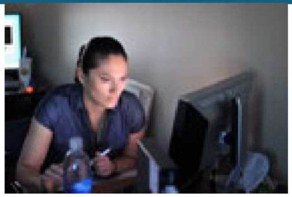
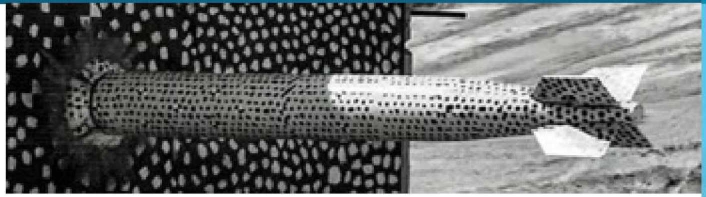
SAND2019-9919PE

WIPP EXPANSION

Evaluation of BRAGFLO Modeling Alternatives in Support of DOE Milestones EXPW-19-03 and EXPW-19-04





Developed by

Brad Day – 8/21/2019

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Overview

Objective

- Perform evaluation to complete two Level 4 DOE Milestones based on an expansion of the current 2-D flared grid modeling methodology
  - EXPW-19-03: Complete an initial computational grid study for use in future performance assessments of the expanded repository
  - EXPW-19-04: Complete and document an initial investigation of the likelihood of brine and gas flow between the current and expanded repository regions

Alternatives

- Utilize two BRAGFLO grids, one for the old "south" repository and one for the new "west" repository with a portion of the experimental area volume attributed to each model, each with a single borehole intrusion in to the "waste panel"
- Utilize one BRAGFLO grid that models connectivity of the old "south" repository with the new "west" repository through a common experimental area with two borehole intrusion locations, one in the old "south" waste panel and one in the new "west" waste panel
- In both cases, the new "west" repository waste areas are assumed to have all panel closures with excavation volumes equal to the old "south" waste areas; the CRA19 waste inventory is unchanged and evenly distributed between the two

Primary Technical Considerations

- Evaluate the degree to which the old "south" repository and the new "west" repository are communicating through brine and gas flows that can lead to conditions in one repository area affecting the conditions in the other repository area
- Evaluate impacts to modification of the TBM 2-D flared grid methodology when applied to an expanded repository

Approach

- Develop two model grids, one for the old "south" and one for the new "west" repository, that attribute 50% of the experimental area to each model for the undisturbed and E1 intrusion scenarios; the attribution of experimental area void space could later be adjusted in an attempt to equalize pressures and saturations in the experimental area between the two models
- Develop a single model grid, combining the old "south" and the new "west" repository areas, that shares a common experimental area void space for the undisturbed and E1 intrusion scenarios with two borehole locations in each of the "waste panels"
- Compare and contrast the 3 sets of results to determine the magnitude of cross-repository communication of brine and gas and the associated impact to adjacent repository results and also inform the decision regarding whether combining two decoupled (isolated) solutions is advisable or implementing a one (integrated) solution is necessary

Model Descriptions and Assumptions

Two-grid models (isolated)

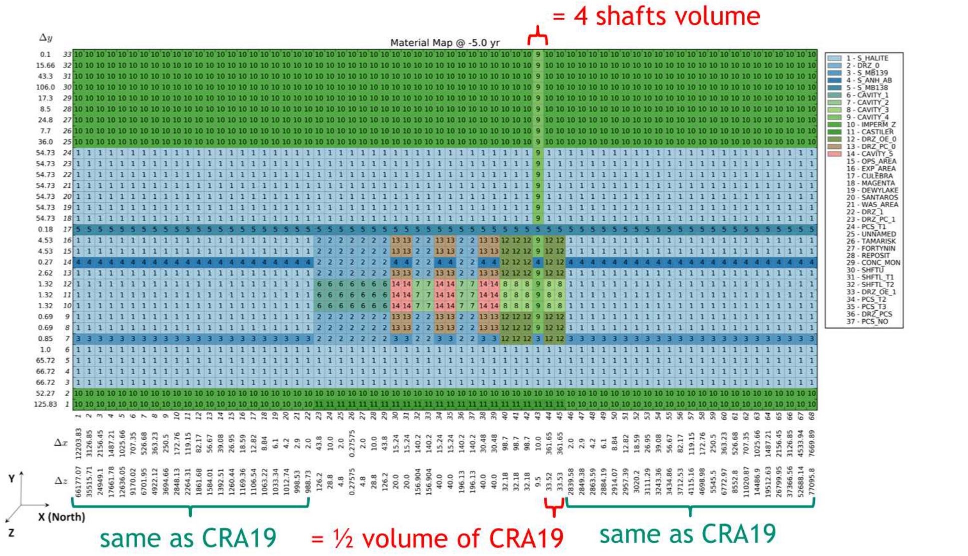
- CRA19S (old "south") – based on CRA19, with only changes being the halving of the inventory parameters (iron, cellulose, radionuclide content, MgO), halving of the experimental area void space, and modification of the shaft to represent the original 4 shafts
- CRA19W (new "west") – based on CRA19S, with only additional changes being modification of the shaft to represent the new 5th shaft and reinstalling the abandoned panel closure for the waste panel
  - Note that the 1 degree Salado dip from experimental area toward the waste panel is applied to both models; the old repository areas dip North to South and the new repository areas dip East to West
- Analysis files located on the Solaris cluster at /nfs/data/CVSLIB/WIPP_SPECIAL_ANALYSES/CRA19SW

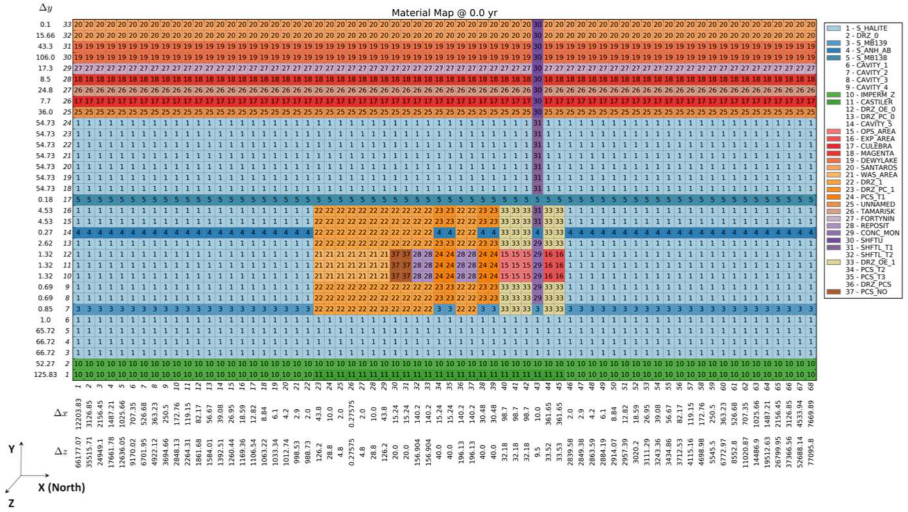
One-grid model (integrated)

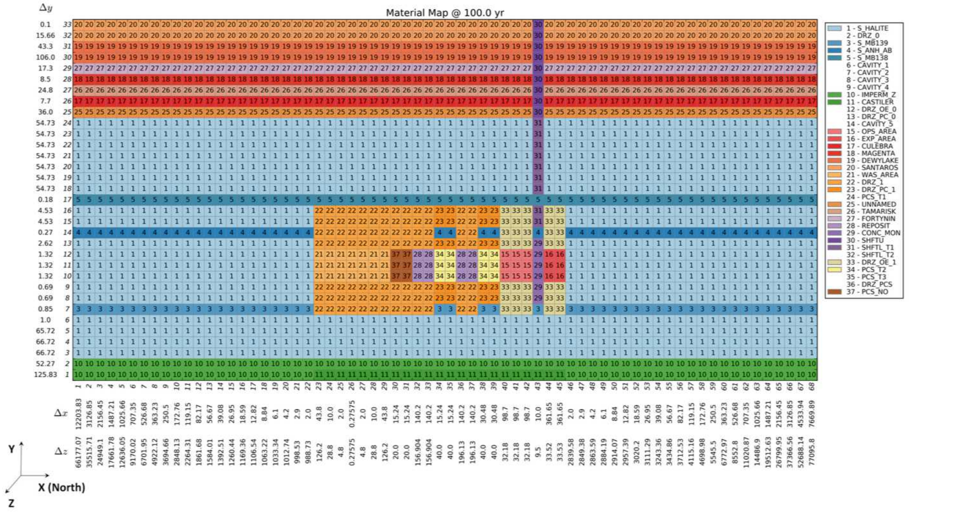
- CRA19SWe - combination of the CRA19S and CRA19W grids, with CRA19W mirrored and located to the north of the CRA19S experimental area (experimental areas joined), with modifications being to generally update the TBM grid flaring methodology to use the centerline of the experimental areas as the assumed flow center, to adjust the center reference point for the Salado dip from the intersection of the CRA19S shaft and MB139 to the intersection of the combined experimental area midline and MB139, and to implement material maps for new intrusion scenarios to accommodate a borehole intrusion in the new "west" waste panel
  - Note that the REFCON:VREPOS parameter (excavated repository volume) is doubled and the full LWA inventory parameters for CRA19 are utilized
  - Note that the 1 degree Salado dip is highest at the center of the experimental area and slopes downward toward the "south" and the "west" repository waste areas
  - Note that Castile brine reservoir porosity is modified in an ALGEBRACDB step to correlate the sampled bulk rock compressibility to an effective porosity that (along with the modeled grid volume in the Castile) gives an equivalent brine (pore) volume ranging from 3.39E6 to 1.69E7 m^3
- Analysis files located on the Solaris cluster at /nfs/data/CVSLIB/WIPP_SPECIAL_ANALYSES/CRA19SW

