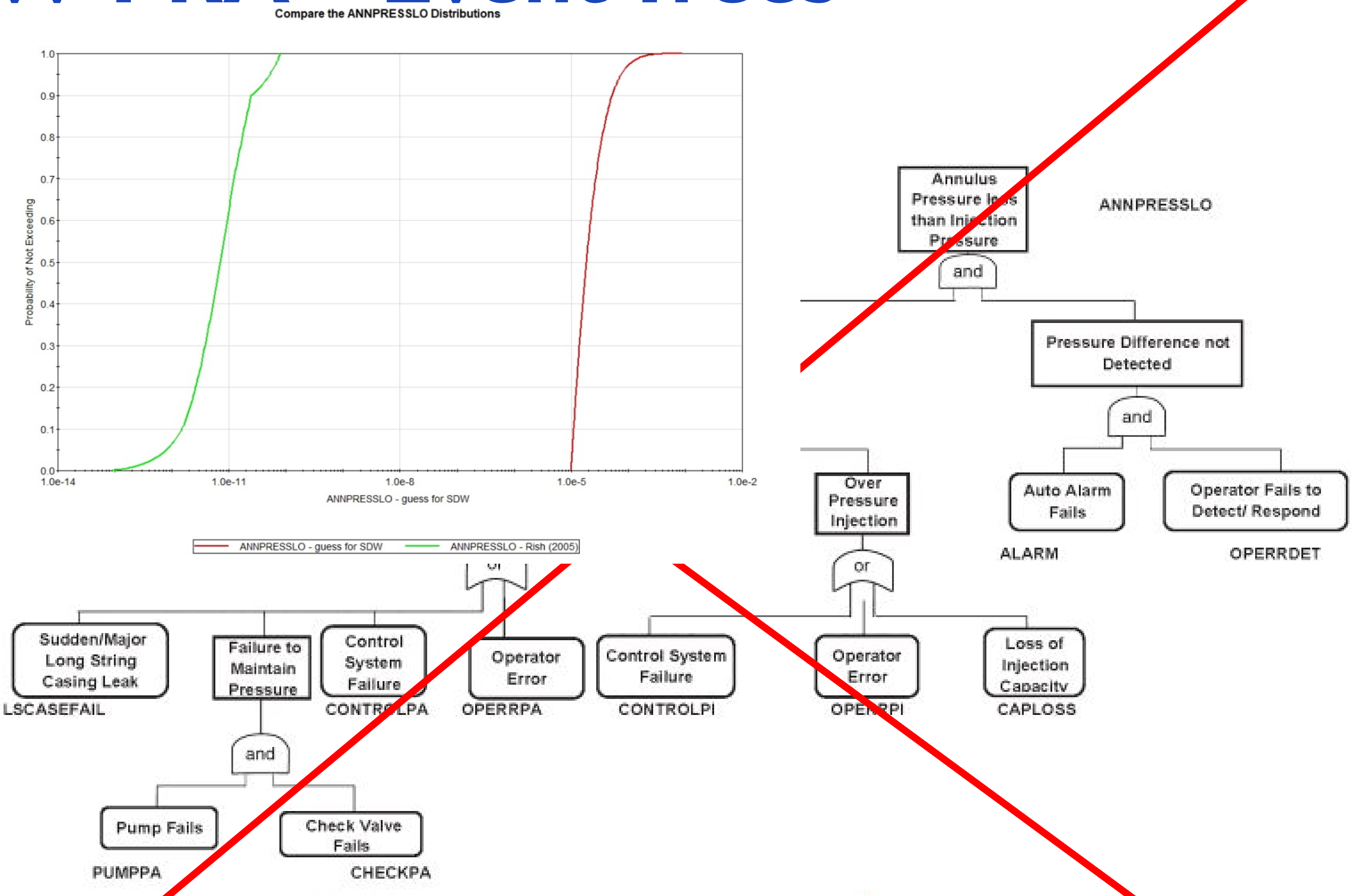


Fig. 10.3. Fault tree for an annulus pressure barrier failure in a Class I hazardous waste injection well.

Annulus pressure barrier fault tree not applicable to SDW and replaced with probability distribution for failure

SDW PRA – Event Trees

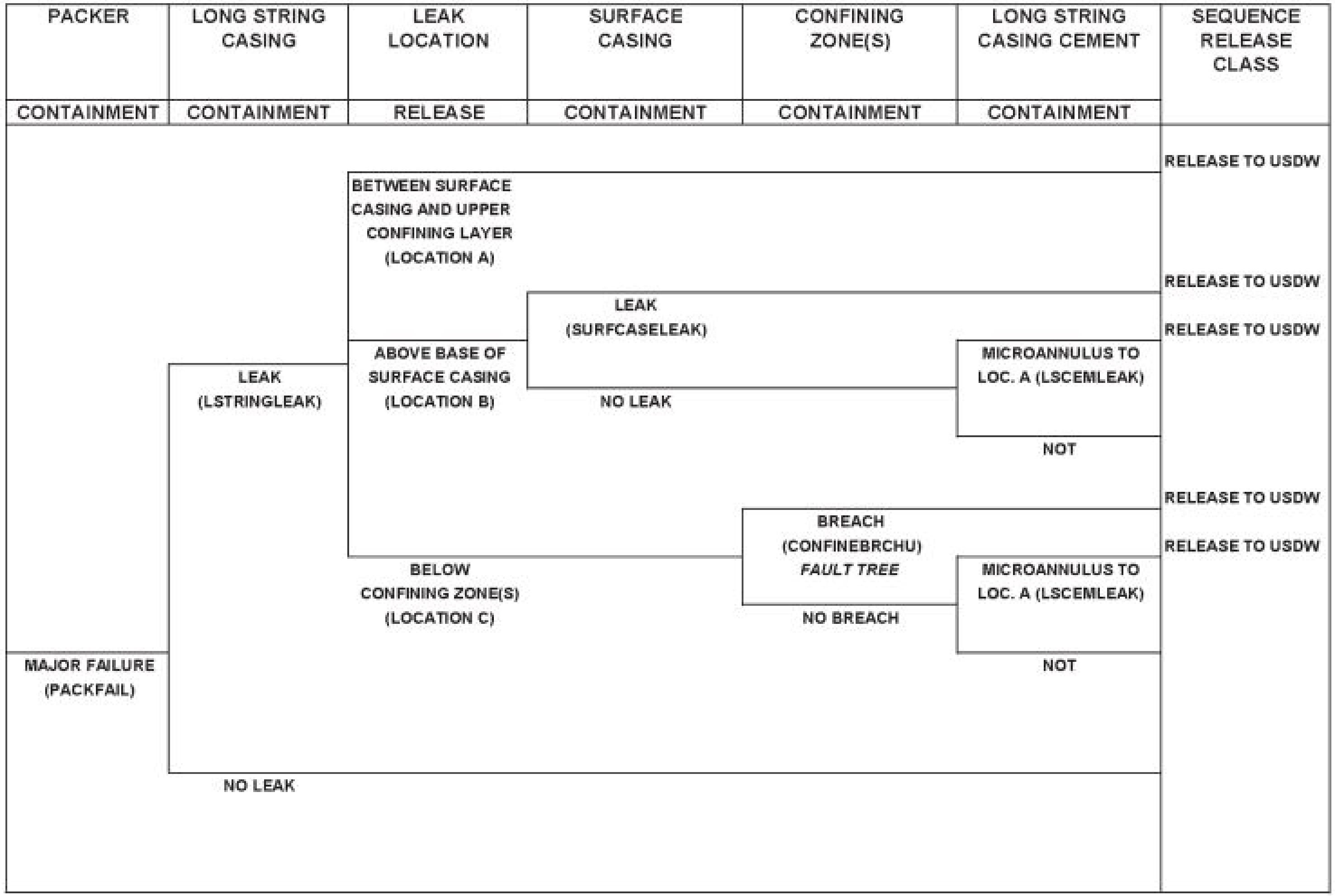


Fig. 10.7. Event tree for major injection tube failure in a Class I hazardous waste injection well.

