Tubing and Packers Life-Cycle Analysis for UGS – Cost/ Benefit Analysis for T&Ps in UGS Wells

Battelle/ Sandia National Laboratories

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U.S. DEPARTMENT OF ENERGY | National Nuclear Security Administration

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Outline

- Battelle/ Sandia team
- Problem statement & objective of this project
- Task outline & budget
- Review of available failure data
- Battelle/ Sandia risk model and approach
- Results of the Battelle/ Sandia risk model
- Knowledge & technology transfer
- Recommendations
- Acknowledgements

Battelle/ Sandia team

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Problem statement & Objective of the project

PHMSA
Pipeline and Hazardous Materials Safety Administration

- UGS wells can fail, causing safety, environmental and financial consequences
- The potential for failure and the range of consequences must be understood
- The objective of this project was to assess the role of tubing and packer (T&P) systems in improving UGS safety, specifically for wells in storage fields developed in depleted hydrocarbon reservoirs
- This project fits into the broader PHMSA mandate to improve UGS safety

Task outline & budget

	Task	Q1			Q2			Q3			Q4			Q5			Q6			Q7			Q8		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	**Task 1 - Compile and review data and incidents for underground storage wells**																								
1.1	Acquire access to agency and industry data collection		◆																						
1.2	Define Requirements of needed data				◆																				
1.3	Collect/define standard for data collection				◆																				
1.4	Prepare Report to DOT on standards and extent of data availability					◆																			
1.5	Task 1 Report to PHMSA						◆																		
2	**Task 2 - Evaluation of well-entry impacts throughout tubing and packer life-cycle**																								
2.1	Assemble and organize relevant data												◆												
2.2	Evaluation of data collection																		◆						
2.3	Task 2 Report to PHMSA																		◆						
3	**Task 3 - Develop recommendations and improvements to current design**																								
3.1	Evaluate risk of well entry caused by T&P																				◆				
3.2	Evaluate industrial coating effectiveness																						◆		
3.3	Develop recommendations and improvements to T&P current design																								◆
3.4	Task 3 Report on Recommendations to PHMSA																								◆
4	**Task 4 - Project management and reporting**																								
4.1	Manage scope, cost, quality management																								
4.2	Meeting Preparation																								
4.3	Kick-off team meeting	◆																							
4.4	Attend DOT project review meetings			◆												◆									
4.5	Mid-term Team Meeting													◆											
4.6	Final Team Meeting																								◆
4.7	Report Preparation																								
4.8	Quarterly Status Reports and Final Project Report			◆			◆			◆			◆			◆			◆			◆			◆
4.9	Publish papers and make presentation																								◆
		◆ = Objective Deadline												= Period of Performance											

Period of performance:

09/28/2018 – 09/30/2020

Total budget: $785,513

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Review of Available Failure Data

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Availability of UGS reliability data

- Journal articles and reports describing major loss of control (LOC) events in UGS wells (ex. articles by D.J. Evans)
- Reports with failure rates specific to UGS wells (ex. British H&SE 2008 report by D. Keeley)
- <u>However, the data available from these sources is not sufficient for well barrier element failure identification, and therefore, limited in identifying T&P reliability</u>
- Battelle/ Sandia team attempted to collect additional data, specific to T&P use, from available state databases and UGS operators – minimal data was found
- Lack of well barrier element reliability data is concerning since the principal requirement to improve safety is to measure key safety indicators and make risk based decisions
- The Battelle/ Sandia Team recommends a well barrier element reliability database.

Battelle/ Sandia Risk Model and Approach

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Risk Model Description

See SSSV presentation for risk model description

https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=743

Comparison of T&P and SSSV risk models

Common aspects of both models:

- The approach for LOFI and COFI calculation during regular operations and workovers
- The four (six) UGS well styles used in simulations
- The twelve consequence environments

Differences between models:

- COFI credits applied to surface and subsurface events differently, depending on the location of T&P and SSSV
- Reliability ranges of T&P and SSSV
- Deliverability impairment factors were assumed for T&P and SSSV depending upon the location of the device and the well deliverability
- Frequencies of workover operations vary according to reliability assumptions

COFI credits due to T&P and T&P + SSSV application – during regular operations

Type of Consequence	COFI Credit	
	T&P Only	T&P + SSSV
Surface release with fire	$C_{Del(T\&P)} \times R_{T\&P} + (1-R_{T\&P})$	$C_{Del(T\&P)} \times R_{T\&P} + (1-R_{T\&P}) \times (1-R_{SSSV})$
Surface release without fire and subsurface release	$0.5 \times C_{Del(T\&P)} + 0.5 \times (1-R_{T\&P})$	$0.5 \times C_{Del(T\&P)} \times (1-R_{SSSV}) + 0.5 \times (1-R_{T\&P})$
Service and financial Fluid flow, toxins and pollutants release	$0.5 \times C_{Del(T\&P)} \times R_{T\&P} + 0.5 \times (1-R_{T\&P})$	$0.5 \times C_{Del(T\&P)} \times R_{T\&P} \times (1-R_{SSSV}) + 0.5 \times (1-R_{T\&P})$
Soil stability, vegetation health, soil productivity, water supply security	$(1-R_{T\&P})$	$(1-R_{T\&P})$
Greenhouse gases emissions social costs	$C_{Del(T\&P)} \times R_{T\&P} + (1-R_{T\&P}) + C_{leakage}$	$C_{Del(T\&P)} \times (1-R_{SSSV}) \times R_{T\&P} + (1-R_{T\&P}) + C_{leakage}$