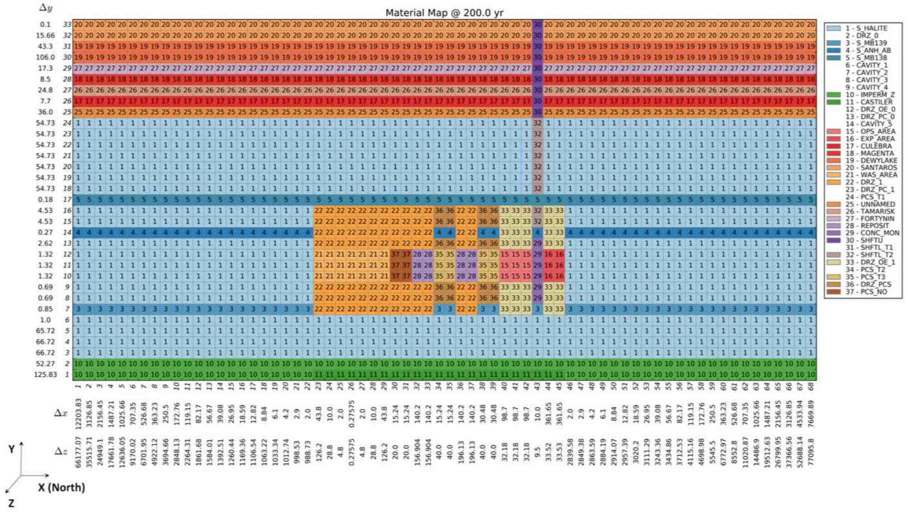
CRA19S Material Maps for Scenario 1

old "south" repository



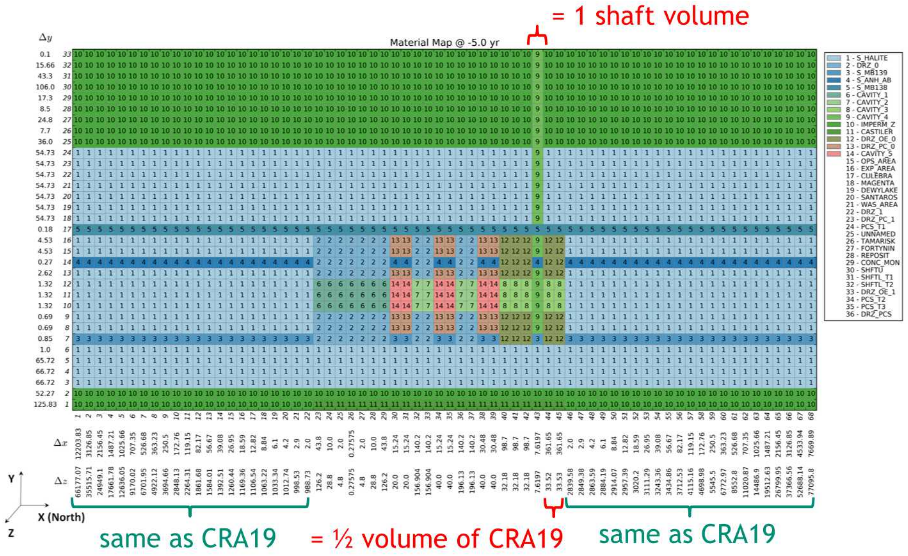


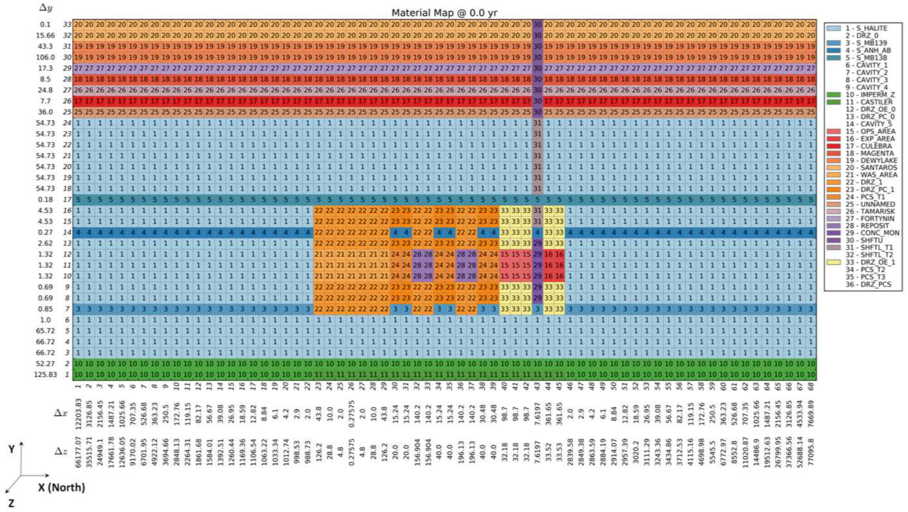


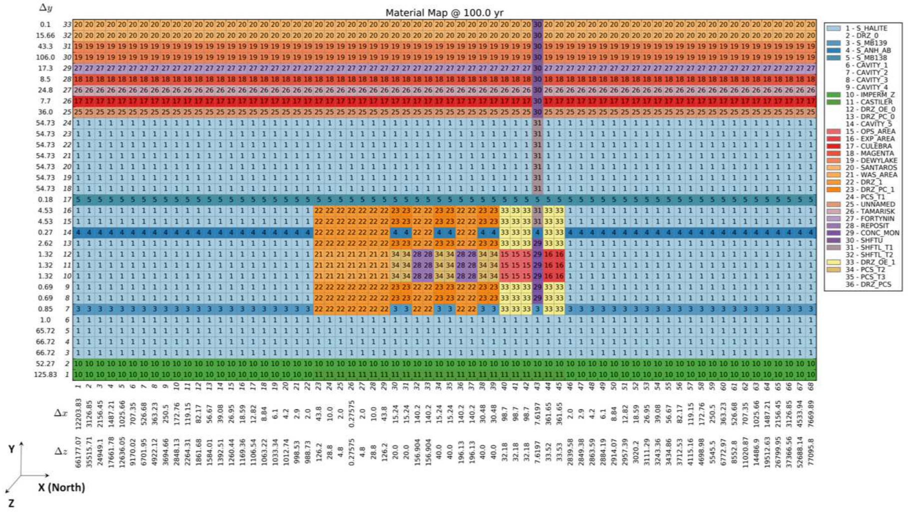


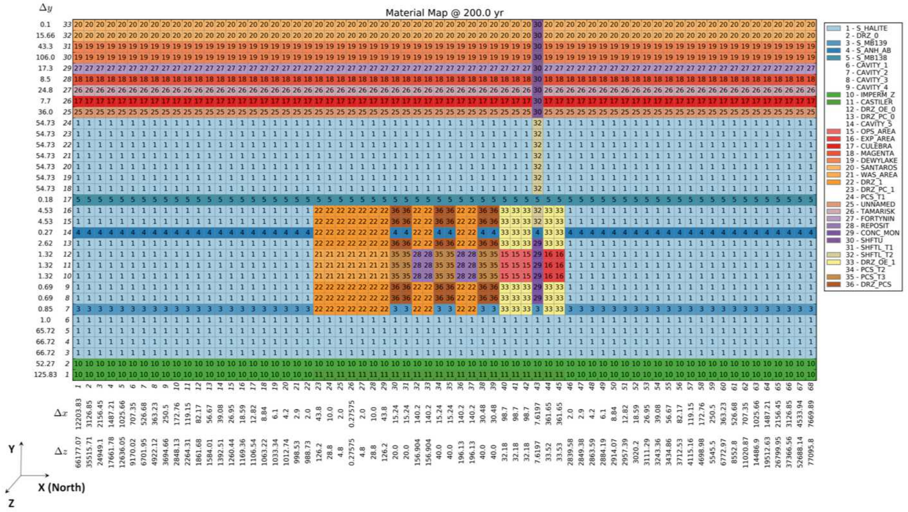
CRA19W Material Maps for Scenario 1

new "west" repository

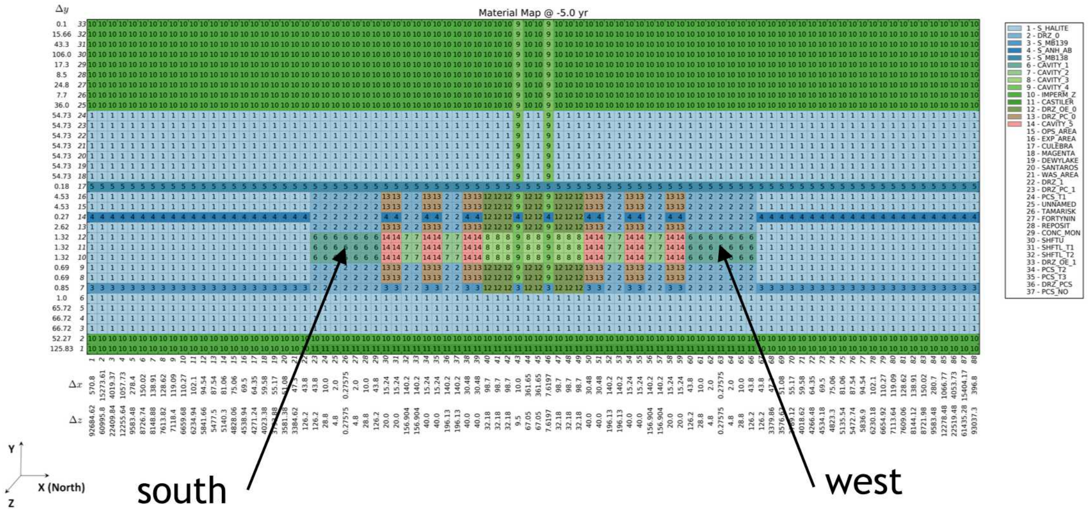


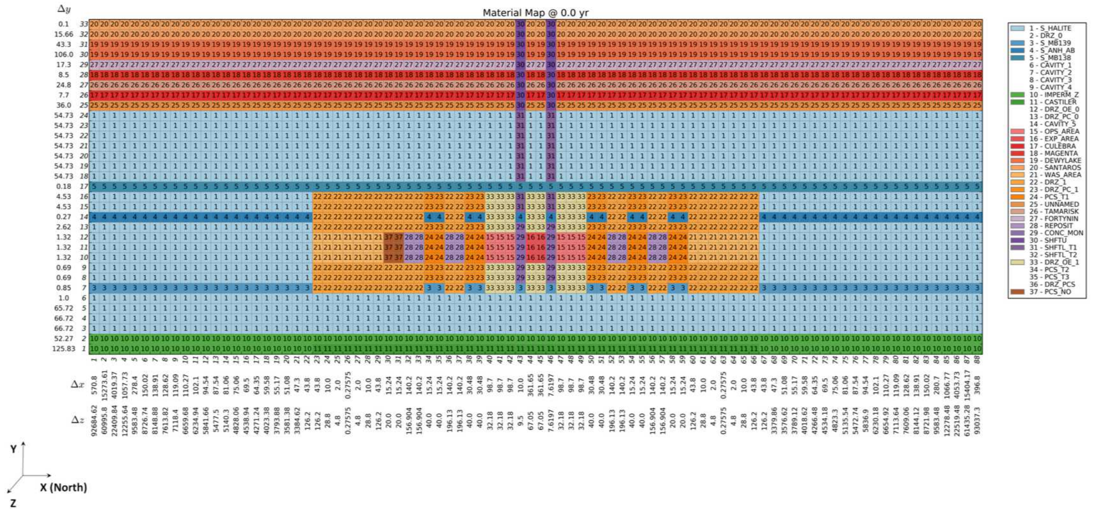


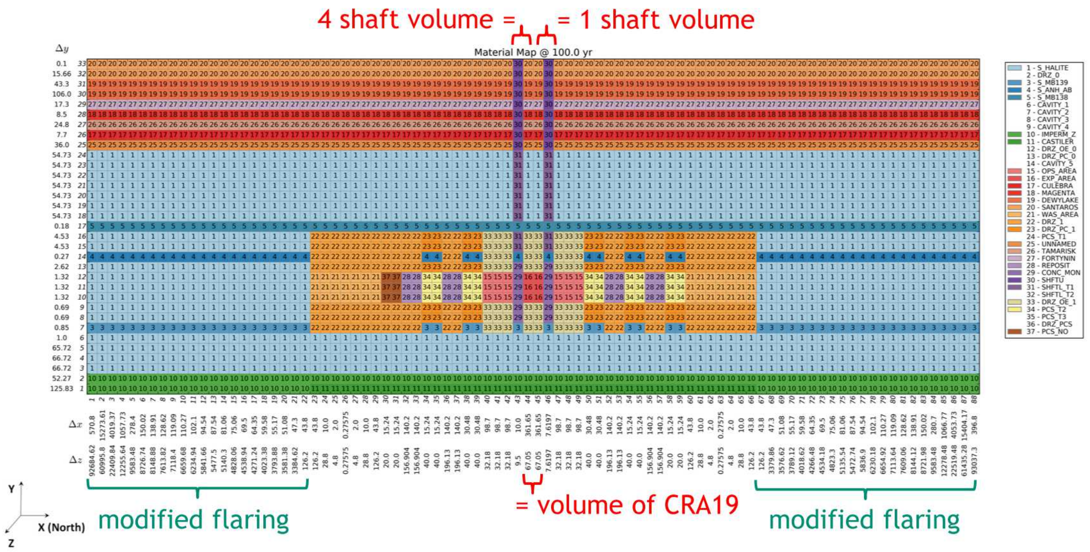


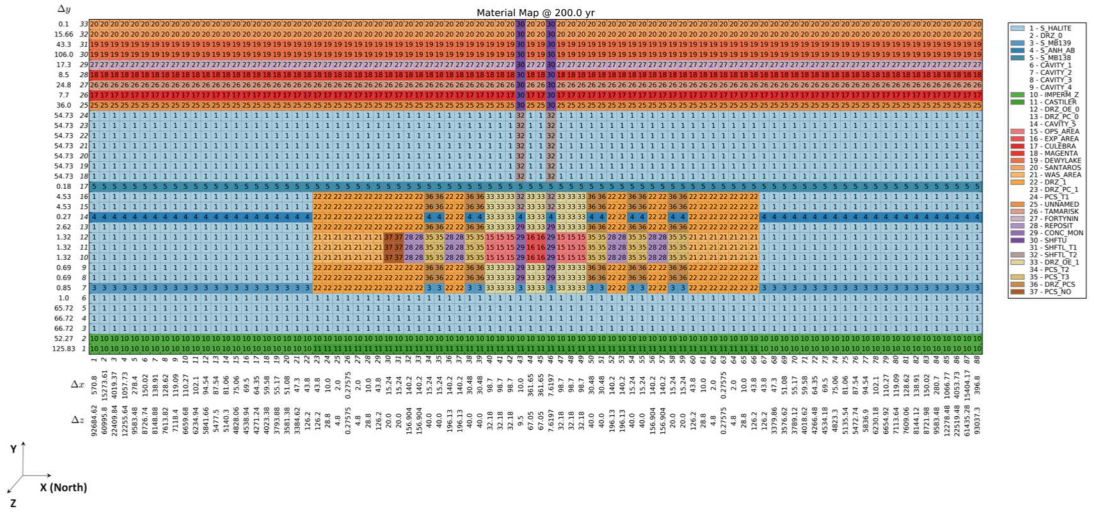


CRA19SWe Material Maps for Scenario 1 integrated "south" and "west" repositories



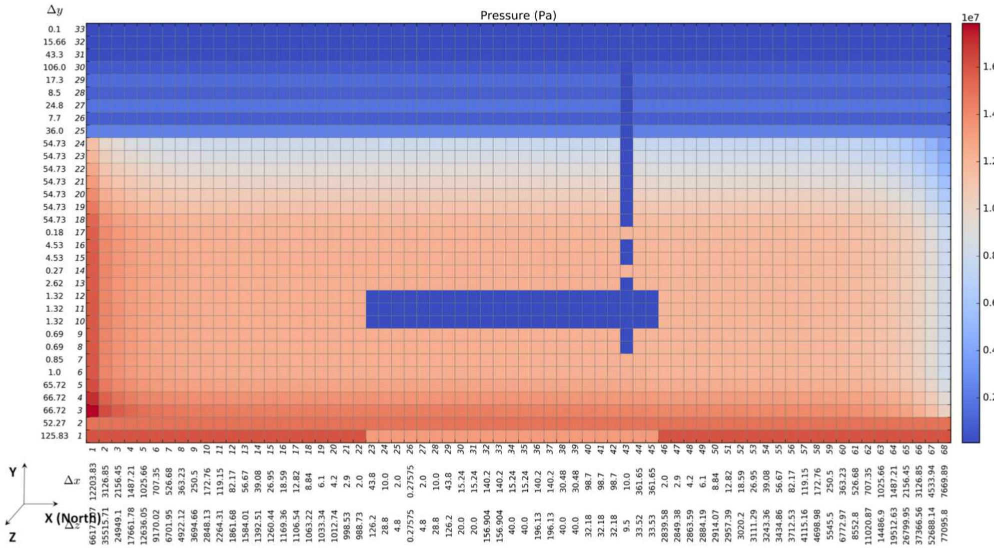




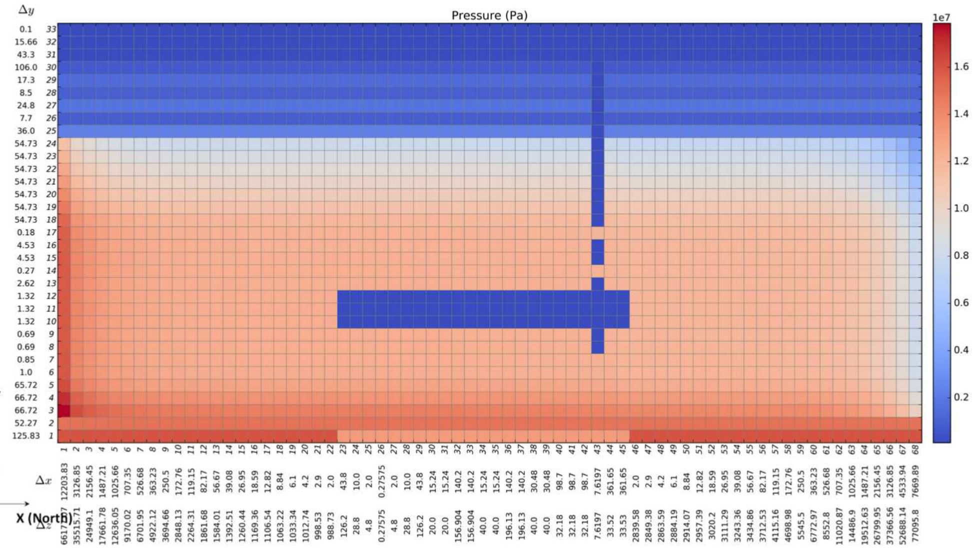


The new "west" repository, physically located to the northwest of the old "south" repository, is rotated 90 degrees such that it resides in-line and to the north of the old "south" repository within the 2-D flared grid