2. Packer failure event tree from Rish (2005), unmodified

SDW PRA – Event Trees

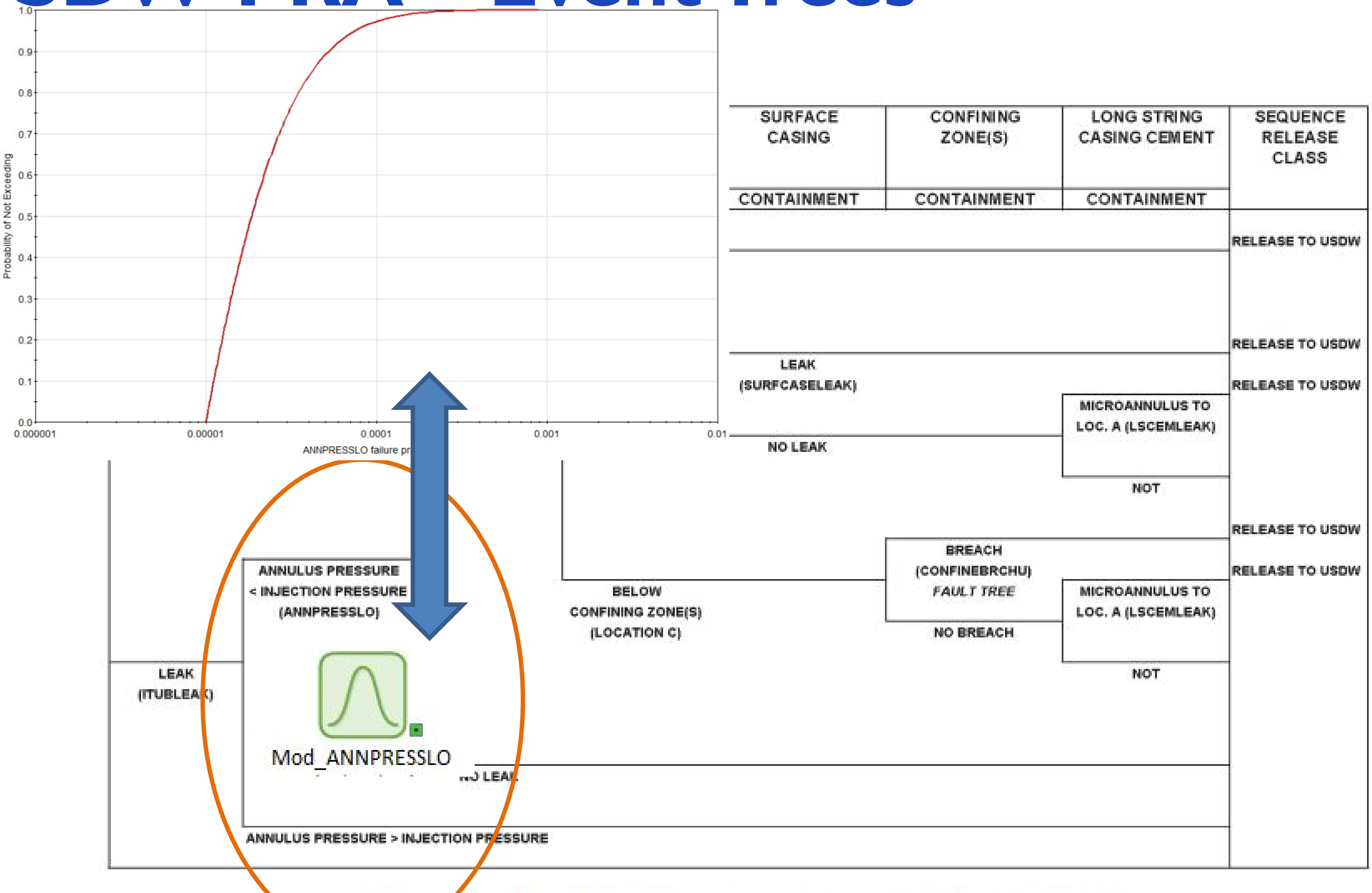


Fig. 10.2. Event tree for packer leak in a Class I hazardous waste injection well.

3. Injection tube leak event tree from Rish (2005), modified for annulus pressure

SDW PRA – Event Trees

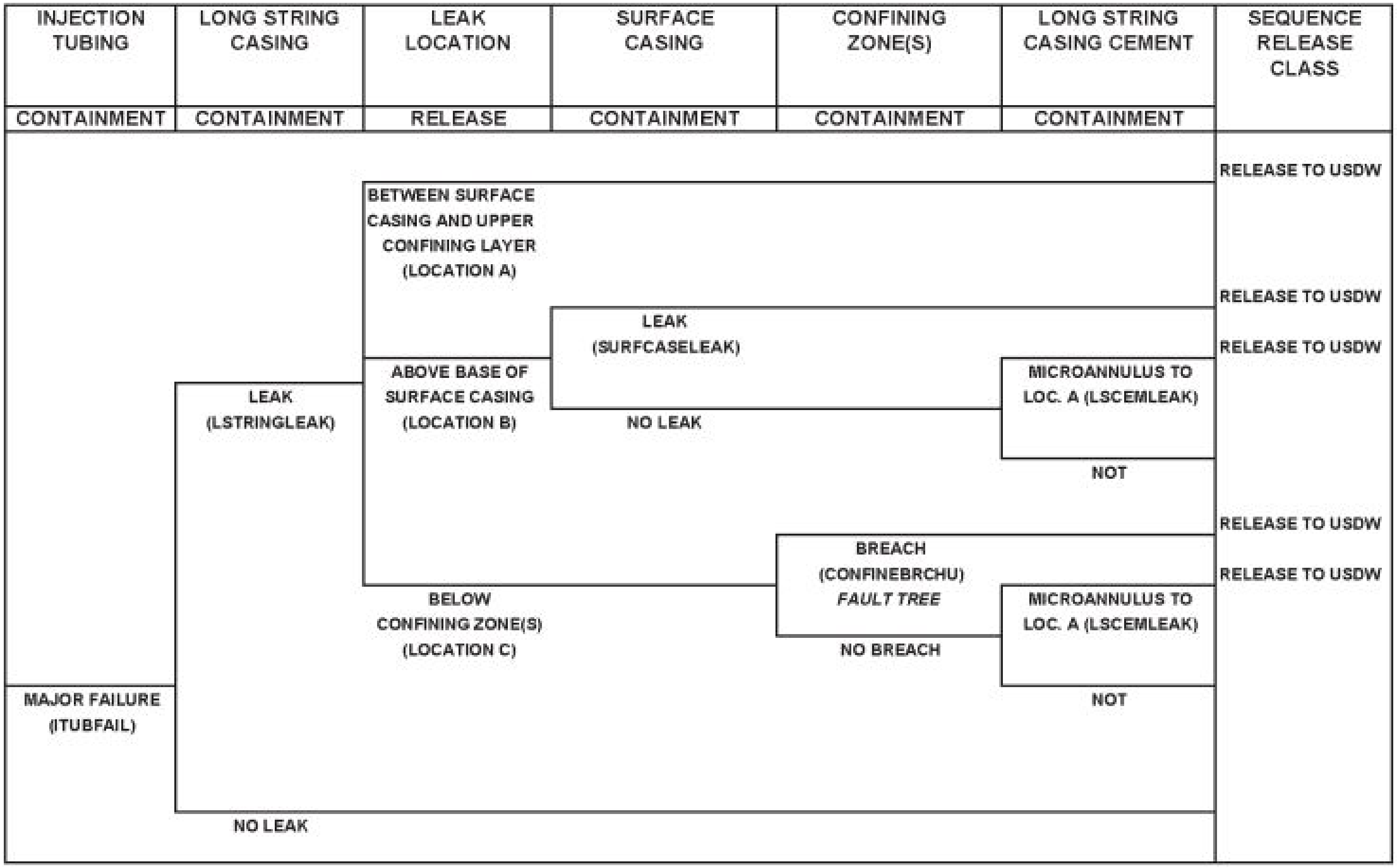


Fig. 10.5. Event tree for a major packer failure in a Class I hazardous waste injection well.