$R_{T\&P}$ is reliability of T&P
R_{SSSV} is reliability of SSSV
$C_{Del(T\&P)}$ is a deliverability reduction factor for T&P
$C_{leakage}$ is a leakage component of credit, assumed to be 0.5% of the reservoir volume per year plus 0.1 MMcf per year

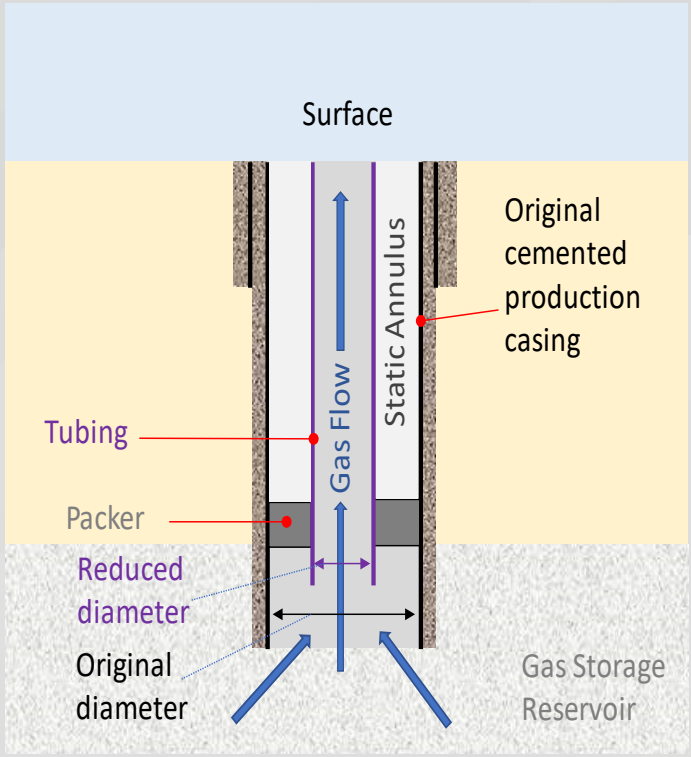
T&P and SSSV handled as mitigation devices, adjustments go to COFI