CRA19S, CRA19W, and CRA19SWe Initial Pressures

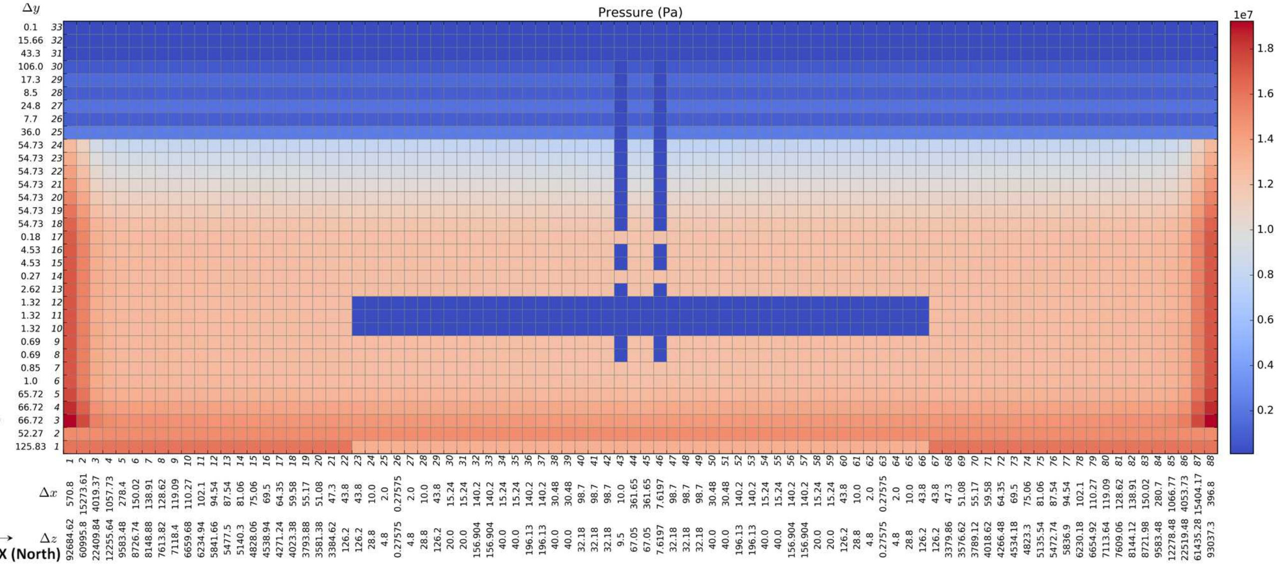


CRA19S

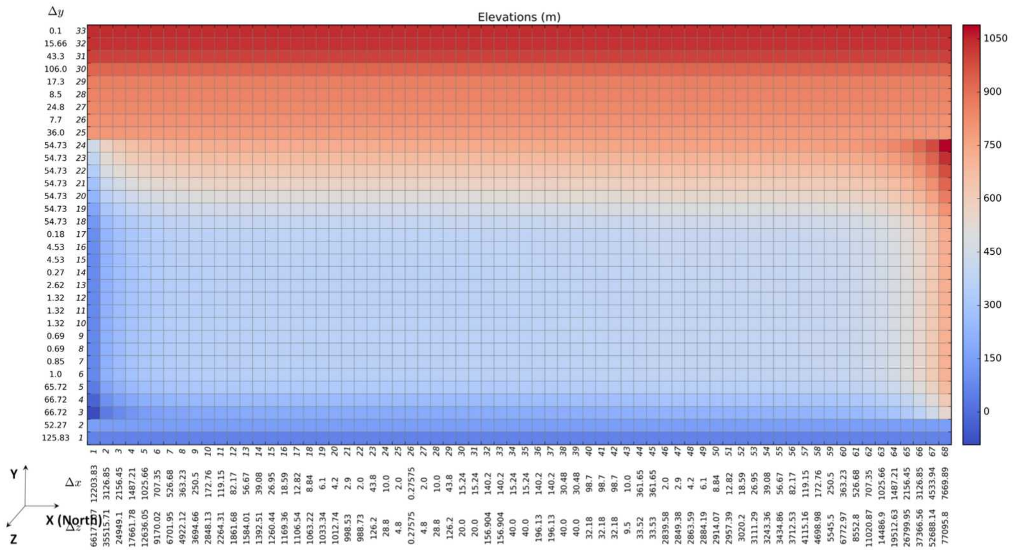


CRA19W

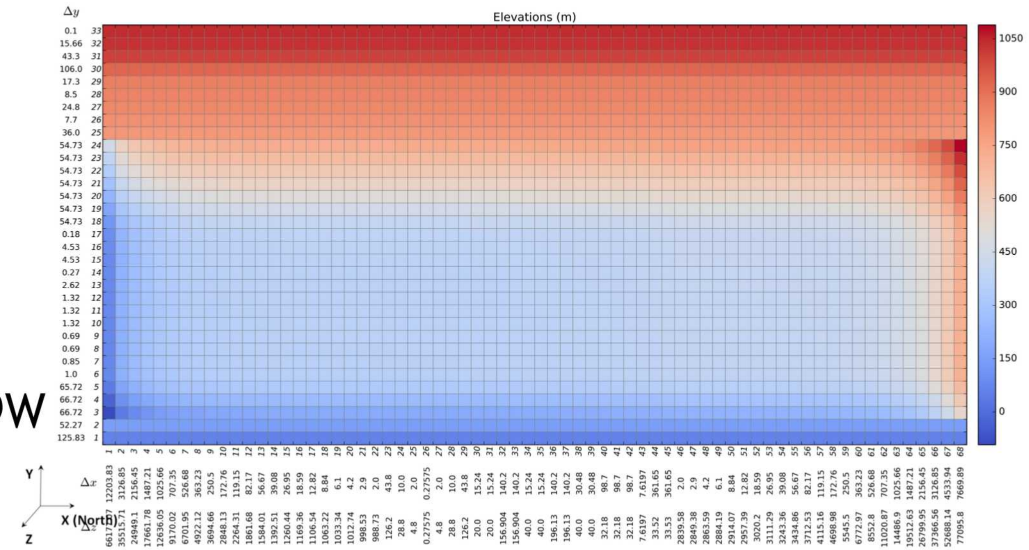
CRA19SWe



CRA19S, CRA19W, and CRA19SWe Elevations



CRA19S



CRA19W

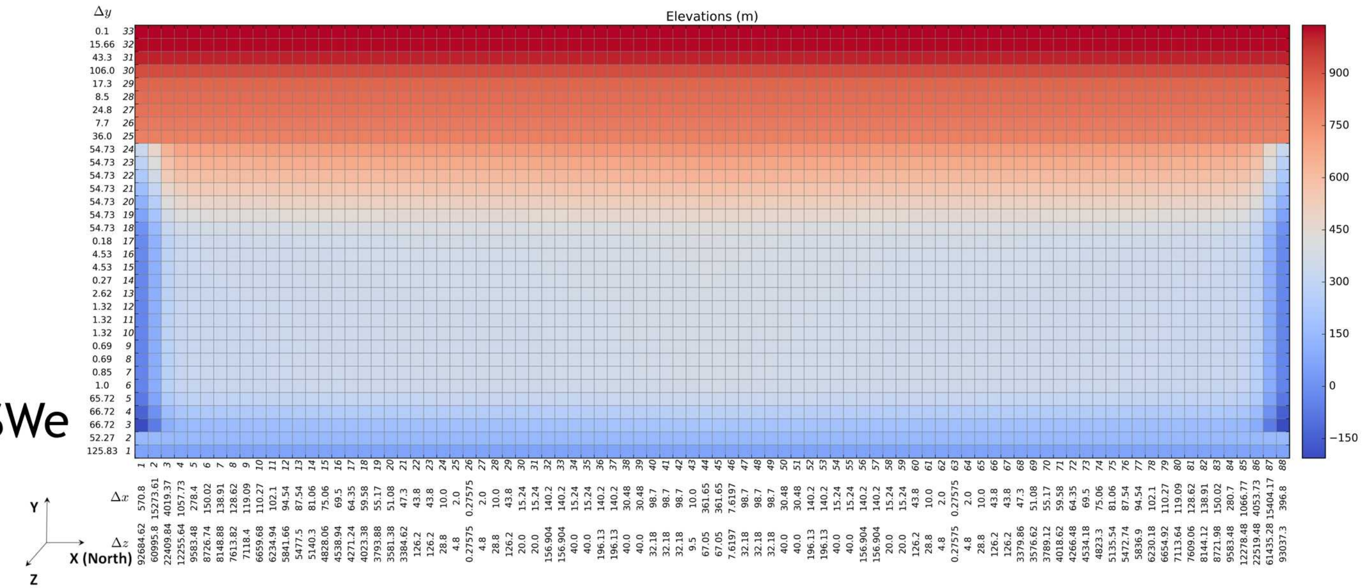
CRA19S and CRA19W

- Dip origin at center of shaft and MB139
- Dip is 1 degree from N-S over entire domain within the Salado

CRA19SWe

- Dip origin at center of experimental area and MB139
- Dip is 1 degree N-S from origin to S and -1 degree S-N from origin towards N within the Salado

CRA19SWe



TBM Flared Grid Methodology Evaluation

Motivation

- Prior to comparing CRA19S and CRA19W results against CRA19SWe, it is necessary to understand the influence of the TBM flared grid methodology on the brine saturation within excavated regions of the repository that are modeled adjacent to the initiation of grid flaring (i.e., outside of the excavations)

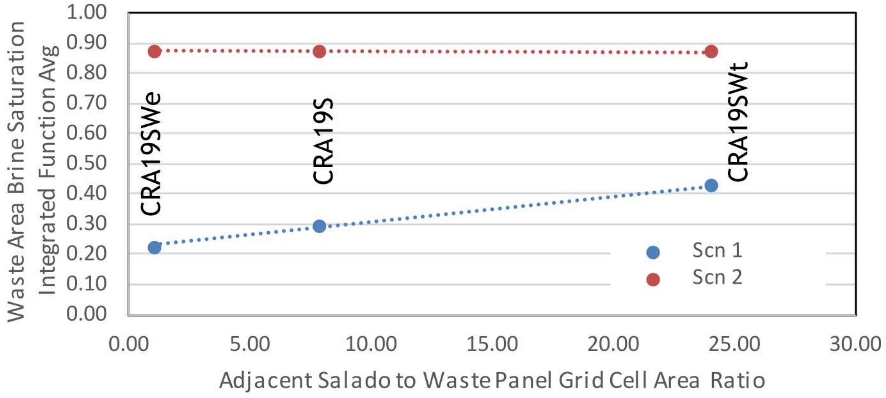
Methodology

- Compare two integrated model analyses with the only differences being the location in which grid flaring is initiated and the ratio of cross-sectional areas between the excavated regions of the repository and the Salado regions that are adjacent to the excavations
  - CRA19SWe – grid cells on either side of the excavations are set equal to the nearest excavated region grid cell such that cross-sectional area and volume ratios are equal to one; grid flaring is initiated from the 2nd cells outside of the excavations outward using an x-dimension refinement factor of 1.08 up to the LWB and an x-dimension refinement factor of 3.80 to within one cell of the domain extents, the final grid boundary cell Δx size is relatively small to limit the effect of BRAGFLO boundary conditions being numerically applied at the cell center
  - CRA19SWt – grid cells on either side of the excavations are set equal to 2.0 m width in the x-dimension (like TBM); grid flaring is initiated from the 1st cells outside of the excavation (like TBM) such that the cross-sectional area and volume ratios are defined by the $\Delta y \Delta z$ dimensions necessary to conserve volume; grid flaring uses an x-dimension refinement factor of 1.37 (similar to TBM) up to the LWB and an x-dimension refinement factor of 2.80 to within one cell of the domain extents , the final grid boundary cell Δx size is relatively small to limit the effect of BRAGFLO boundary conditions being numerically applied at the cell center
    - Analysis files located on the Solaris cluster at /nfs/data/CVSLIB/WIPP_SPECIAL_ANALYSES/CRA19SW

CRA19S, CRA19SWe, and CRA19SWt Grid Flaring Results

	Waste Area Cell 21					Waste Area Cell 22					Waste Area Cell 23				
	Δx	Δy	Δz	A	V	Δx	Δy	Δz	A	V	Δx	Δy	Δz	A	V
CRA19S	2.9	3.9624	998.53	3957	11474	2	3.9624	988.73	3918	7835	43.8	3.9624	126.2	500	21902
CRA19SWt	2.74	3.9624	3040	12046	33005	2	3.9624	3030.5	12008	24016	43.8	3.9624	126.2	500	21902
CRA19SWe	47.3	3.9624	3384.6	13411	634351	43.8	3.9624	126.2	500	21902	43.8	3.9624	126.2	500	21902

	Flaring Ratios				Saturation	
	A21/22	V21/22	A22/23	V22/23	Scn 1	Scn 2
CRA19S	1.01	1.46	7.83	0.36	0.29	0.87
CRA19SWt	1.00	1.37	24.01	1.10	0.43	0.87
CRA19SWe	26.82	28.96	1.00	1.00	0.23	0.87