4. Injection tube failure event tree from Rish (2005), unmodified

SDW PRA – Event Trees

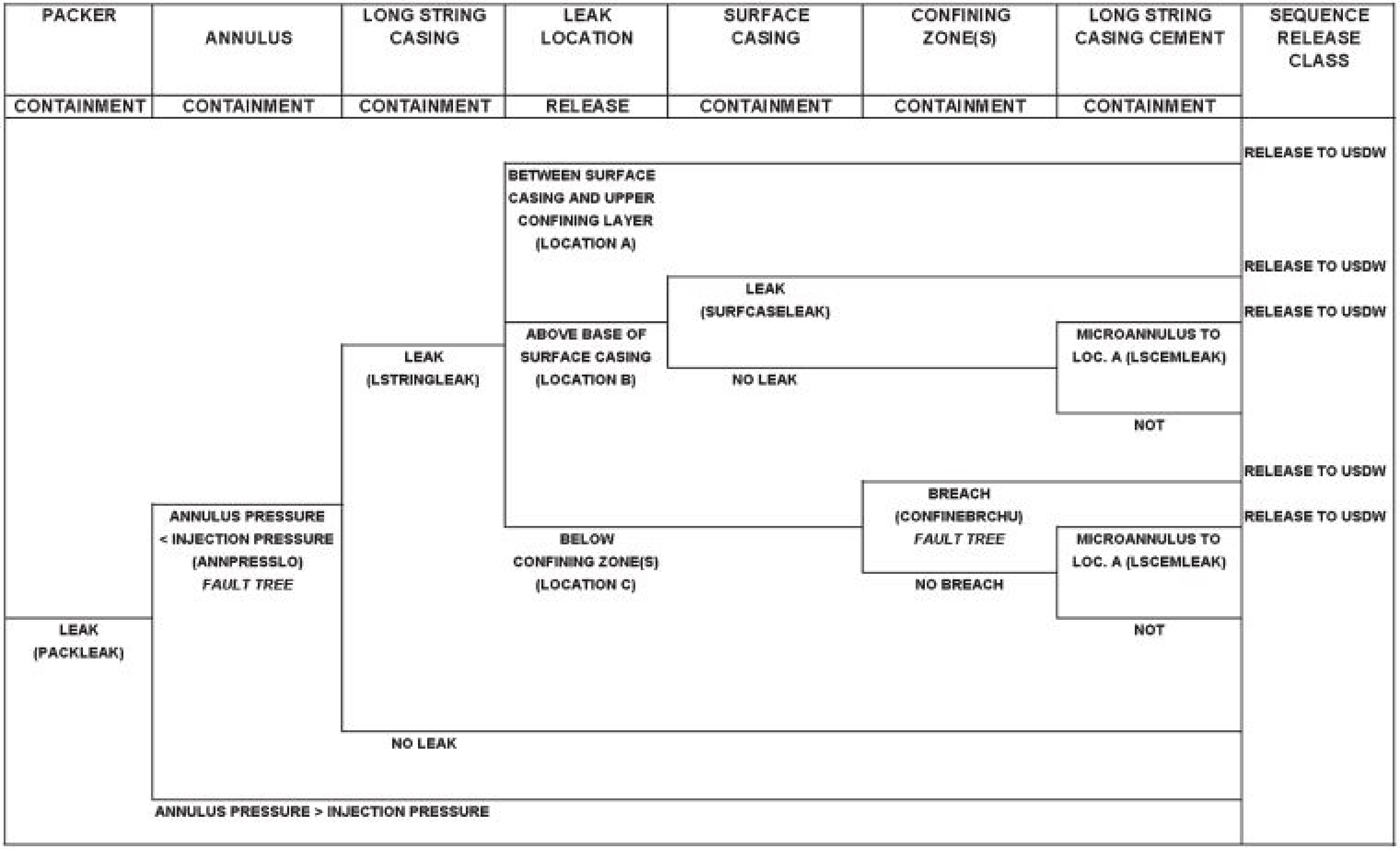


Fig. 10.6. Event tree for an injection tube failure in a Class I hazardous waste injection well.