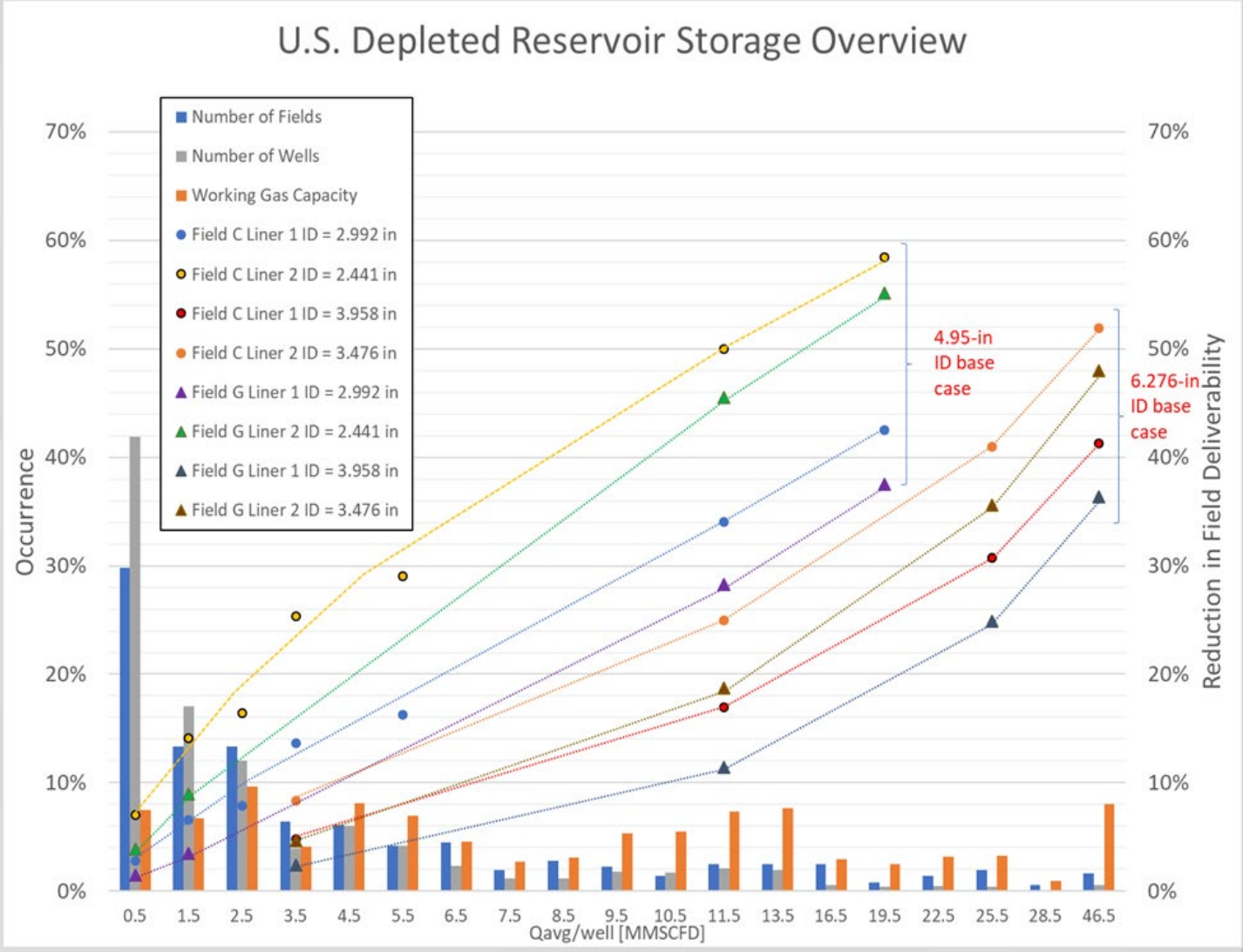
Reliability of T&P and SSSV systems

Estimation	Reliability of T&P	Reliability of SSSV	
		Shallow-set	Deep-set
Very low	0.875	0.60-0.67	0.36
Low	0.940	0.80	0.67
Medium	0.978	0.905	0.84
High	0.990	0.985	0.94

- Generally higher reliability of T&P affects the workover frequency, causing slightly different workover risk between T&P and SSSV