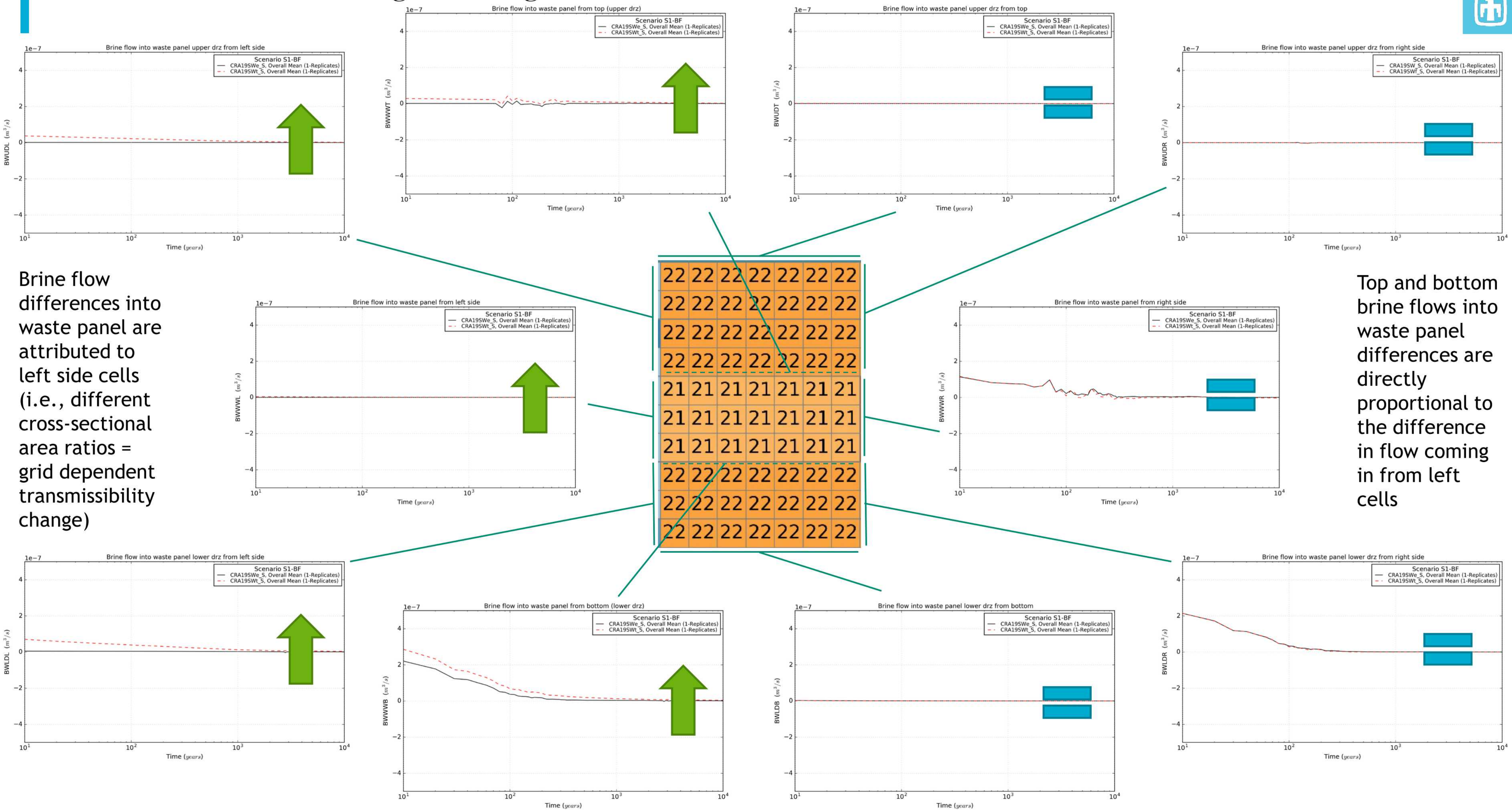
5	5	5	5	5	5
1	1	1	22	22	22
1	1	1	22	22	22
4	4	4	22	22	22
1	1	1	22	22	22
1	1	1	21	21	21
1	1	1	21	21	21
1	1	1	21	21	21
1	1	1	22	22	22
1	1	1	22	22	22
3	3	3	22	22	22
1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	1	1	1
10	10	10	10	10	10
10	10	10	11	11	11
20	21	22	23	24	25

Harmonically-averaged transmissivity is a function of cross-sectional area (A) such that A22/23 ratios change the interfacial flow conductance between the waste panel and the adjacent (and much less permeable) Salado and marker beds

- Scenario 1 waste panel brine saturation is increased by flow from the adjacent Salado and marker bed grid cells when the adjoining cell area ratios increase
- Scenario 2 is largely unaffected because brine inflow is dominated by flow up the borehole from the Castile

Brine flow sources into Waste Panel under Scenario 1 are evaluated on next slide

Where are the brine changes coming from?



Brine flow differences into waste panel are attributed to left side cells (i.e., different cross-sectional area ratios = grid dependent transmissibility change)

Top and bottom brine flows into waste panel differences are directly proportional to the difference in flow coming in from left cells

TBM Grid Flaring Methodology Conclusions

Results

- The cross-sectional area of grid cells adjacent to the waste panel(s) (and experimental area for single grid models) significantly influences the resultant transmissivity between these highly-permeable excavations and the adjacent low-permeability host rock such that larger adjacent cell area ratios result in an increased lateral flow conductance that allows brine and gas flow to/from the excavations and host rock
- This arbitrary grid cell dependence has a large impact on brine saturation solutions in the excavations adjacent to host rock that should be minimized and/or avoided, if possible

Location of Center of Flow

- The center of flow should be relocated to the midpoint of the two repositories (i.e., at the centerline of the experimental region) for consistency with the radial-concentric flow assumption

Grid Cell Size, Cross-sectional Area, and Flaring Refinement

- The columns of cells adjacent to waste panel excavations should be sized equivalent to and maintain area and volume ratios of unity with the waste panel cells to expand the starting location for flaring to ensure that brine saturation of the waste panels is not governed by an arbitrary grid cell size and derived cross-sectional area dependence

TBM Grid Flaring Methodology Conclusions (cont.)

Base Volume to Grid Flaring

- To achieve unity in area and volume ratios of adjacent to waste panel cells, the grid flaring should not include the adjacent to waste panel cells; flaring at the 2nd cell outside the adjacent waste panel cells and beyond will continue to conserve volume surrounding the repository for transport calculation considerations

Left/Right Model Domain Boundary Cells

- To ensure that boundary conditions are not artificially moved closer to the repository excavations, the left and right-most cells should be relatively small (Δx) in order to have the "cell center" boundary conditions not inadvertently applied some 6000 meters closer than anticipated (as is the case for CRA19S with the leftmost cell column with a +12000-meter width)

Domain Extents

- Establish a left/right domain boundary of 15 miles from the center of the repository experimental areas (note further adjustments will need to be made once knowledge of the expanded repository design solidifies)

Comparison of CRA19S and CRA19W vs CRA19SWe

Objective

- Evaluate pressure, saturation, and brine/gas flow within the repository to determine the degree to which two "isolated" vs one "integrated" model and revised grid flaring affects the repository predictions
- Evaluate impact of modifications to TMB grid flaring methodology for the integrated model

Scope

- Evaluate the first 100 vectors (Replicate 1) for Scenario 1, Scenario 2, and Scenario 7
  - Scenario 1 – undisturbed (no borehole)
  - Scenario 2 – E1 intrusion through the "old" south repository waste panel into the underlying Castile reservoir
  - Scenario 7 – E1 intrusion through the "new" west repository waste panel into the underlying Castile reservoir [new scenario]

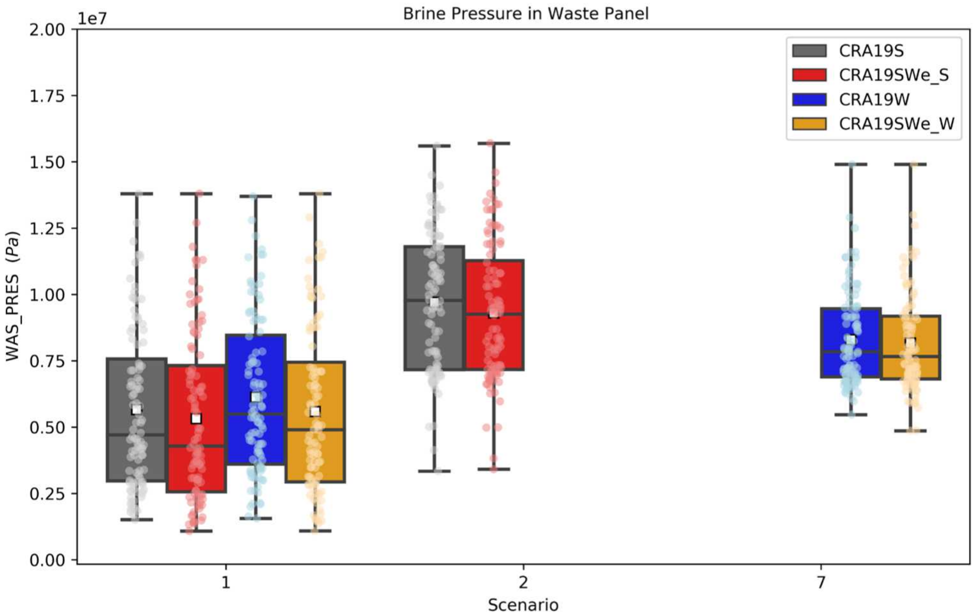
Note

- Box plots represent the temporal average values (integrated function average over the simulation duration) with whiskers representing min and max values, box indicating the 1st and 3rd quartiles, horizontal black line indicating the median, and white square box indicating the mean

Naming Conventions

- CRA19S – results for old "south" repository from two-grid uncoupled model
- CRA19W – results for new "west" repository from two-grid uncoupled model
- CRA19SWe_S – results for old "south" repository from one-grid integrated model
- CRA19SWe_W – results for new "west" repository from one-grid integrated model

Comparison of CRA19S and CRA19W vs CRA19SWe

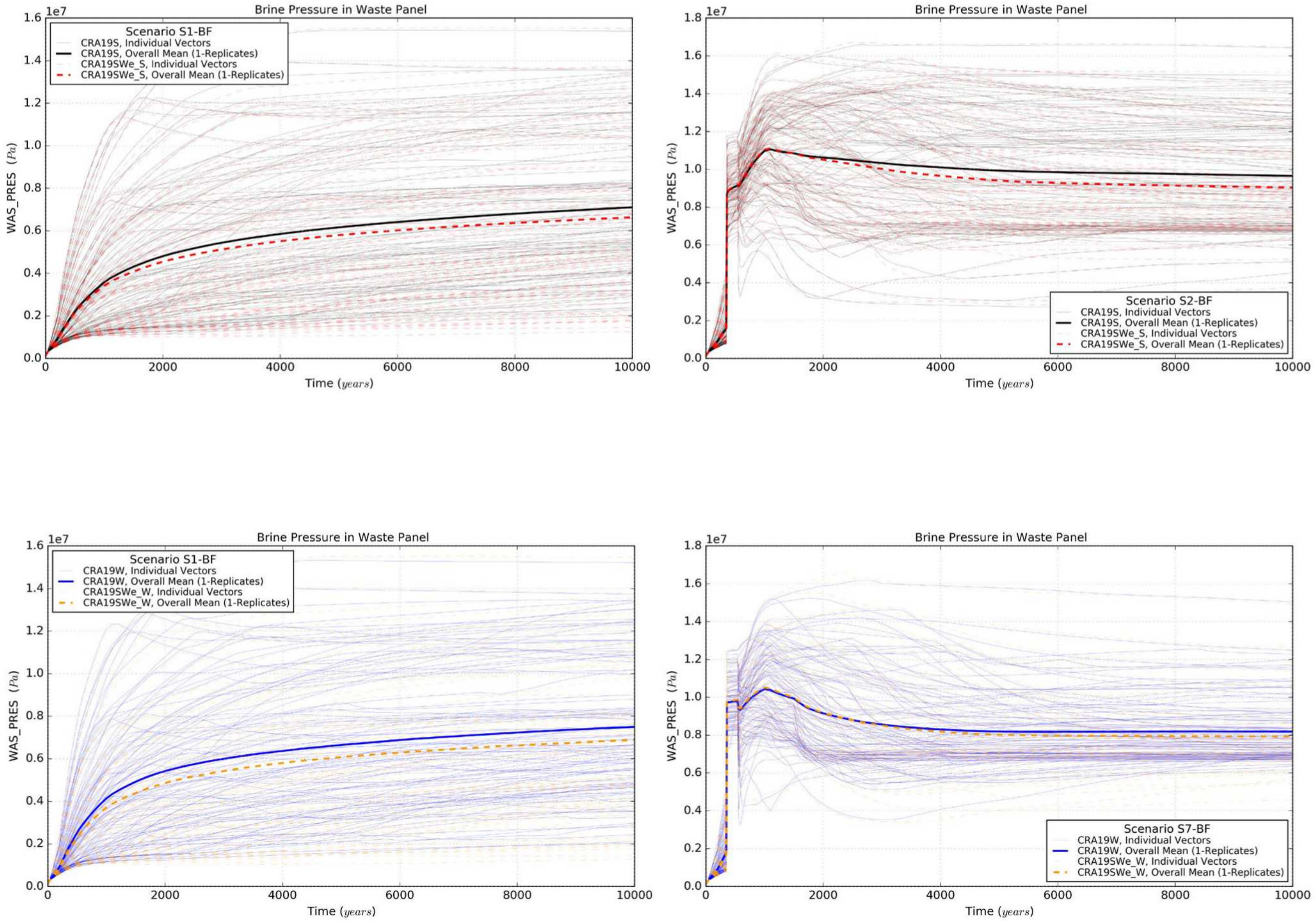


Scenario 1

Scenario 2/7

old "south"

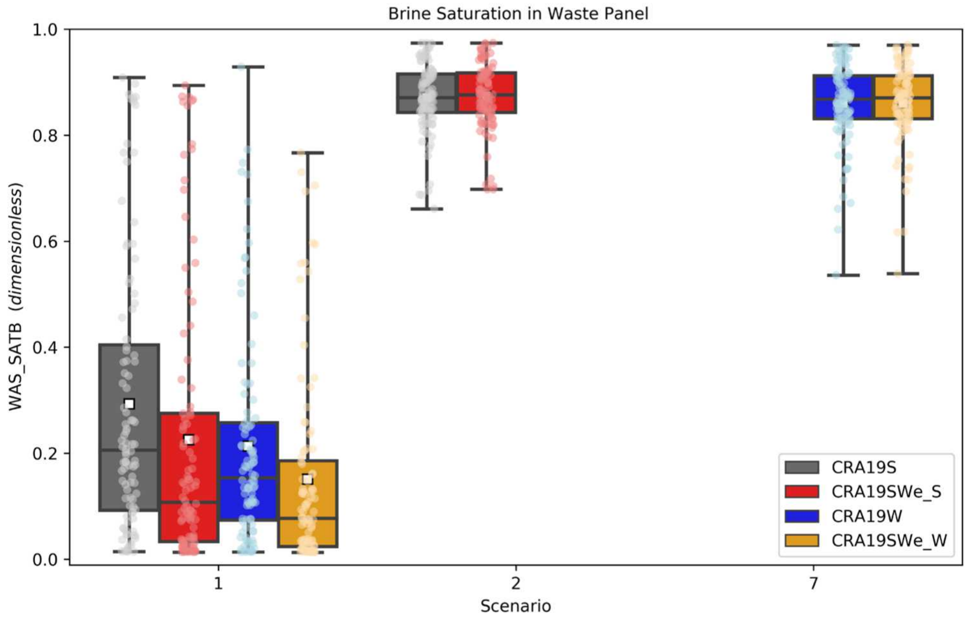
new "west"



Waste Panel Brine Pressure

- S1
  - Integrated grid model predicts lower brine pressures in the "south" and lower brine pressures in the "west" due to reduced waste panel brine saturations and associated gas generation
- S2/7
  - Integrated grid model predicts lower brine pressures in the "south" and lower brine pressures in the "west" due to an enhanced ability to flow generated gas into the full size experimental area (and beyond)