5. Cement microannulus leak event tree from Rish (2005), unmodified

SDW PRA – Event Trees

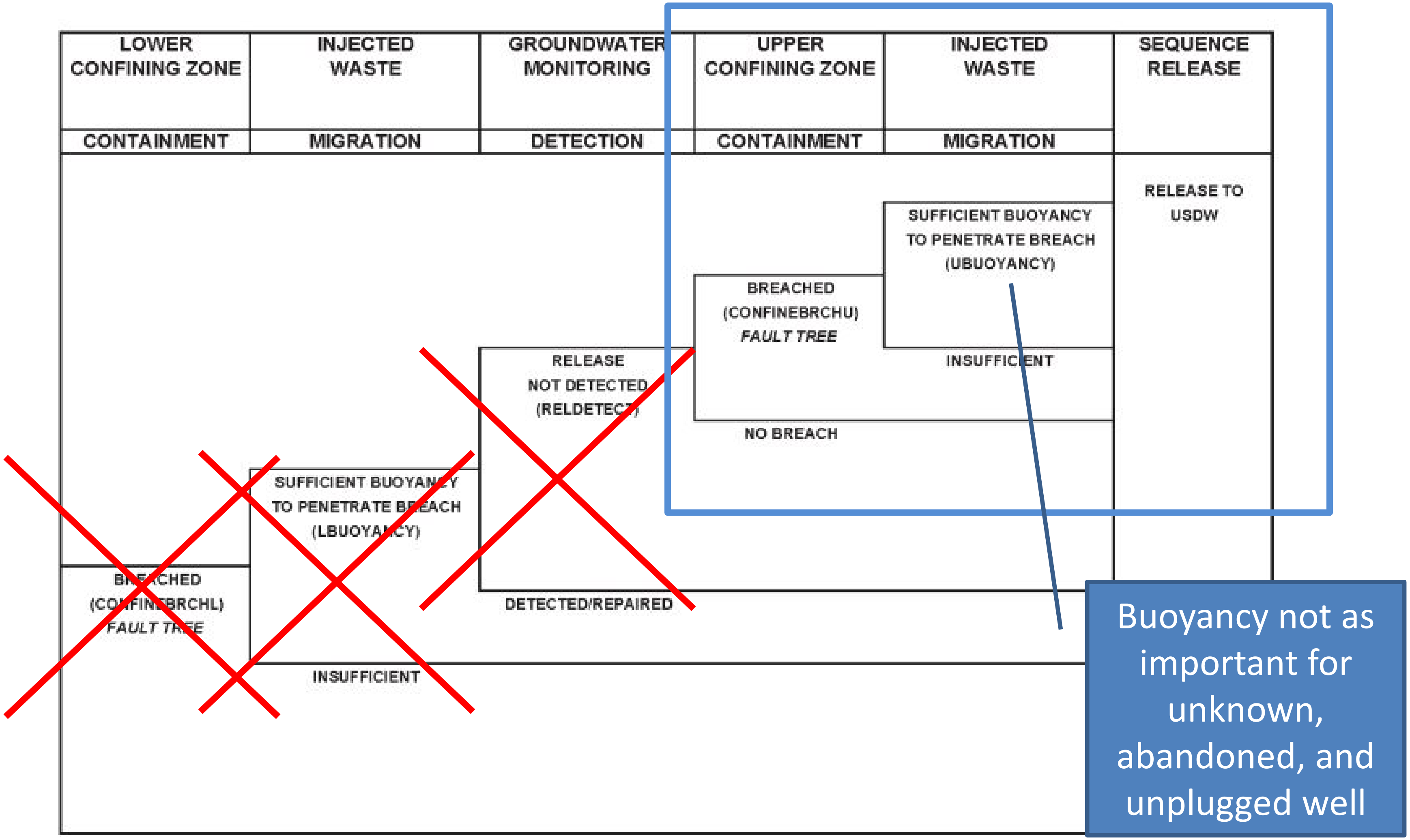
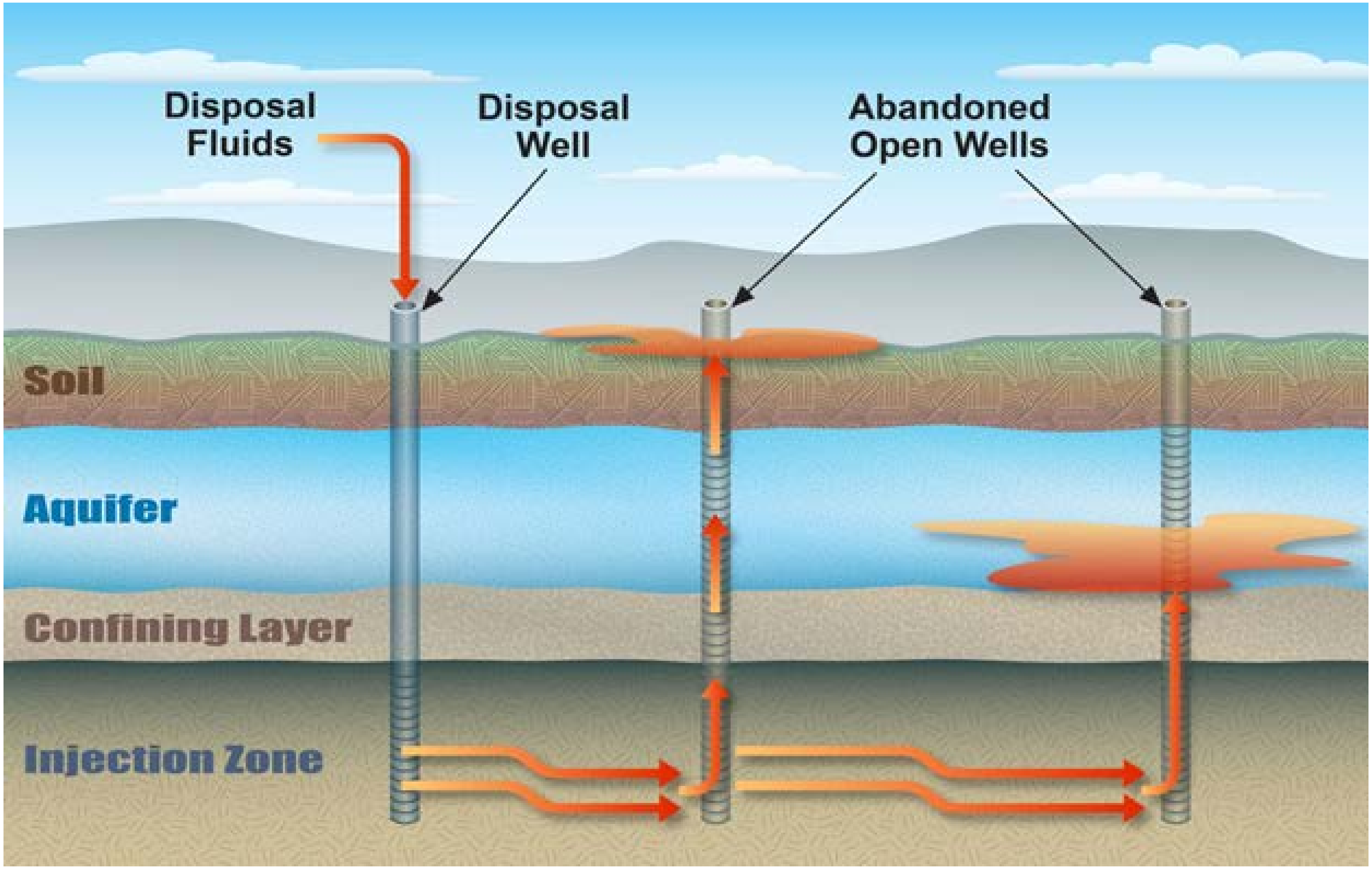


Fig. 10.10. Event tree for lower and upper confining zone breaches in a Class I hazardous waste injection well.

6. Confining zones breach event tree from Rish (2005) modified to only upper

SDW PRA – Abandoned Wells



SDW PRA – Event Trees

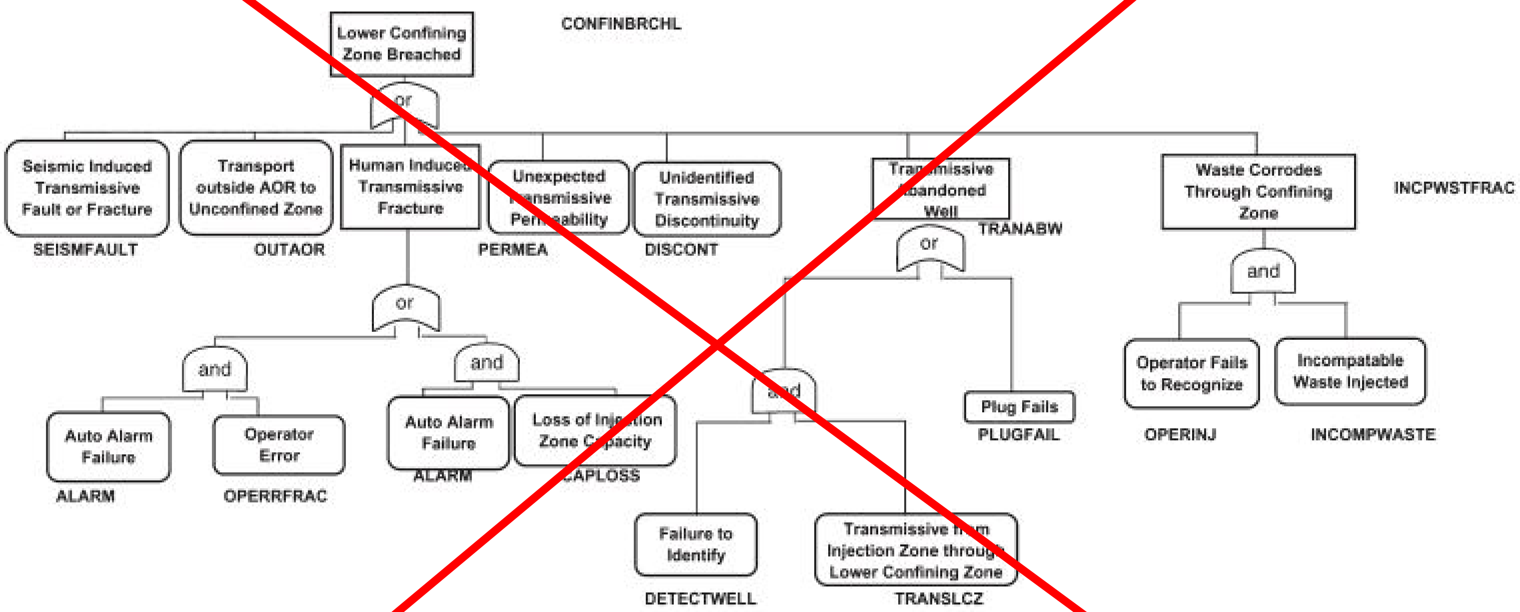


Fig. 10.4. Fault tree for a lower confining zone breach in a Class I hazardous waste injection well.