Deliverability impairment model

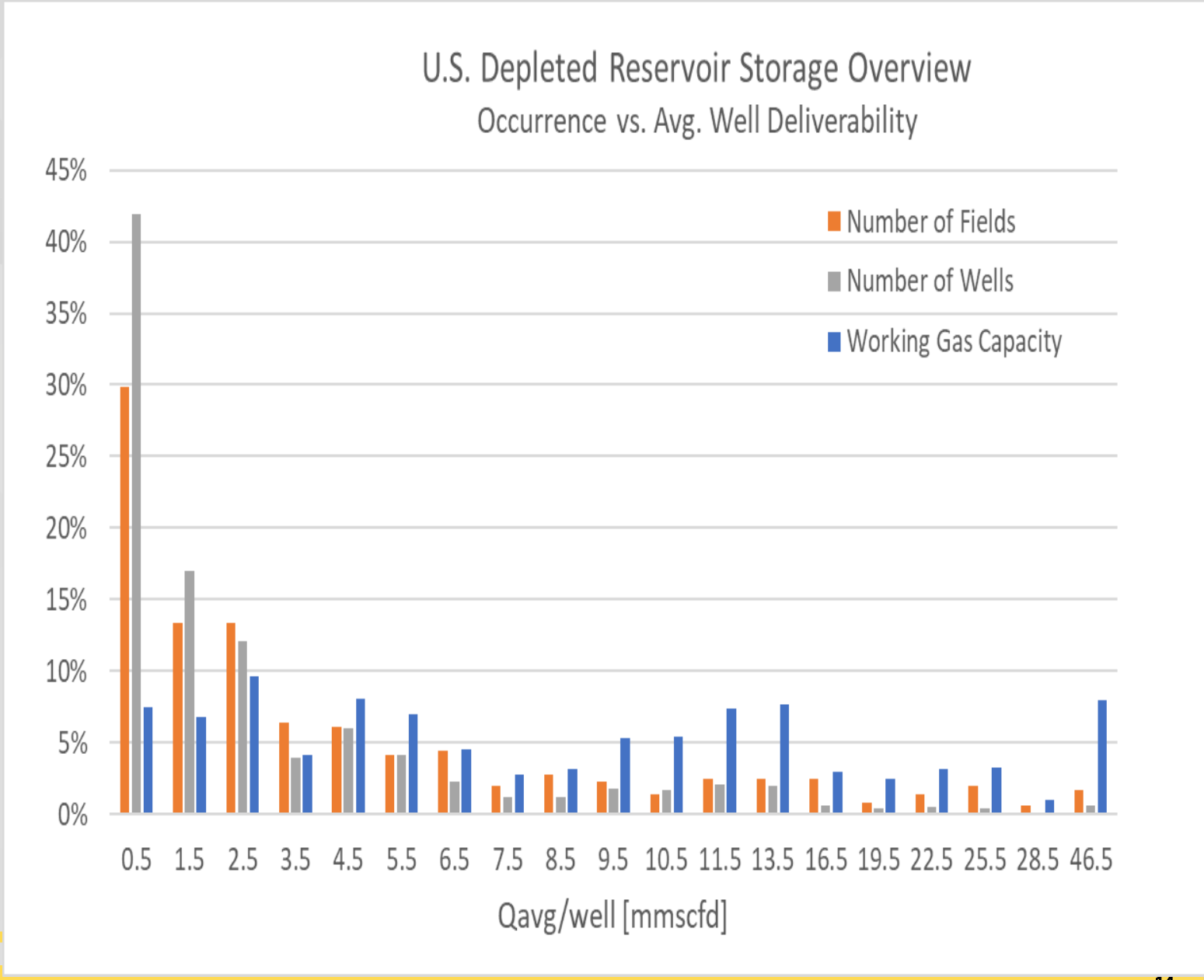




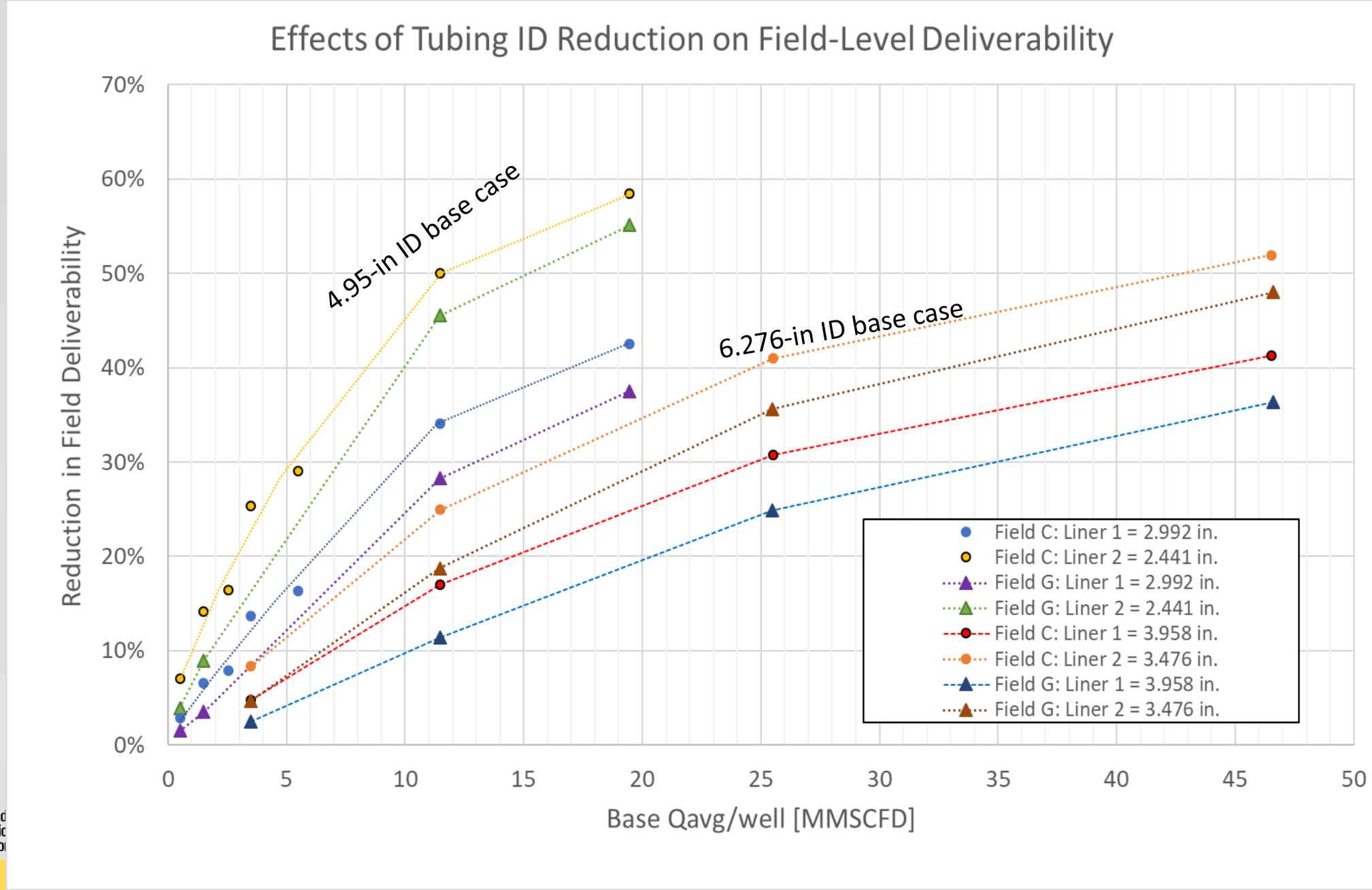
The Battelle/ Sandia model provides evaluation of deliverability impairment effects introduced by T&P or SSSV application.