Comparison of CRA19S and CRA19W vs CRA19SWe

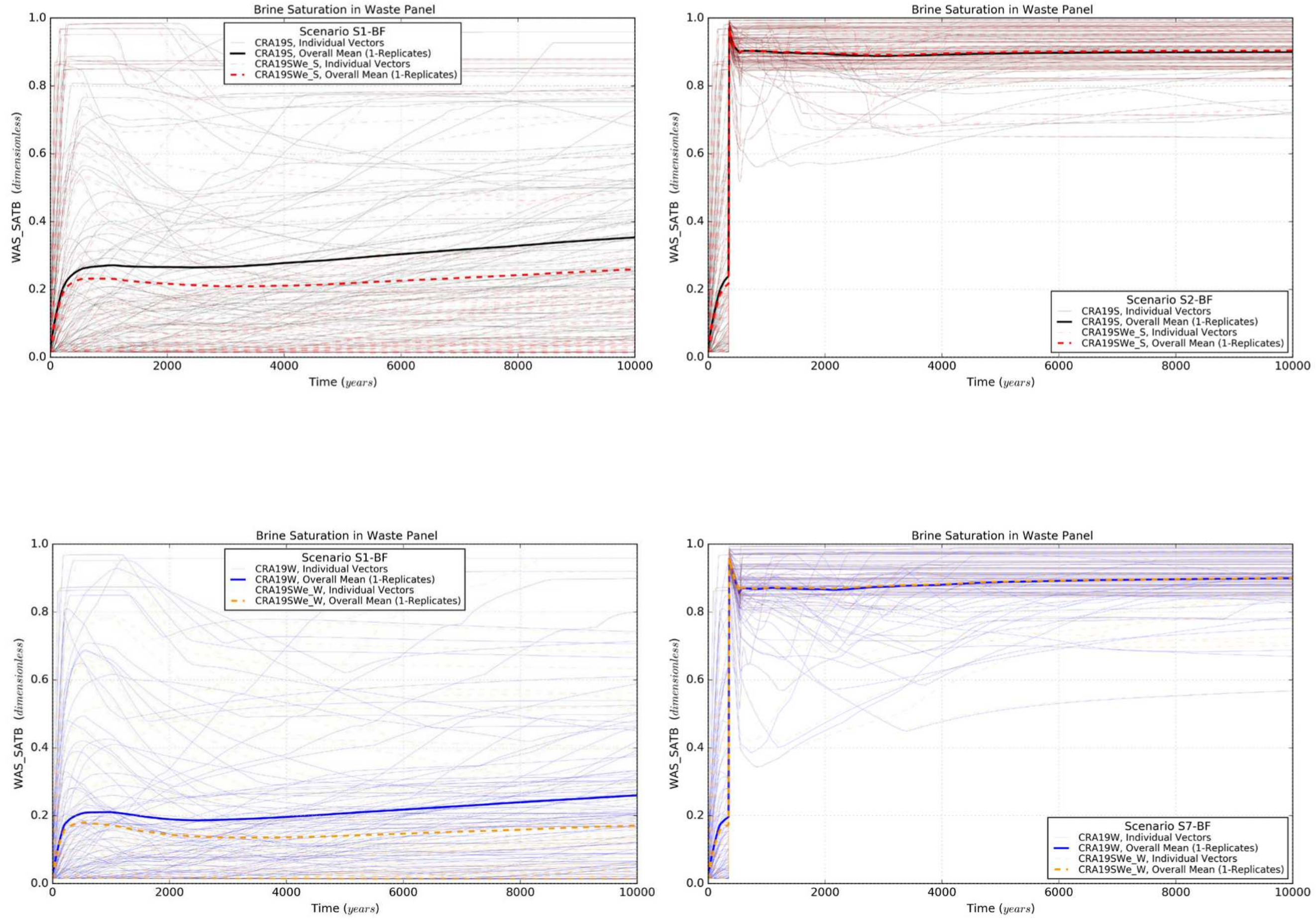


Scenario 1

Scenario 2/7

old "south"

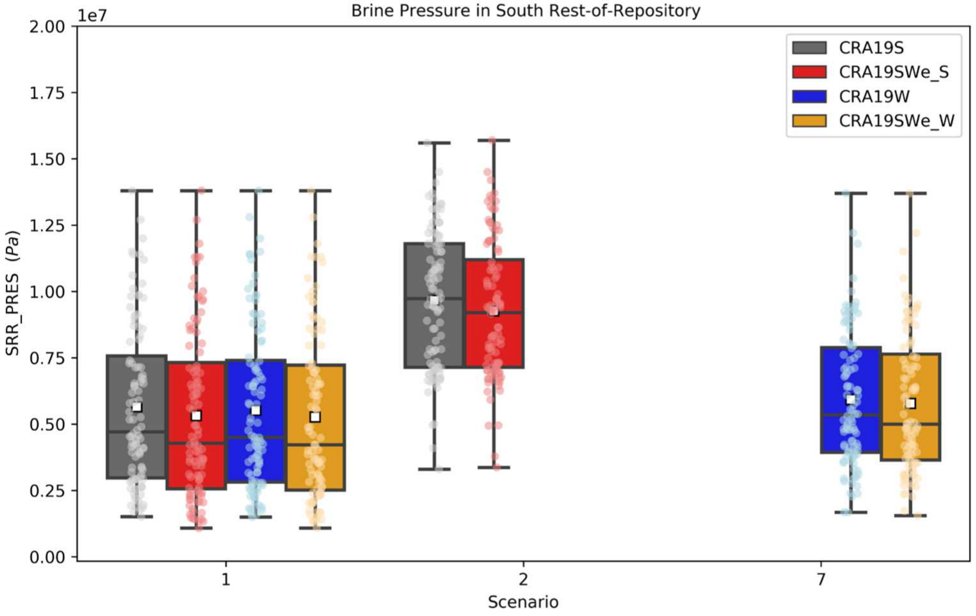
new "west"



Waste Panel Brine Saturation

- S1
  - Integrated grid model predicts substantially lower brine saturation in the "south" and substantially lower brine saturation in the "west" due to reduced adjacent Salado grid cell cross-sectional area ratios
- S2/7
  - Integrated grid model predicts slightly higher brine saturation in the "south" and slightly higher brine saturation in the "west" due to reduced waste panel brine pressures

Comparison of CRA19S and CRA19W vs CRA19SWe

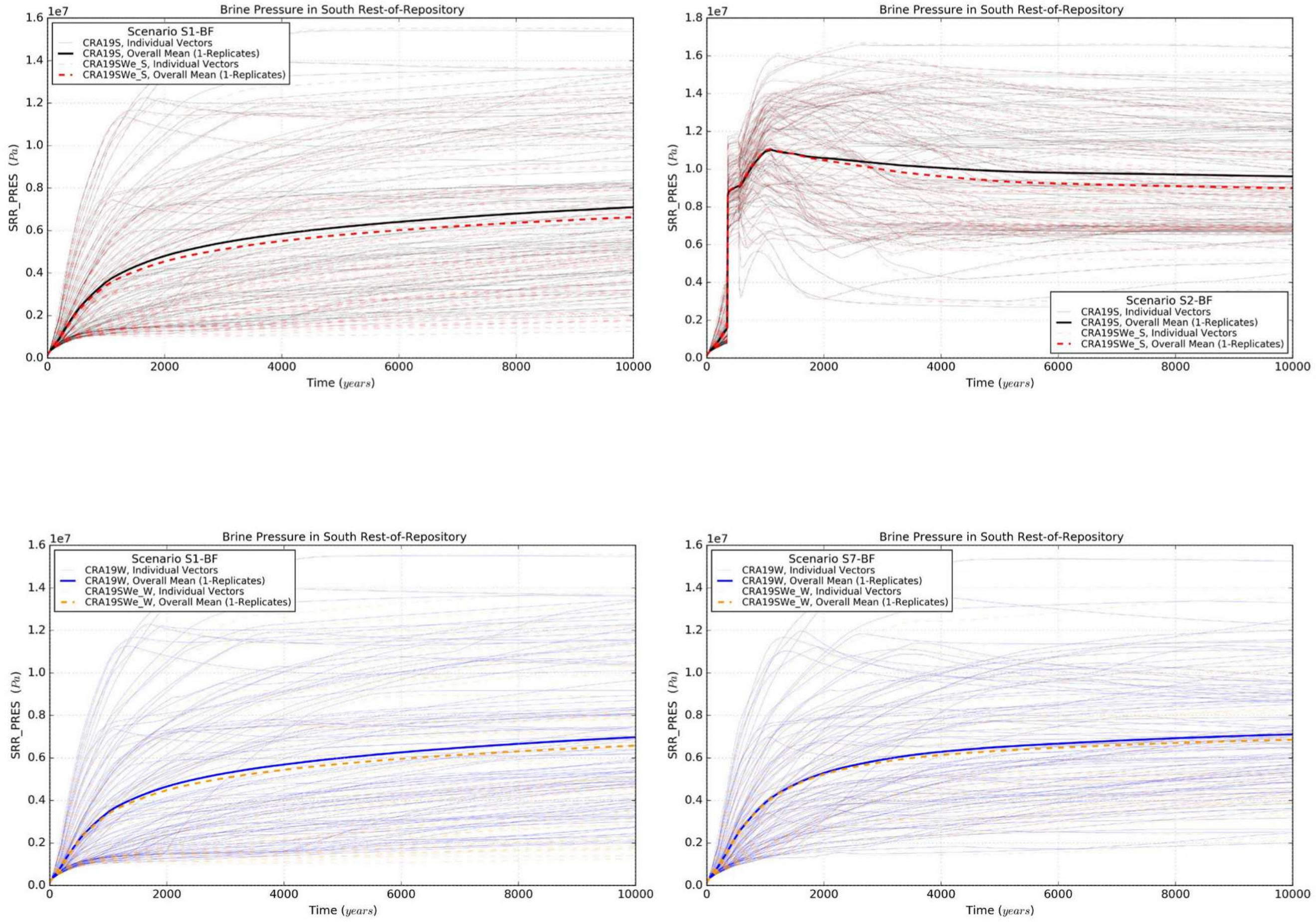


Scenario 1

Scenario 2/7

old "south"

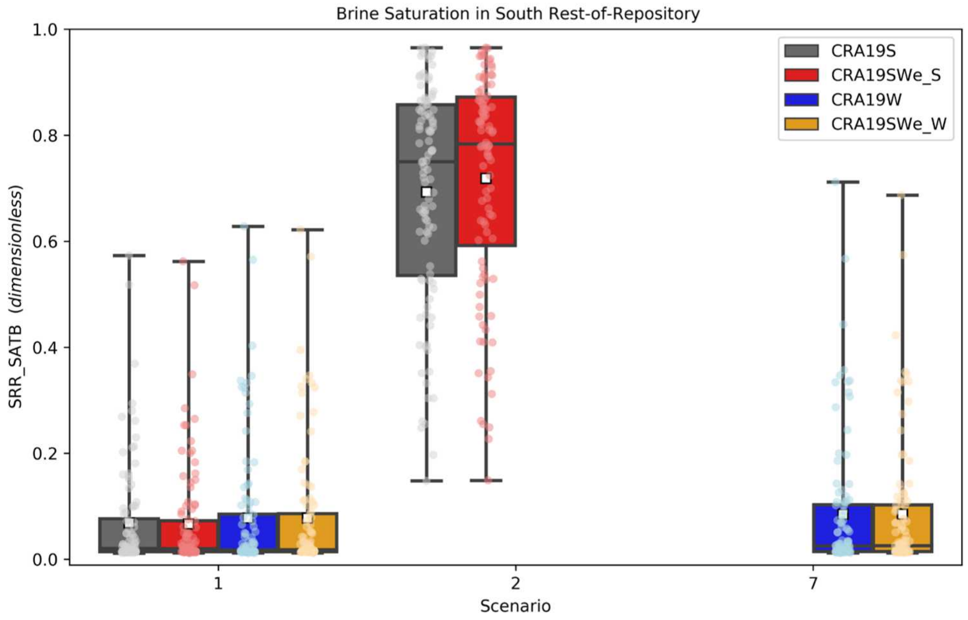
new "west"



South Rest-of-Repository Brine Pressure

- S1
  - Integrated grid model predicts lower brine pressures in the "south" and lower brine pressures in the "west" due to reduced SRoR brine saturations and associated gas generation
- S2/7
  - Integrated grid model predicts lower brine pressures in the "south" and lower brine pressures in the "west" due to an enhanced ability to flow generated gas into the full size experimental area (and beyond)

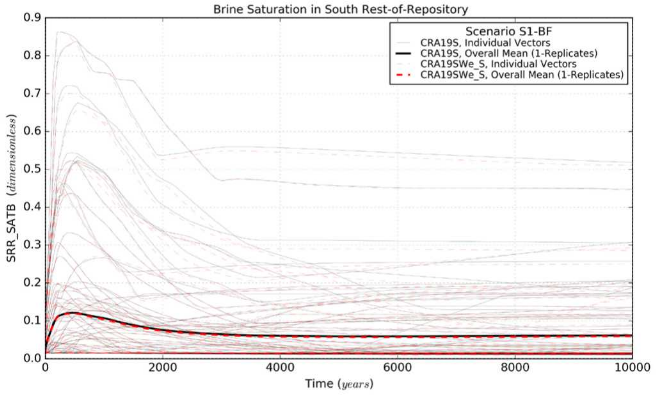
Comparison of CRA19S and CRA19W vs CRA19SWe

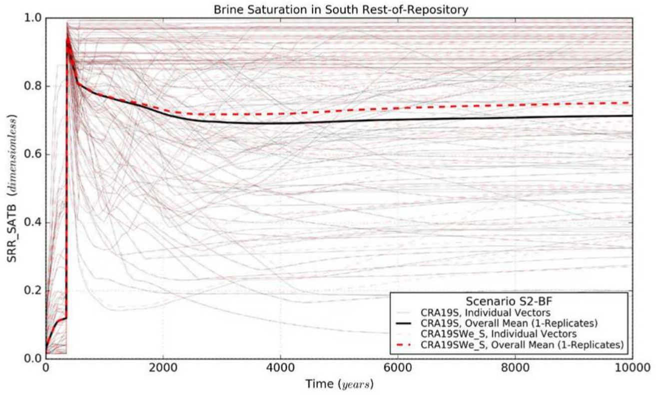


Scenario 1

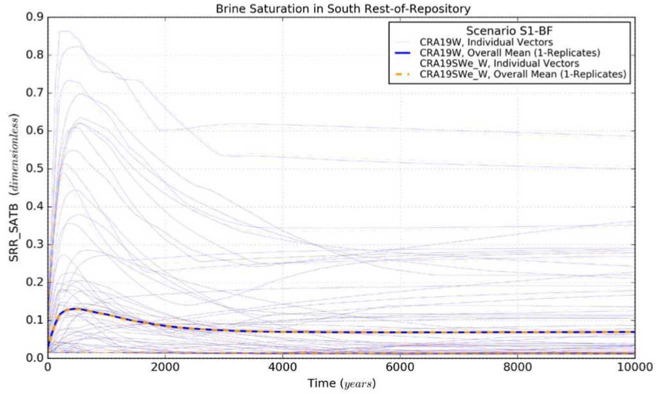
Scenario 2/7

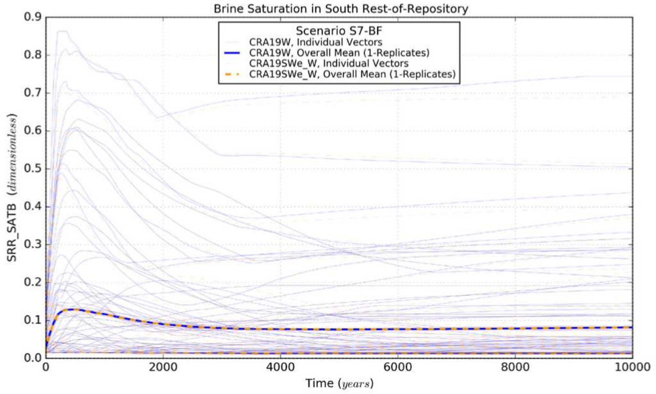
old "south"





new "west"