Lower of at least 2 confining zones (between injection and base of USDW) removed from the SDW PRA

SDW PRA – Event Trees

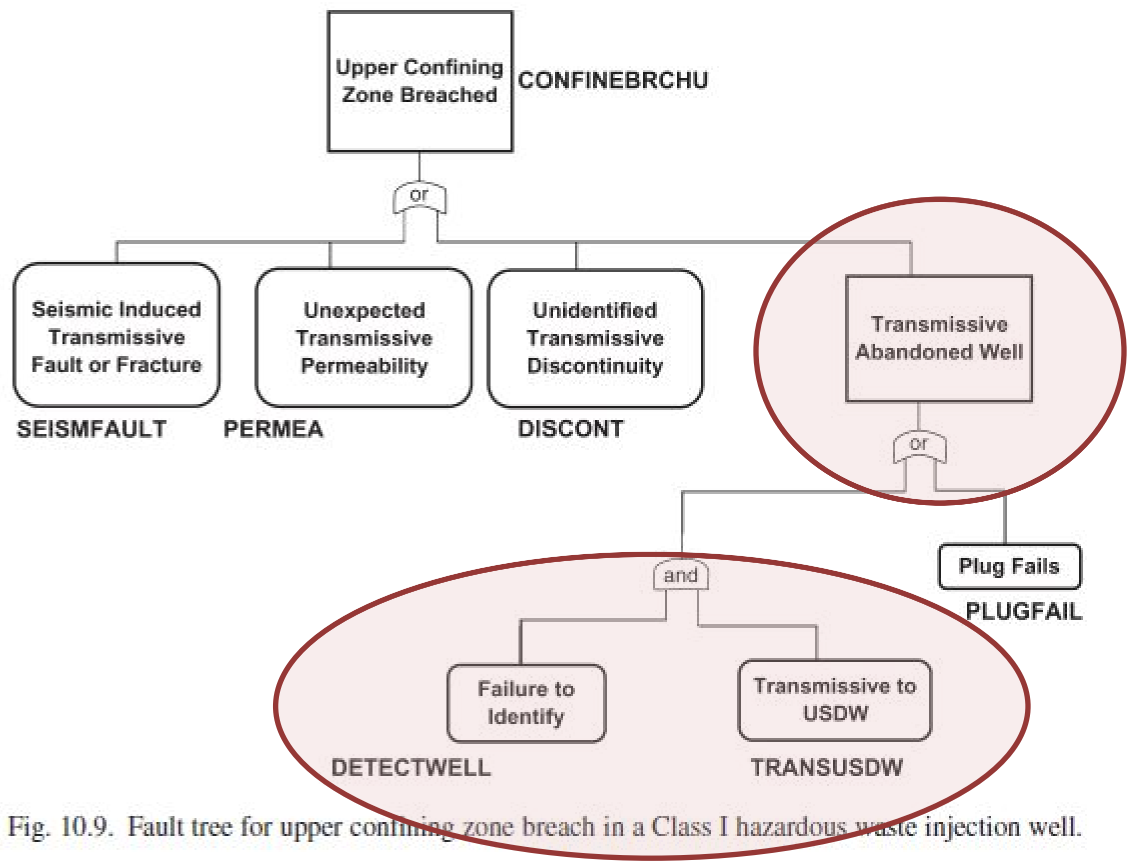


Fig. 10.9. Fault tree for upper confining zone breach in a Class I hazardous waste injection well.

Fault tree for upper confining zone breach from Rish (2005). In the SDW PRA, the failure to identify a transmissive, abandoned well will be the most important

SDW PRA – Event Trees

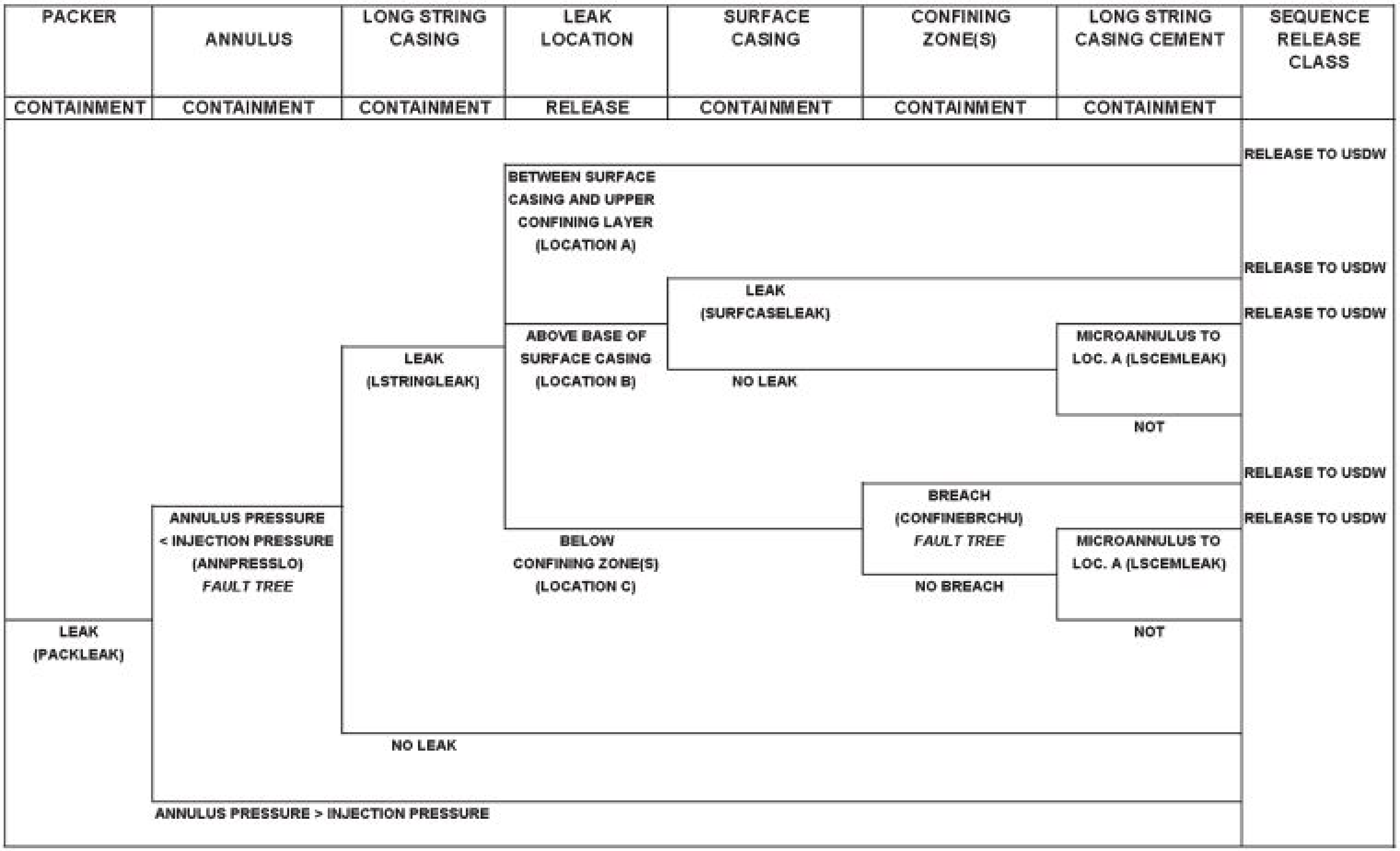


Fig. 10.6. Event tree for an injection tube failure in a Class I hazardous waste injection well.