U.S. Depleted Reservoir Storage Average Deliverability Per Well Distribution

- Most fields and wells are in lower-end deliverability bins
  - Tubing-affected reductions in deliverability across most wells, most fields in U.S. will thus be at the lower end (5-20%) of what has been shown
- Working gas capacity is more evenly distributed across bins
  - Tubing-affected reductions will affect ability to access working gas capacity, as a few high-deliverability fields are associated with much of the current U.S. capacity



Deliverability Reduction Based on Flow and Tubing Size



T&P Deliverability Analysis Conclusions

- Adding T&P could reduce deliverability due to flow restrictions; the extent of reduction depends on whether the current wells are reservoir-limited or tubing-limited
  - Tubing-limited wells will show notable reductions in flowrate with additional ID restrictions
  - Reservoir-limited wells will show small to no reductions in flowrate with additional ID restrictions
- Operators have actual well performance data and models that best predict the response of their own fields to changes in configuration
- While the modeling indicates that deliverability reductions of less than 25% should be seen across the majority of wells and fields in the U.S., operator concerns of 40-60% reductions in deliverability for the highest-flowing wells and fields are possible, though infrequent on a national scale

Results of the Battelle/ Sandia risk model

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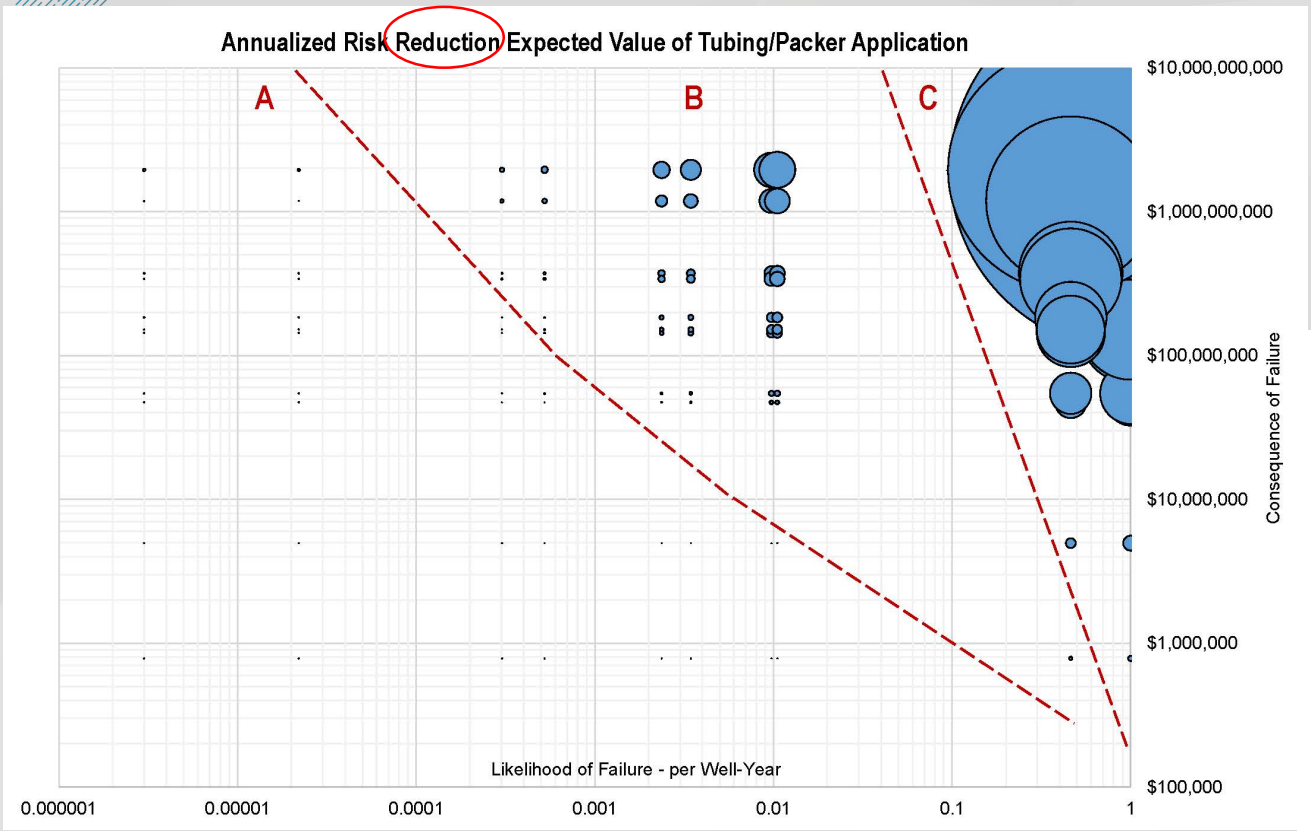
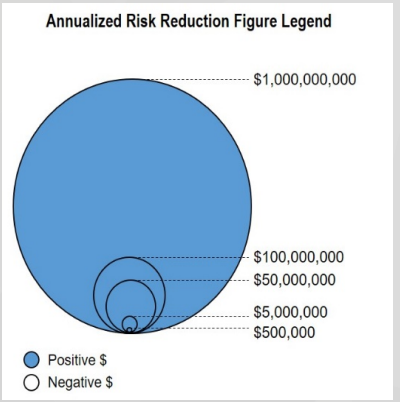
Applicability of T&P needs to be evaluated on a well-by-well basis