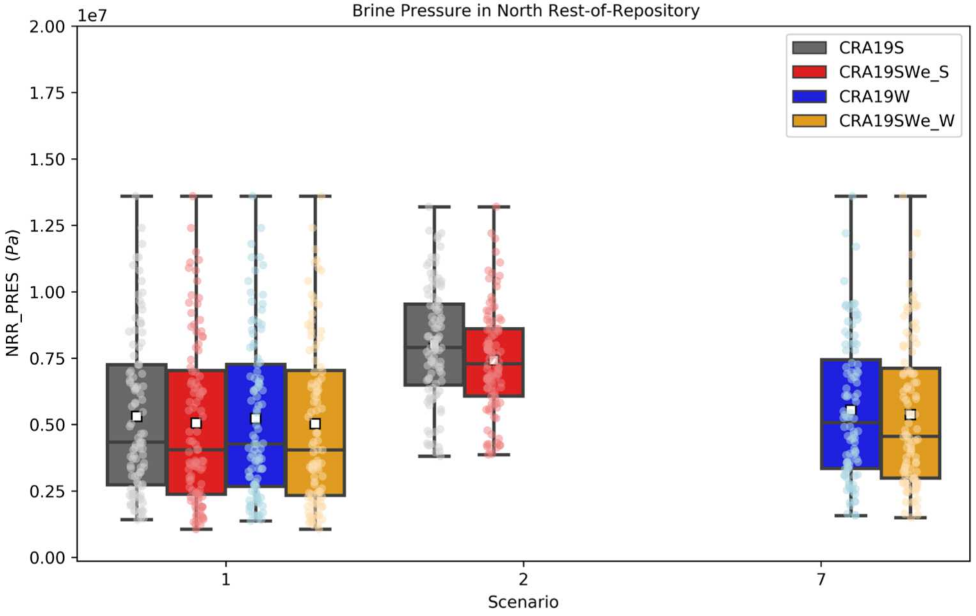




South Rest-of-Repository Brine Saturation

- S1
  - Integrated grid model predicts slightly lower brine saturation in the "south" due to open communication with the lower brine saturation in the waste panel and equivalent brine saturation in the "west" due to the isolation by panel closures from adjacent areas
- S2/7
  - Integrated grid model predicts higher brine saturation in the "south" and slightly higher brine saturation in the "west" due to lower SRoR brine pressures

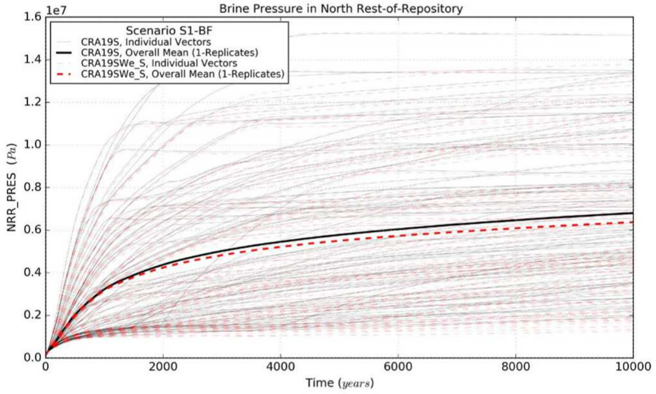
Comparison of CRA19S and CRA19W vs CRA19SWe

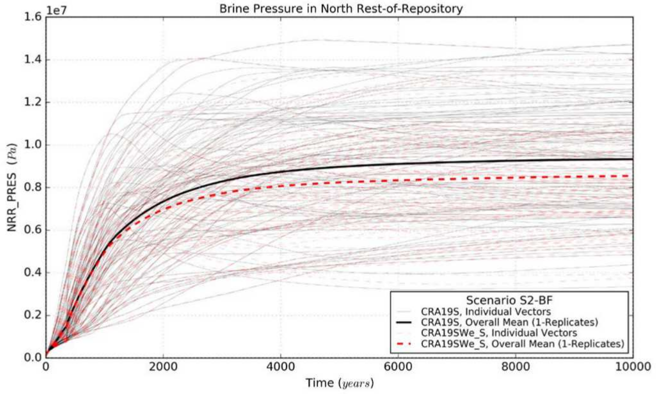


Scenario 1

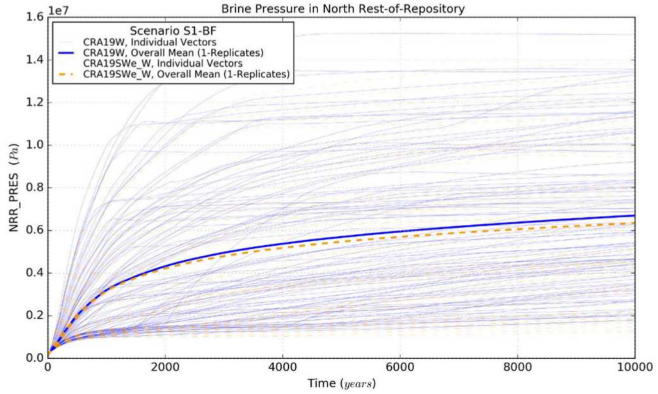
Scenario 2/7

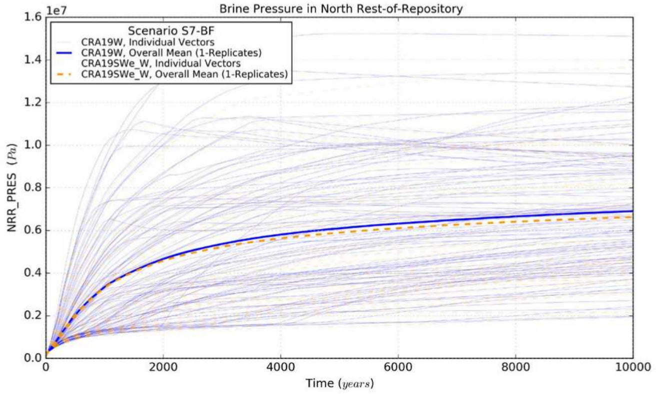
old "south"





new "west"

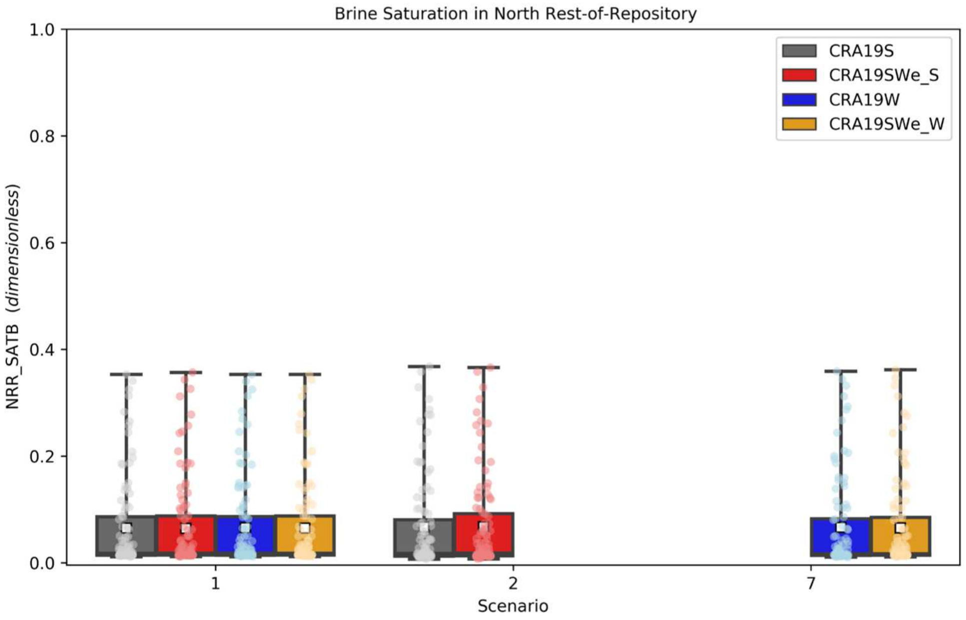




North Rest-of-Repository Brine Pressure

- S1
  - Integrated grid model predicts lower brine pressures in the "south" and lower brine pressures in the "west" due to reduced NRoR brine saturations and associated gas generation
- S2/7
  - Integrated grid model predicts lower brine pressures in the "south" and lower brine pressures in the "west" due to an enhanced ability to flow generated gas into the full size experimental area (and beyond)

Comparison of CRA19S and CRA19W vs CRA19SWe



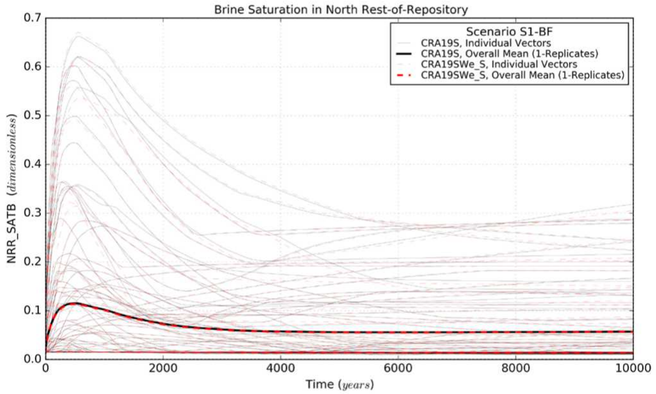
North Rest-of-Repository Brine Saturation

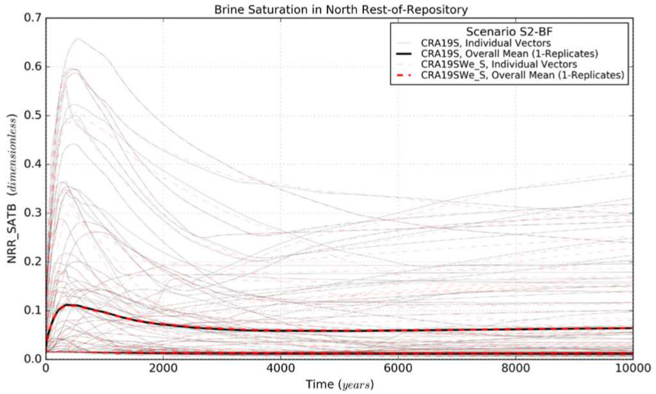
- S1
  - Integrated grid model predicts slightly lower brine saturation in the "south" and slightly lower brine saturation in the "west" due to isolation by panel closures from adjacent areas
- S2/7
  - Integrated grid model predicts slightly higher brine saturation in the "south" and slightly lower brine saturation in the "west" due to isolation by panel closures in adjacent areas

Scenario 1

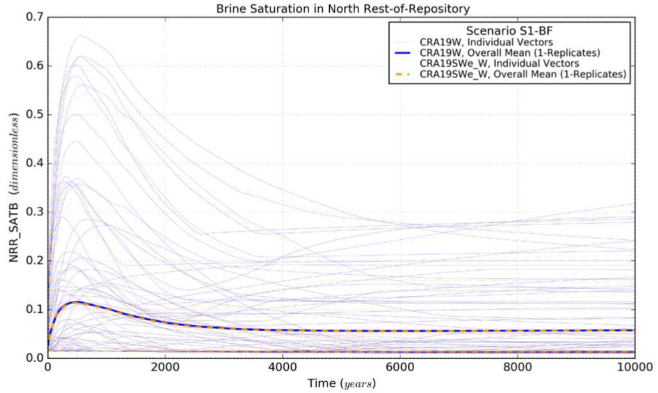
Scenario 2/7

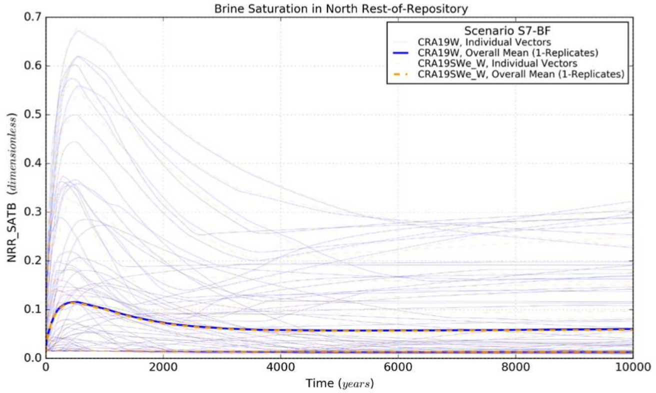
old "south"