7. Inadvertent injection zone extraction event tree from Rish (2005)

SDW PRA - Consequences

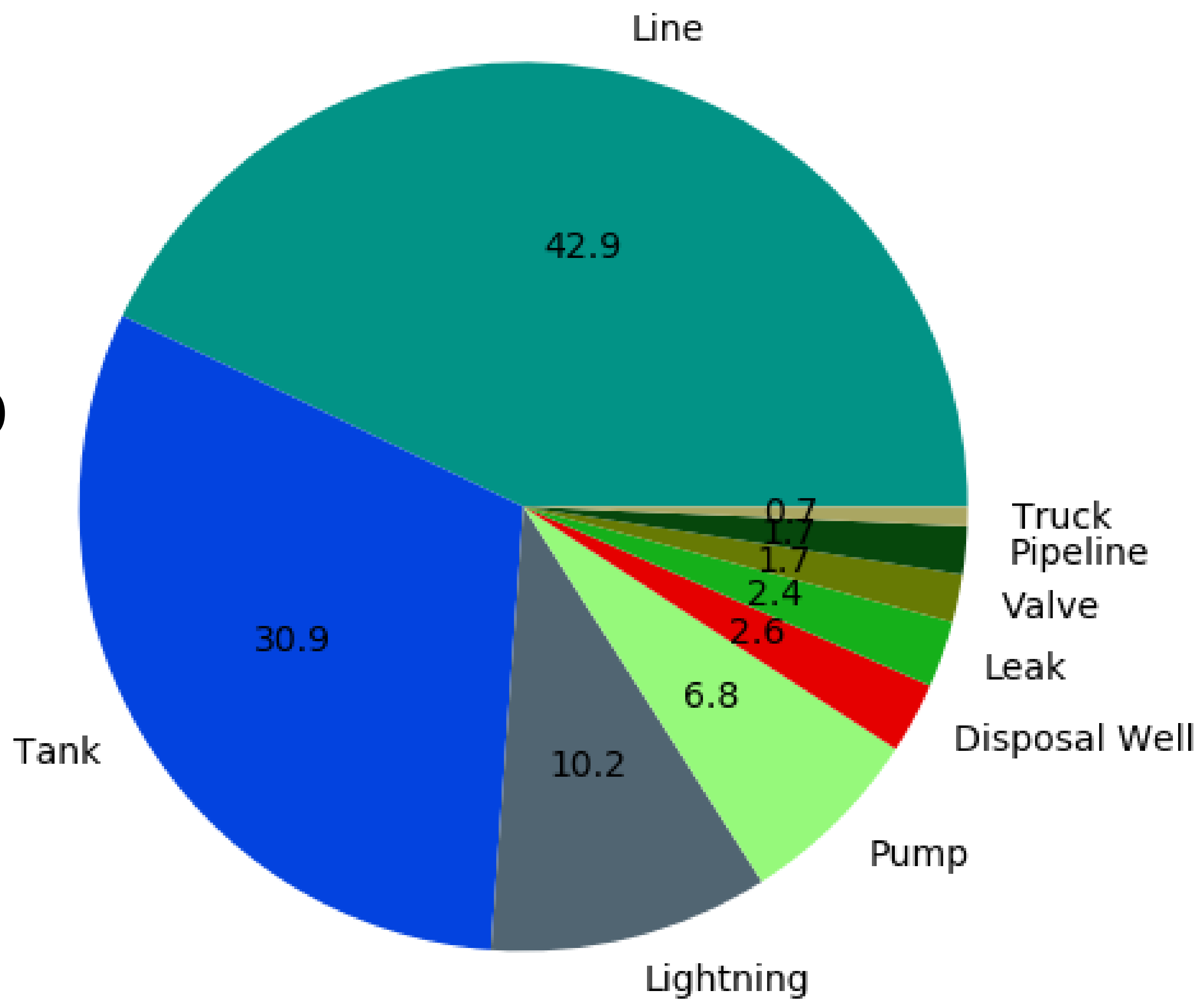
- Produced water spill information, in Texas, is not easy to come by-
  - "In Texas, there were more than 2,700 spills at oil and gas sites last year {2015}. But the state tracked only about half of those.
  - Unlike other states, Texas doesn't track spills of wastewater. The Texas Railroad Commission (RRC), which regulates oil and gas, tracks only spills of petroleum products -- primarily crude oil."
  - Energy Wire provides a national database of spills during 2009-2015 that includes produced water spill information in Texas.

[http://www.eenews.net/assets/2016/07/19/document_ew_01.xlsx]

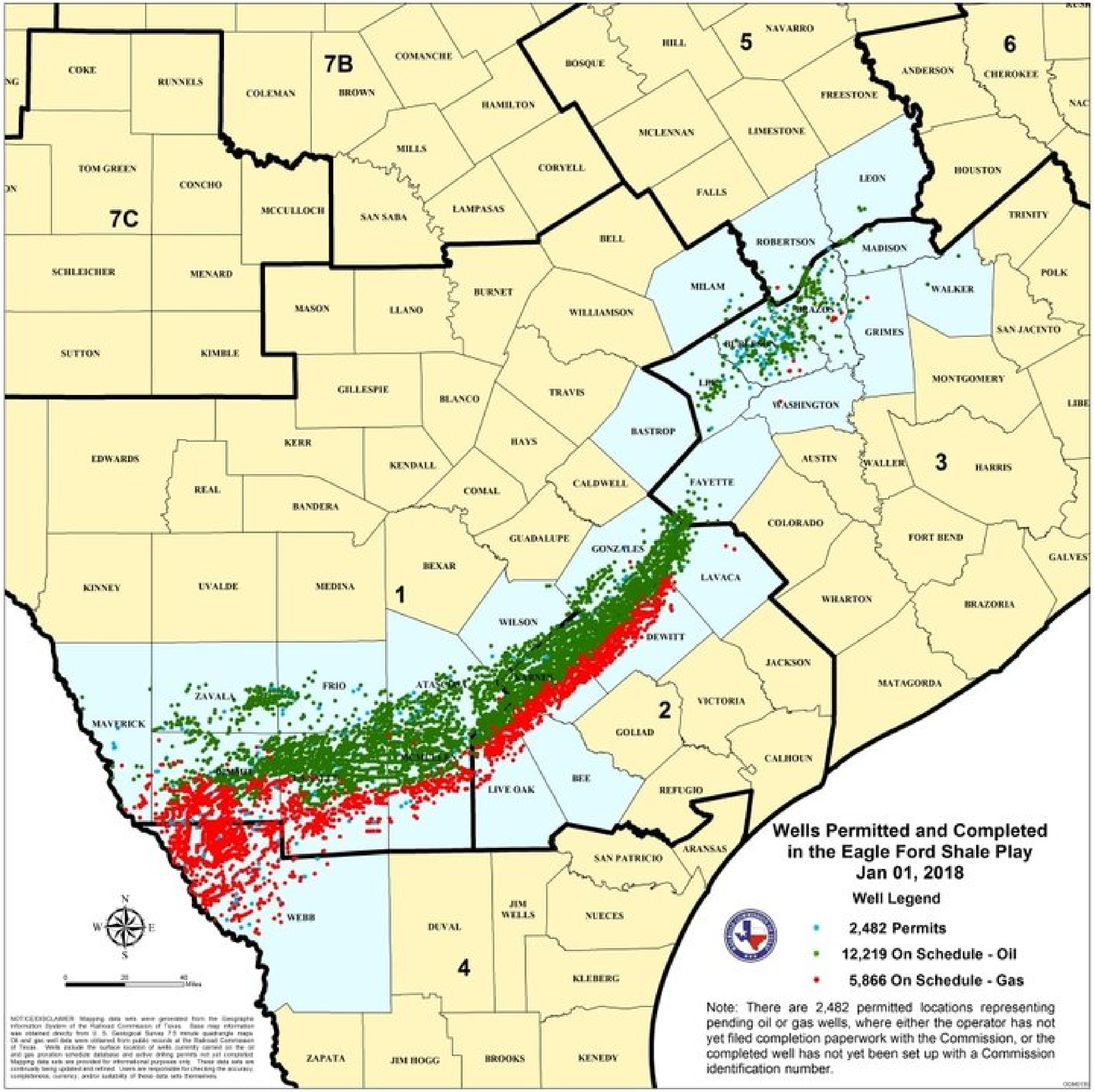
[Soraghan, M. (2016, August 2). ENFORCEMENT: In Texas, wastewater spills get less scrutiny. E&E News: Energy Wire.]