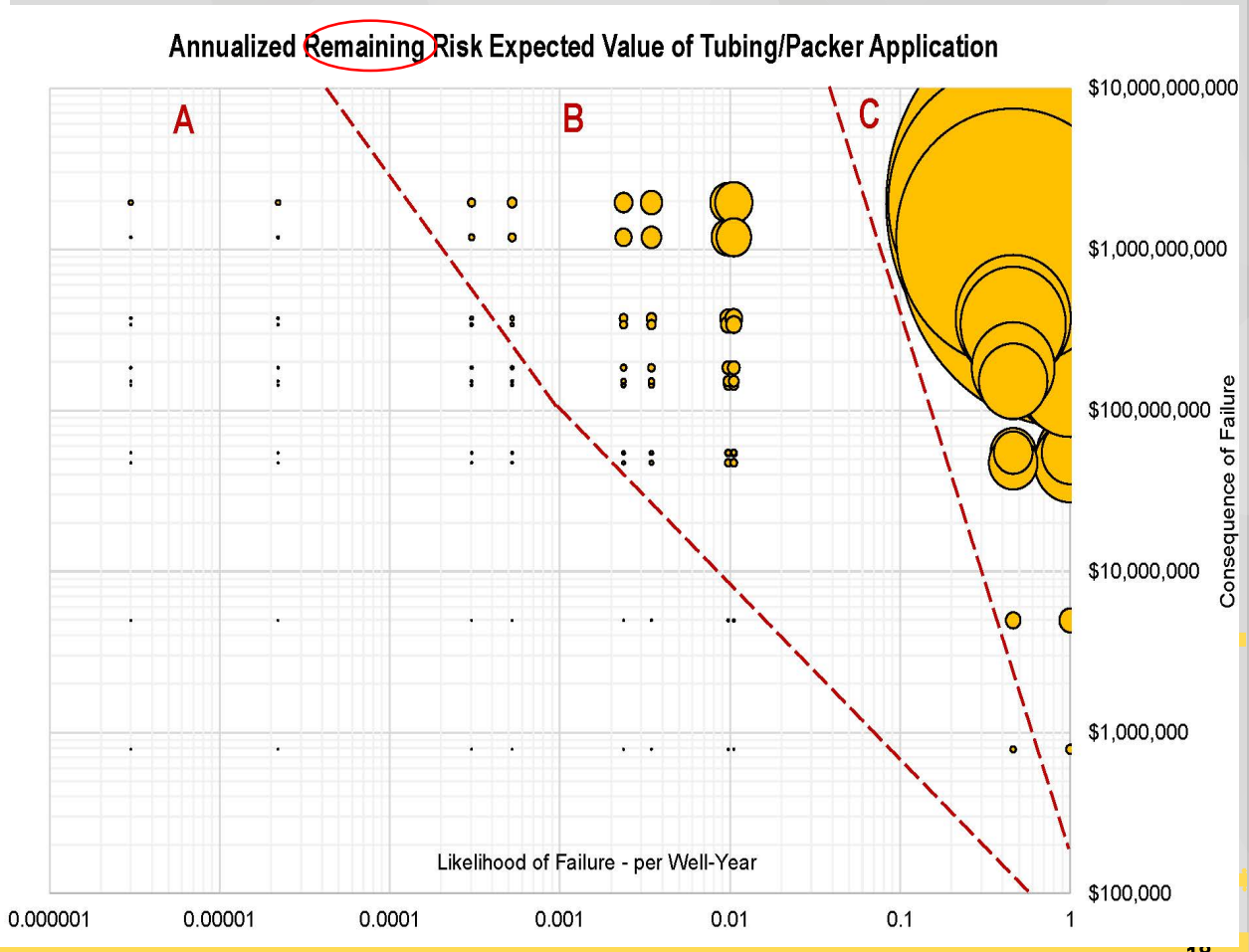
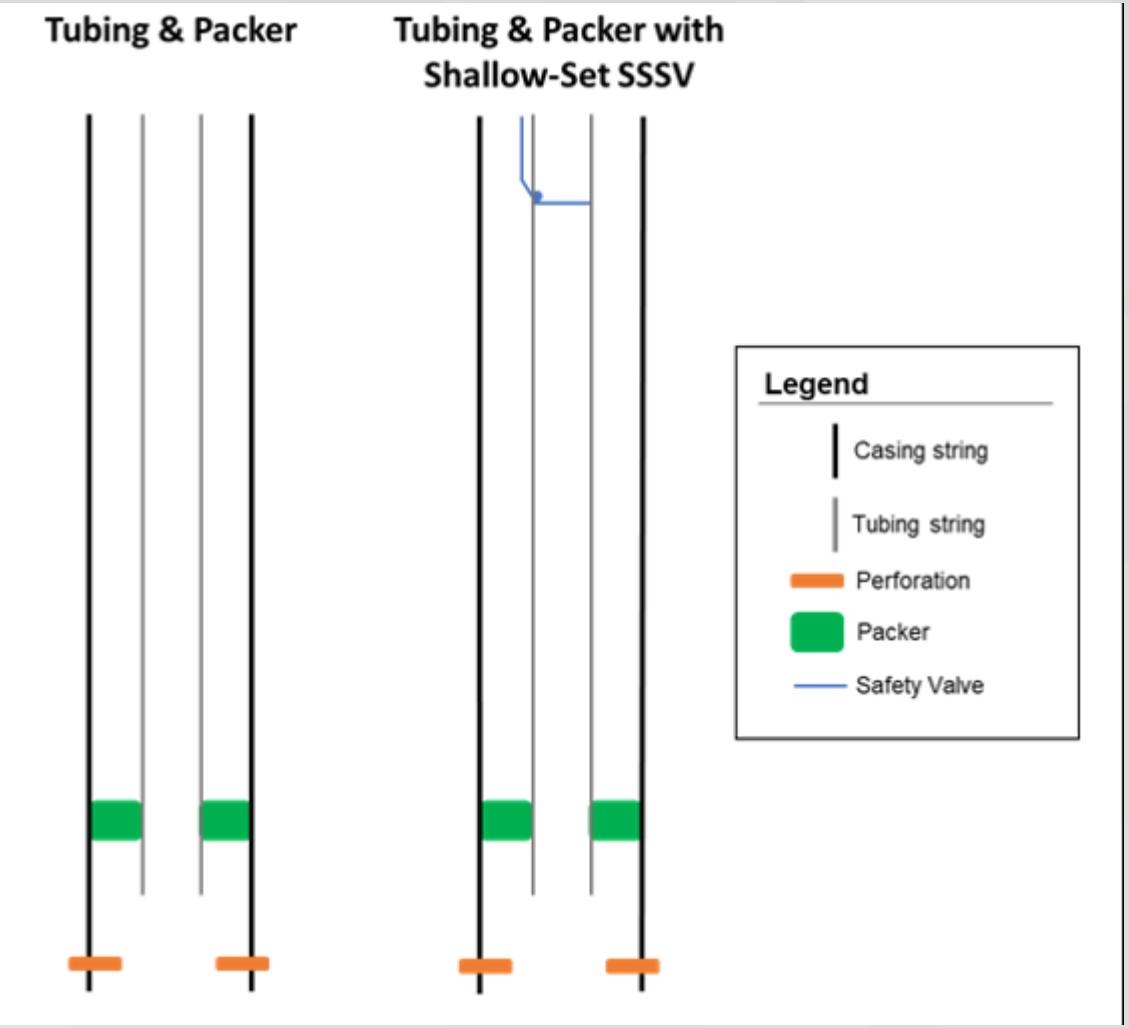