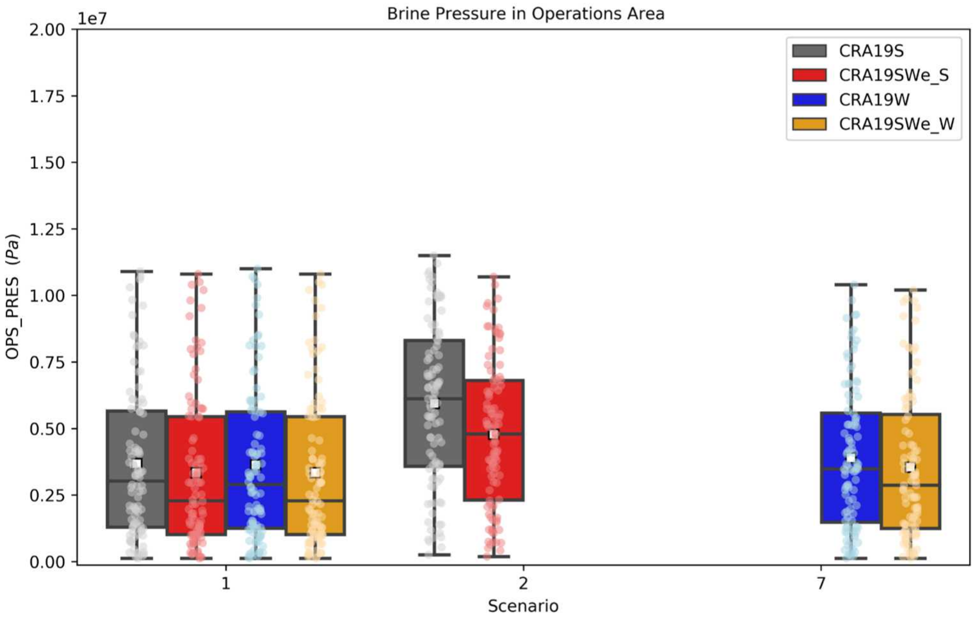


new "west"





Comparison of CRA19S and CRA19W vs CRA19SWe



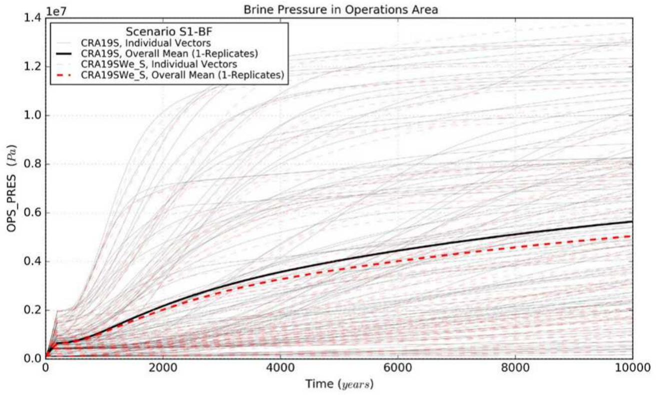
Operations Area Brine Pressure

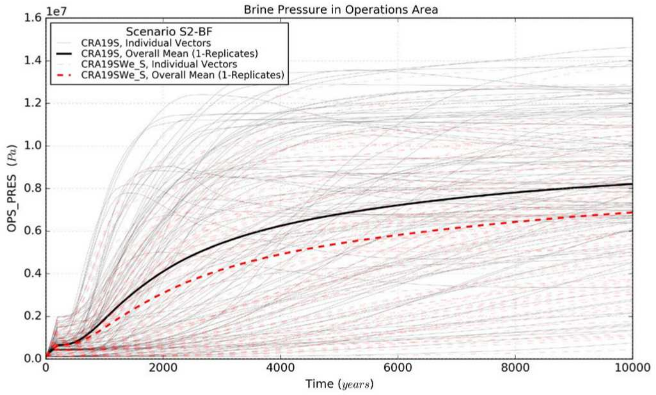
- S1
  - Integrated grid model predicts lower brine pressures in the "south" and lower brine pressures in the "west" due to lower operations area brine saturation
- S2/7
  - Integrated grid model predicts substantially lower brine pressures in the "south" and lower brine pressures in the "west" due to lower operations area brine saturation

Scenario 1

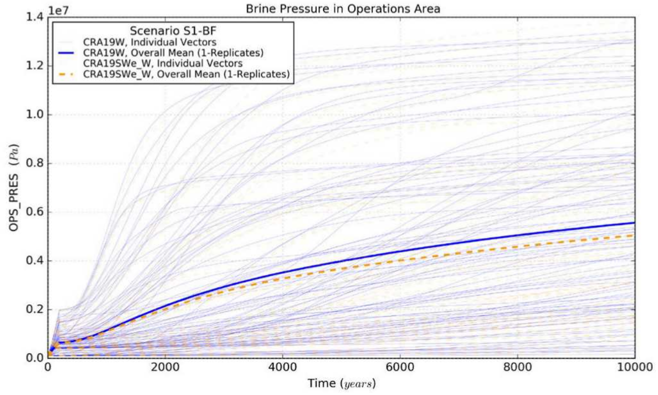
Scenario 2/7

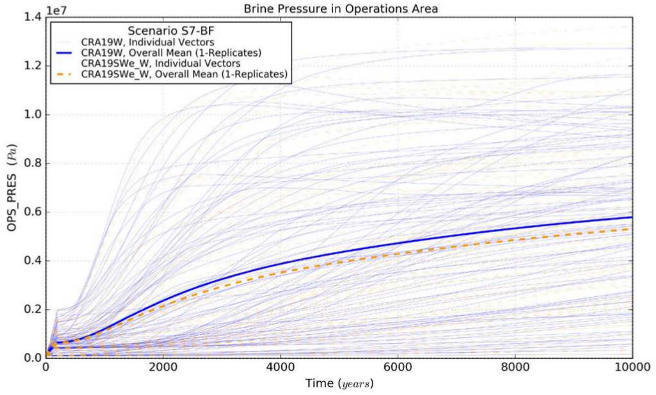
old "south"



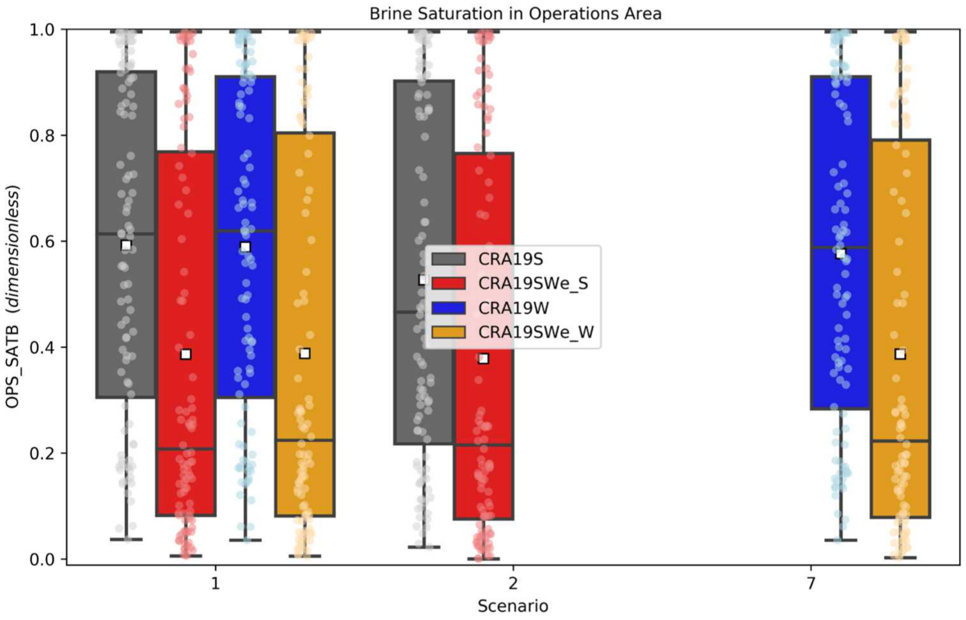


new "west"





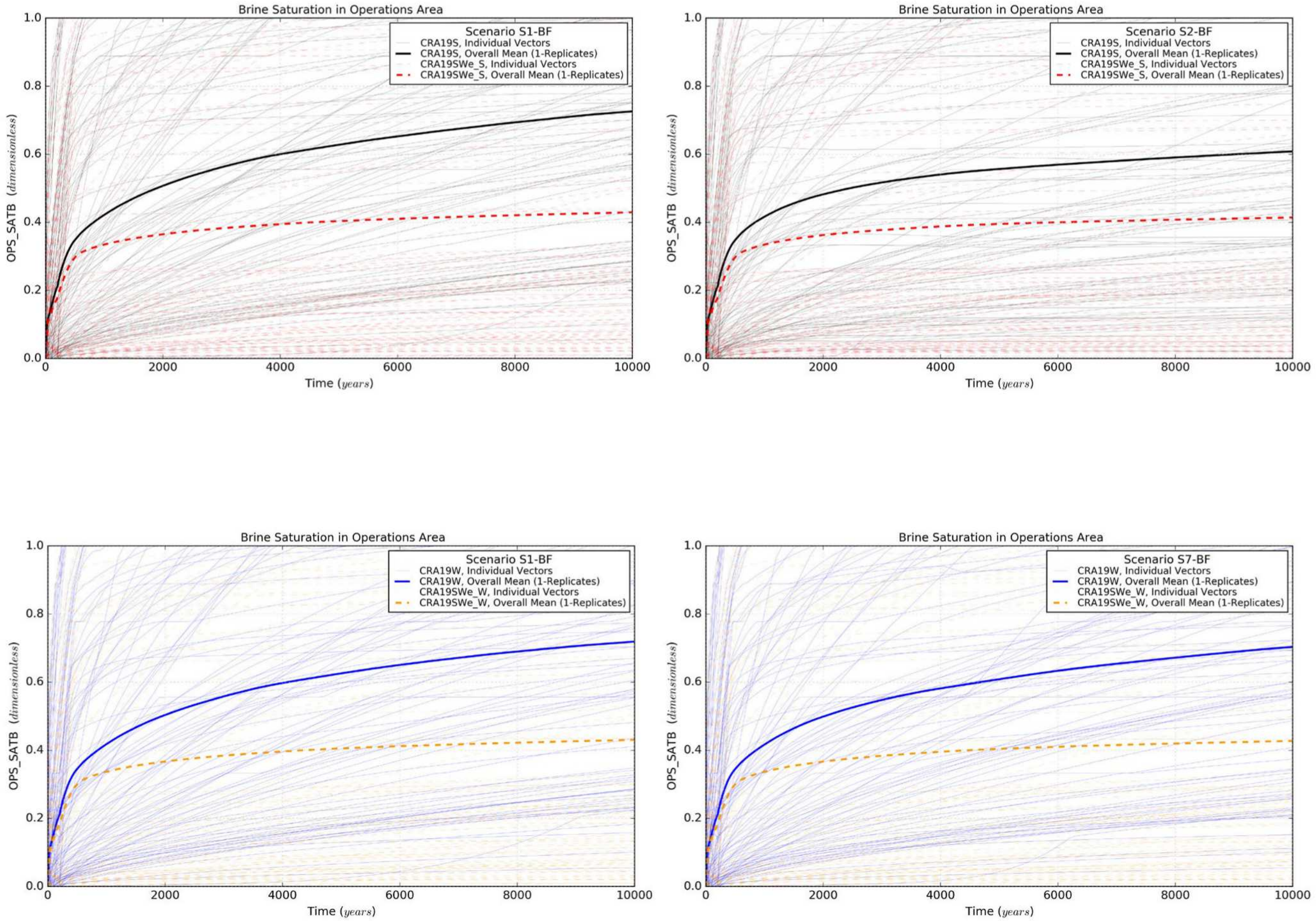
Comparison of CRA19S and CRA19W vs CRA19SWe



Scenario 1 Scenario 2/7

old "south"

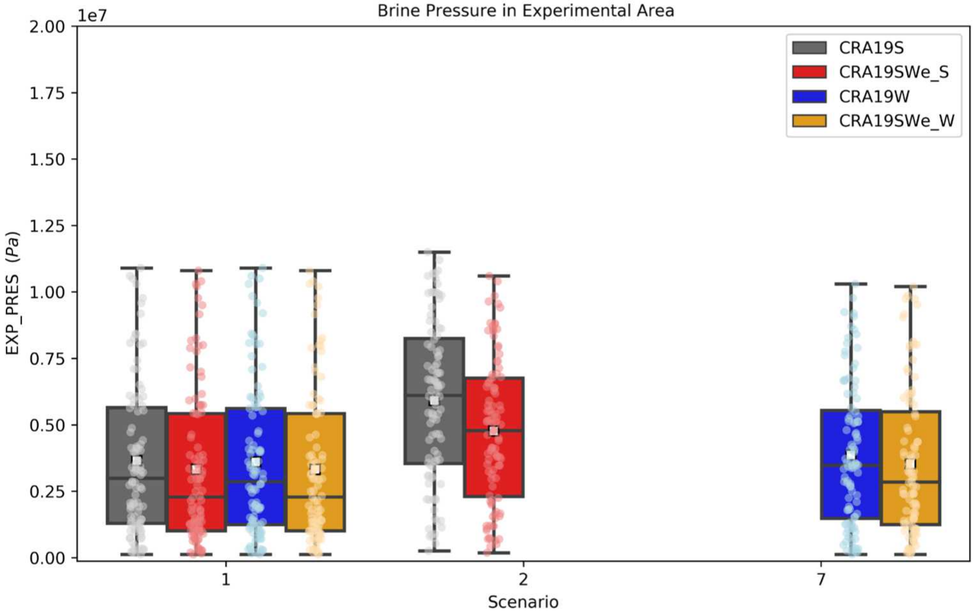
new "west"



Operations Area Brine Saturation

- S1
  - Integrated grid model predicts substantially lower brine saturation in the "south" and substantially lower brine saturation in the "west" due to lower experimental area saturation
- S2/7
  - Integrated grid model predicts substantially lower brine saturation in the "south" and substantially lower brine saturation in the "west" due to lower experimental area saturation