Produced Water Spill Information

- 5,655 produced water spill incidents in Texas between 2009 and 2015
- Categorized 4,880 as shown at the right
- 126, or 2.6%, of the characterized spills were from SDWs



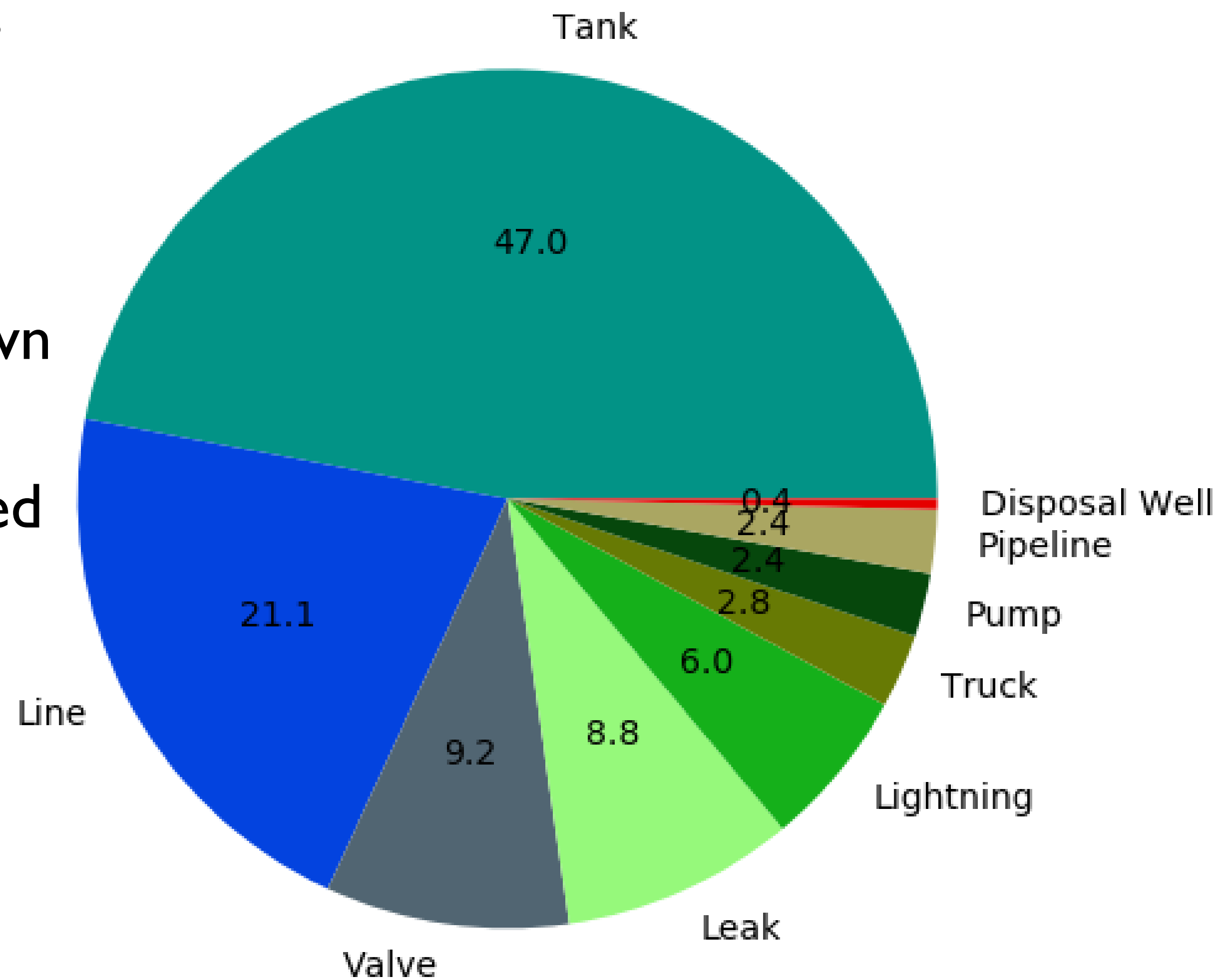
- Eagle Ford



https://eaglefordshale.com/

Produced Water Spill Information

- Eagle Ford counties have 403 of these spills
- 251 which were categorized as shown at the right
- 1 was a SDW-related spill



SDW PRA - Consequences

- A SDW, or Class II well, failure event is a release of untreated produced water to the biosphere where the biosphere denotes a region where the produced water comes into contact with humans and other organisms
  - Could be release to an underground source of drinking water (USDW)
  - Could be release to ground surface or surface waters outside of containment facilities
- Consequences are the bad things that happen as a result of a failure event

SDW PRA - Likelihoods

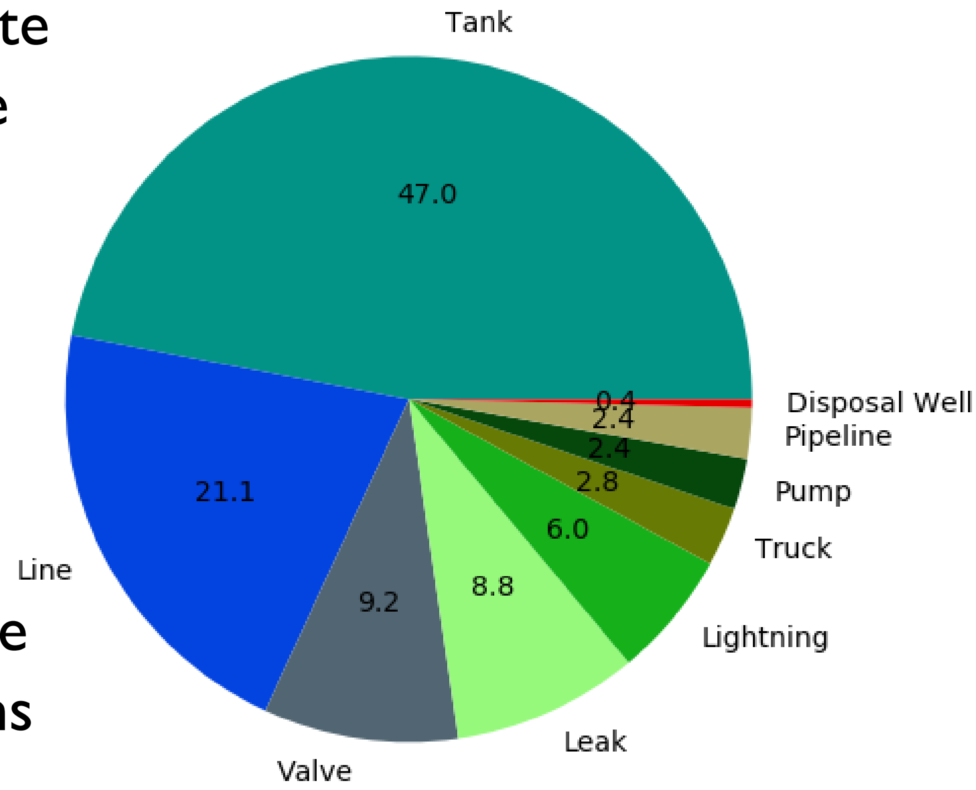
- Event tree modifications have been proposed. The final piece of information that is required is likelihoods or probabilities for component faults in the modified parts of the event trees
  - Leak and spill data attributed to specific faults is the best way to determine likelihoods
- Unfortunately, these types of data are not readily available.
  - Reporting of produced water spills in Texas may not be required

SDW PRA – What-If Analysis

- In the absence of these data, use a "What-If Analysis" or a modeling experiment to understand the possibilities related to the anecdotal information on system faults/failures
- Anecdotal comparison evidence for Class II to Class I facilities would be -
  - Class II:
    - Texas had at least 5,655 produced water spills during 2009-2015 (7 years); Eagle Ford counties had at least 430 produced water spills during the same period
    - 126 were associated with SDWs in Texas; 1 with SDWs in Eagle Ford counties
    - Observed, high TDS hot spots and anecdotal reporting of salt kills and produced water in bar ditches
  - Class 1:
    - Nationwide there have been 4 incidents over more than 3 decades

SDW PRA – What-If Analysis

- Use the SDW PRA with Monte Carlo simulation in an inverse approach
- Goal is to see what could produce a median probability of 1 failure in 10 years
- Median == 50th percentile
- Hypothetical scenario because of the lack of available "lessons learned" investigations and analyses related to the self-reported spills



SDW PRA -Results

Saltwater Disposal Well (SDW): Probabilistic Risk Assessment (PRA)