Table 15. The three zones categorizing applicability of T&P installation in UGS wells.

Zone	Criteria Identifying this Zone	Interpretation	T&P Applicable?	Example
A	The annualized risk reduction, estimated by the risk model, less than $10,000 -$40,000 per year, or even negative	Addition of T&P increases risk or risk reduction in negligible	No	Example 1
B	Intermediate LOFI and COFI values	Addition of T&P reduces risk in meaningful or significant ways	Yes, but compare to other possible risk treatments	Example 2
C	Very high LOFI approaching or exceeding 0.1 per year combined with COFI exceeding ~$10,000,000	Addition of T&P reduces risk by substantial amounts, but substantial LOFI also remains	Yes, but remaining risk might be too high to tolerate and more immediate risk treatment might be necessary, particularly for reducing LOFI	Example 3

Configurations used for analysis

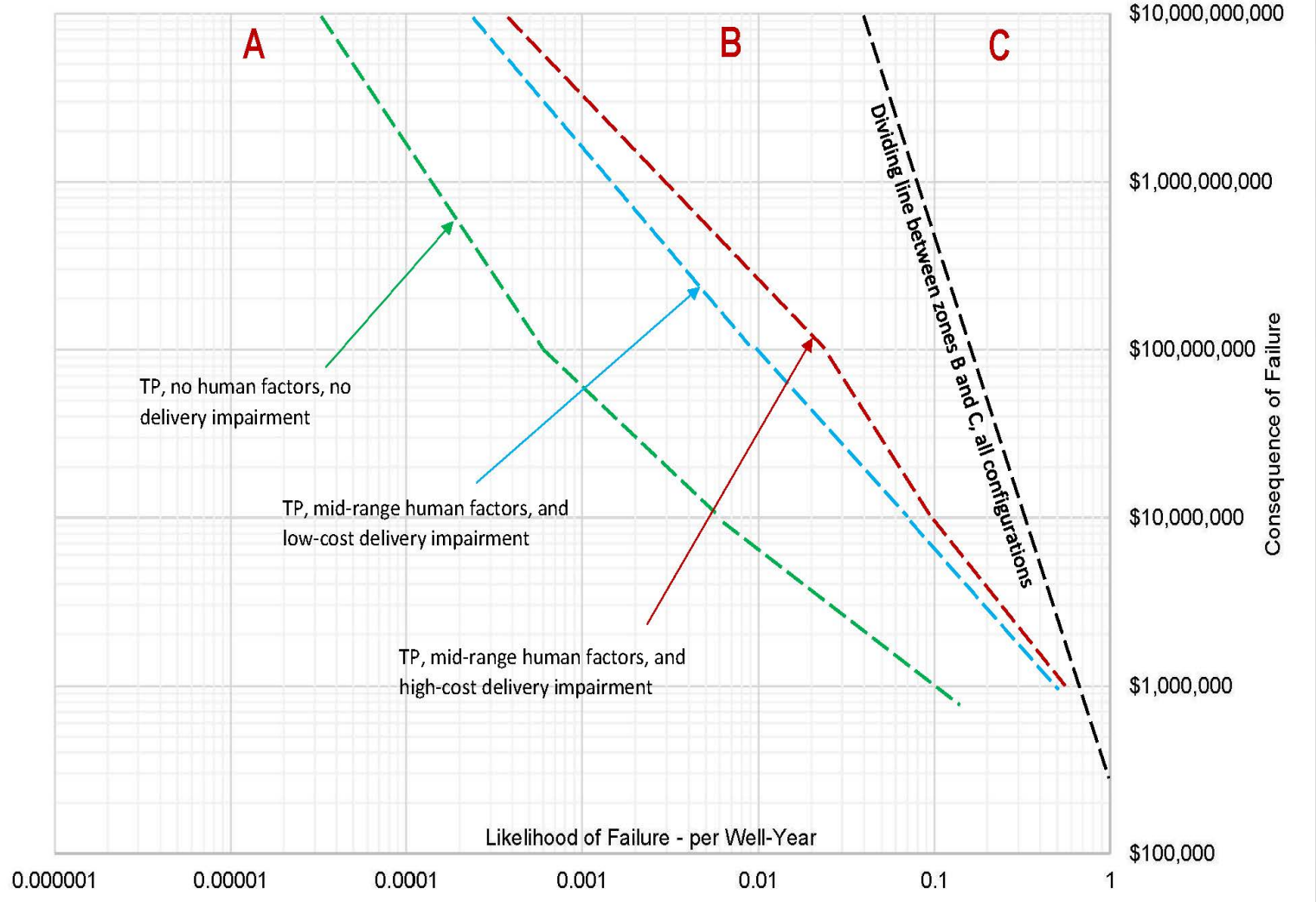


The model was applied to two types of configurations:

- Wells with T&P
- Wells with T&P and shallow-set SSSV

See the final project report for results of these simulations

Effect of human factors, deliverability impairment effects



Human factors:

- "no human factors" = credit (multiplier) of 1 in the LOFI workover equation
- "mid-range human factors" = credit (multiplier) of 15 in the LOFI workover equation

See the final project report for more information about these effects

Knowledge & Technology Transfer

- Discussions with UGS operators and PHMSA
- Project deliverables:
  - Final Project Report
  - Excel Implementation of the Model
  - Final Information Dissemination Presentation
  - Python Code
  - Journal Article (to be published)

Recommendations

- Application of T&P might reduce risk in some but not all UGS wells
- Applicability of T&P in UGS wells should be assessed for each well instead of a broad regulation that mandates the use of T&P for all UGS wells
- Broader use of quantitative risk models should be encouraged
- Assessment of T&P applicability in UGS should include effects of workover operations and possible deliverability restrictions
- Standardized data collection and analysis on well barrier element reliability information, including T&P
- Further research related to effects of human factors and management quality should be carried out with respect to T&P maintenance, reliability and repair

The results of this project can be obtained from:

- The project deliverables are available from the PHMSA web site: https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=745
- Journal article outlining the risk model approach and its results will be published, likely in the Journal of Petroleum Science and Technology

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- UGS operators for numerous discussions, comments about our approach, failure data

Q & A

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