Time Simulation Settings

Monte Carlo Simulation Time Settings

Run Model

0.51	Upper Confining Zone Probability of Failure
0.99	UBUOYANCY, uniform, minimum
1.0	UBUOYANCY, uniform, maximum

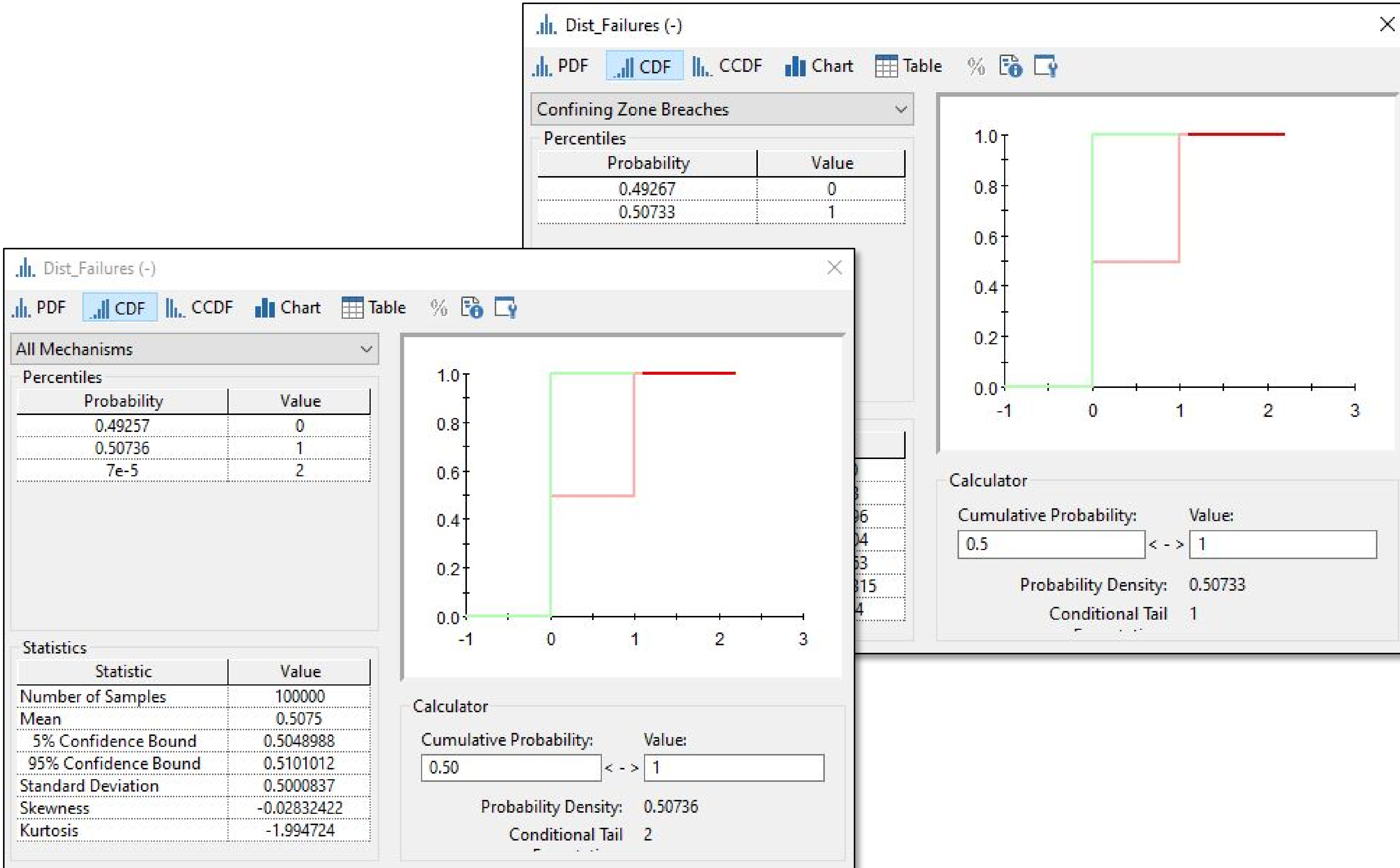
Inputs Dashboard

Results Dashboard

Injection Tube, Mean Failure Time	4026.25 yr
Injection Tube, Mean Leak Time	40.26 yr
Packer, Mean Failure Time	5951.85 yr
Packer, Mean Leak Time	59.52 yr
Annulus Cement, Mean Leak Time	248.9 yr
Long string casing, Mean Failure Time	6518.69 yr
Long string casing, Mean Leak Time	65.19 yr
Surface casing, Mean Leak Time	651.87 yr
Abandoned well plug, failure rate per well	0.0008 1/item
Abandoned well plugs, Mean Failure Time all wells	75 yr
Mean probability, presence of transmissive discontinuity	0.215 %
Mean probability, unexpected transmissive permeability	0.0215 %
Mean probability, migration outside of AOR	0.0055 %

Mean probability, failure to detect abandoned well in AOR	87.5 %
Probability, abandoned well transmissive through upper	50 %

SDW PRA - Results



SDW PRA - Results

Dist_CONFINEB (-)

PDF | CDF | CCDF | Chart | Table | %

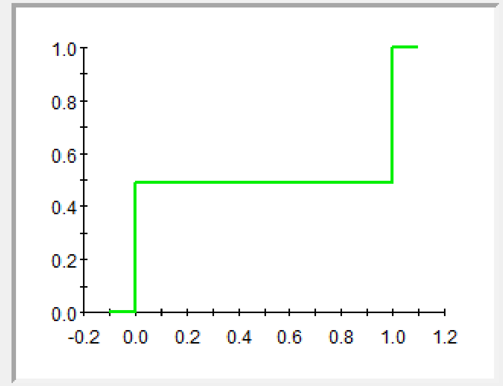
Upper_Confining_Breach

Percentiles

Probability	Value
0.4906	0
0.5094	1

Statistics

Statistic	Value
Number of Samples	100000
Mean	0.5094
5% Confidence Bound	0.5067997
95% Confidence Bound	0.5120003
Standard Deviation	0.4999116
Skewness	-0.03760665
Kurtosis	-1.998586



Calculator

Cumulative Probability: 0.5 < - > Value: 1

Probability Density: 0.5094

Conditional Tail 1

Upper Confining Zone Fault Tre

500	# of abandoned wells
0.0008	Plug failure rate per abandoned well
30	Number of years that plug failure rate applies to
1e-5	Minimum probability for unrecognized high permeability z
0.001	Maximum probability for unrecognized high permeability zone
1e-5	Minimum probability for migration outside of AOR
0.0001	Maximum probability for migration outside of AOR
0.5	Probability for unidentified abandoned well transmissive through upper confining
0.8	DETECT well failure, minimum uniform
0.95	DETECT well failure, maximum uniform

SDW PRA – What-If Analysis

- Regulations and standards for Class II wells provide for a highly engineered system with redundant safety mechanisms
- **If** the 50th percentile scenario is 1 failure in 10-yrs, **what** event pathway and series of faults would explain these results?
  - Only feasible route within the PRA is to assume high probabilities for the existence of unidentified, unplugged, and abandoned wells
  - The possibility of elevated likelihoods for unidentified, unplugged, and abandoned wells is supported by the large number of known, unplugged, and abandoned wells (~ 13,700)
- Another way to achieve our **If** scenario would be to assume that SDW are not being constructed and operated according to the standards and guidelines

SDW PRA - Conclusions

- Data are not available at this time to make a rigorous analysis
- It is not clear if "lessons learned" studies, "best management practice" studies, and operations optimization studies are being conducted in the produced water disposal field or if any of these types of studies may become part of standard practice in the future
  - Without these types of practices and analyses can only fall back to "what-if" analyses that rely solely on educated guesses and assumptions
- The large number of known, unplugged, and abandoned wells (~13,700) suggests that unknown, unplugged and abandoned wells are likely to be an important limitation on the safety and effectiveness of produced water disposal via Class II wells.

Produced Water PRA

- Continued data collection and database building
- SDW PRA
  - Need to add components to provide for consequence comparison
- Produced Water Disposal PRA
  - Extend the SDW PRA to apply to the whole disposal site
- Produced Water PRA
  - Extend disposal PRA to the entire produced water lifecycle – from the production well to disposal, treatment, recycling, or beneficial use

Questions ?