Comparison of CRA19S and CRA19W vs CRA19SWe

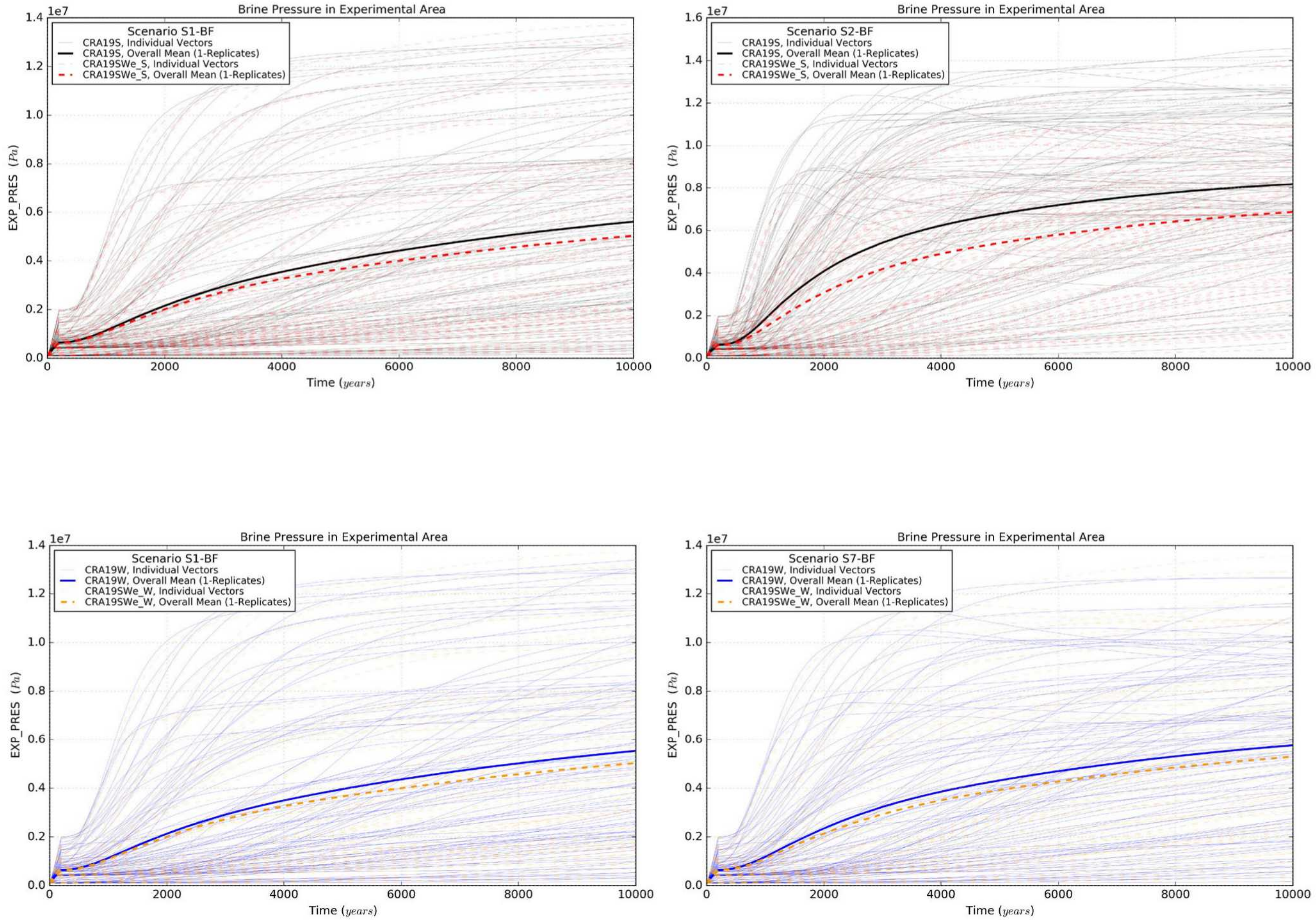


Scenario 1

Scenario 2/7

old “south”

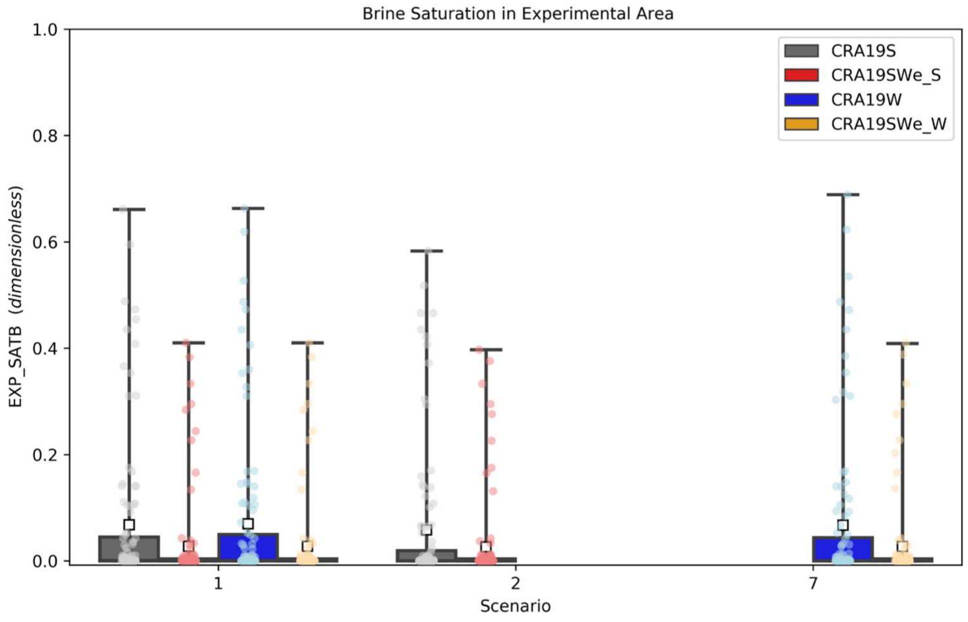
new “west”



Experimental Area Brine Pressure

- S1
  - Integrated grid model predicts lower brine pressures in the “south” and lower brine pressures in the “west” due to increased experimental area volume and reduced experimental area brine saturation
- S2/7
  - Integrated grid model predicts lower brine pressures in the “south” and lower brine pressures in the “west” due to increased experimental area volume and reduced experimental area brine saturation

Comparison of CRA19S and CRA19W vs CRA19SWe

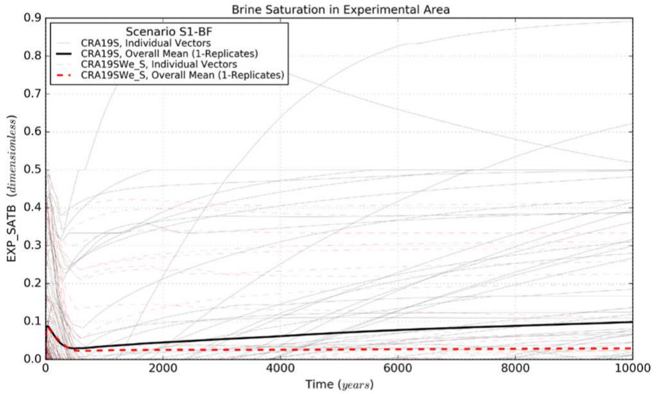


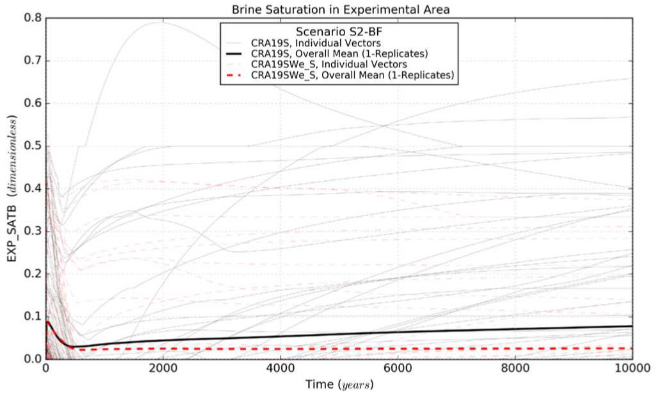
Experimental Area Brine Saturation

- S1
  - Integrated grid model predicts substantially lower brine saturation in the "south" and substantially lower brine saturation in the "west" due to reduced adjacent grid cell cross-sectional area ratios
- S2/7
  - Integrated grid model predicts substantially lower brine saturation in the "south" and substantially lower brine saturation in the "west" due to reduced adjacent grid cell cross-sectional area ratios

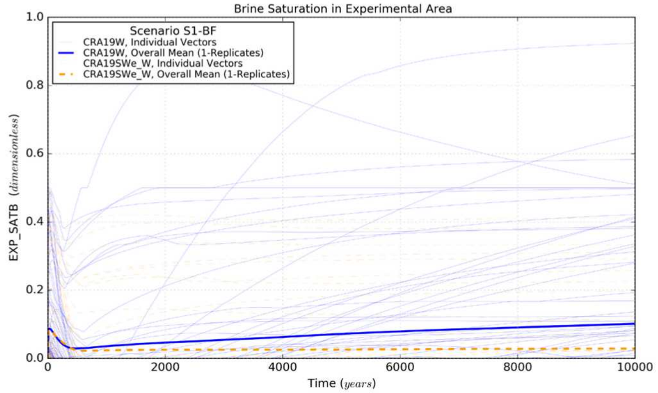
Scenario 1 | Scenario 2/7

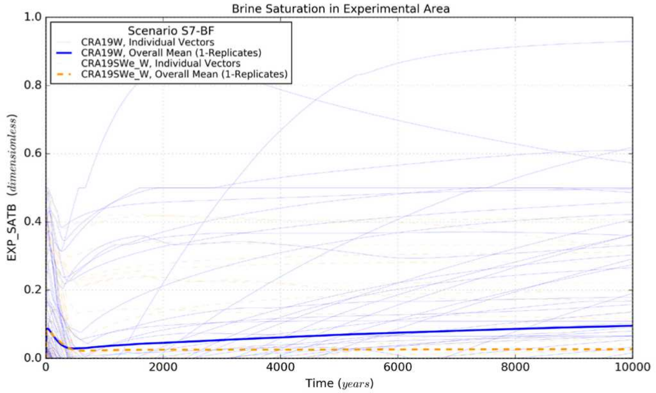
old "south"



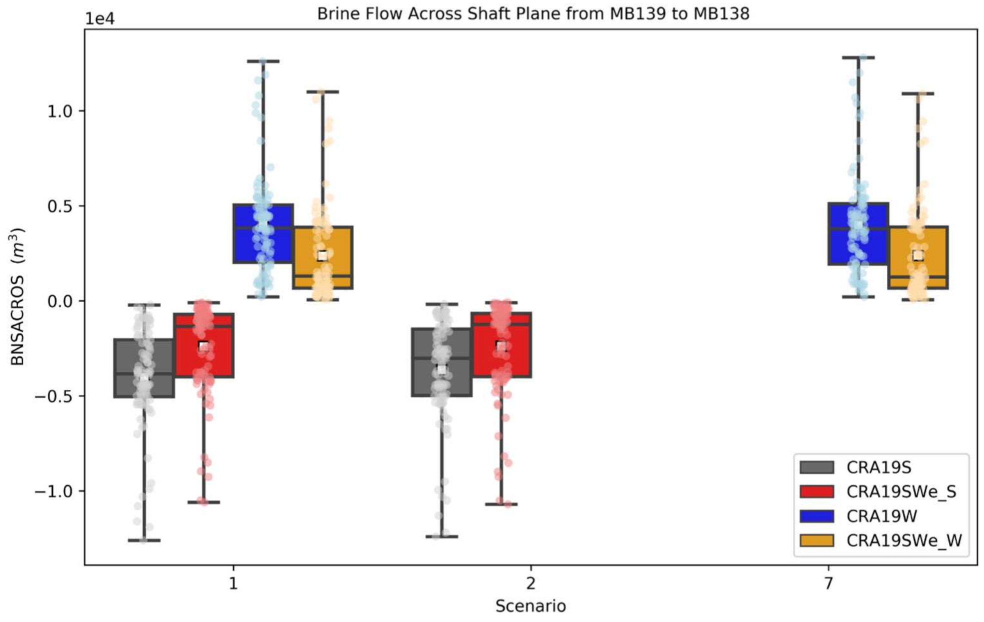


new "west"





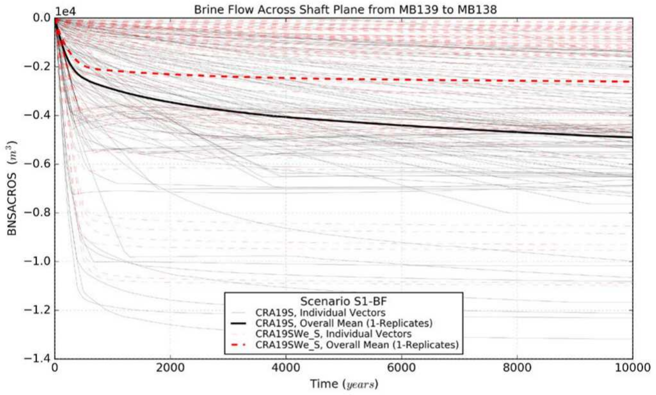
Comparison of CRA19S and CRA19W vs CRA19SWe

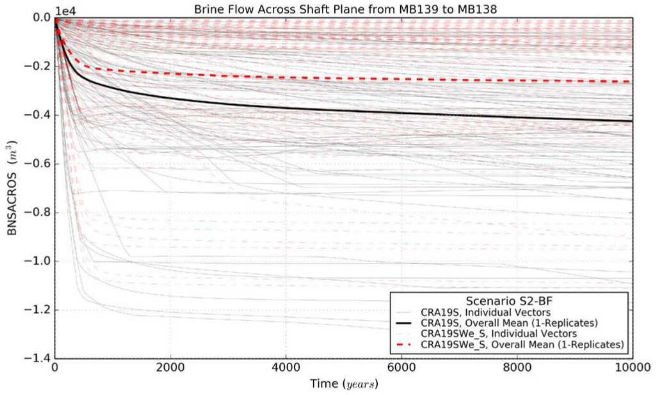


Scenario 1

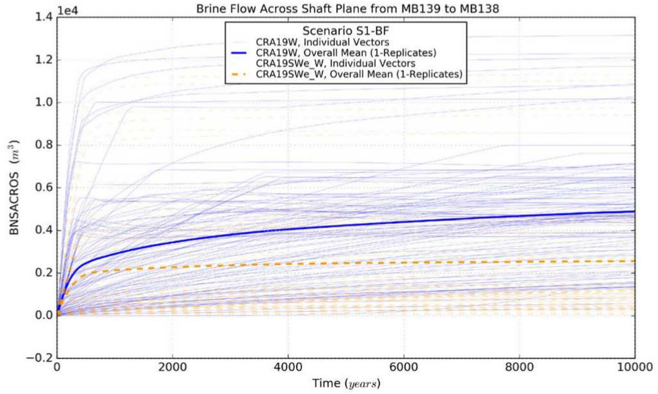
Scenario 2/7

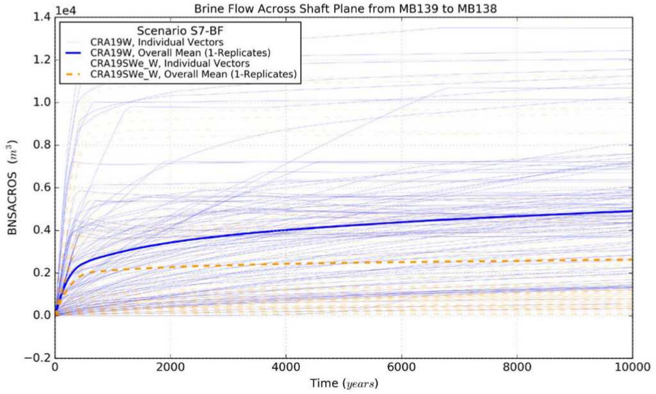
old "south"





new "west"



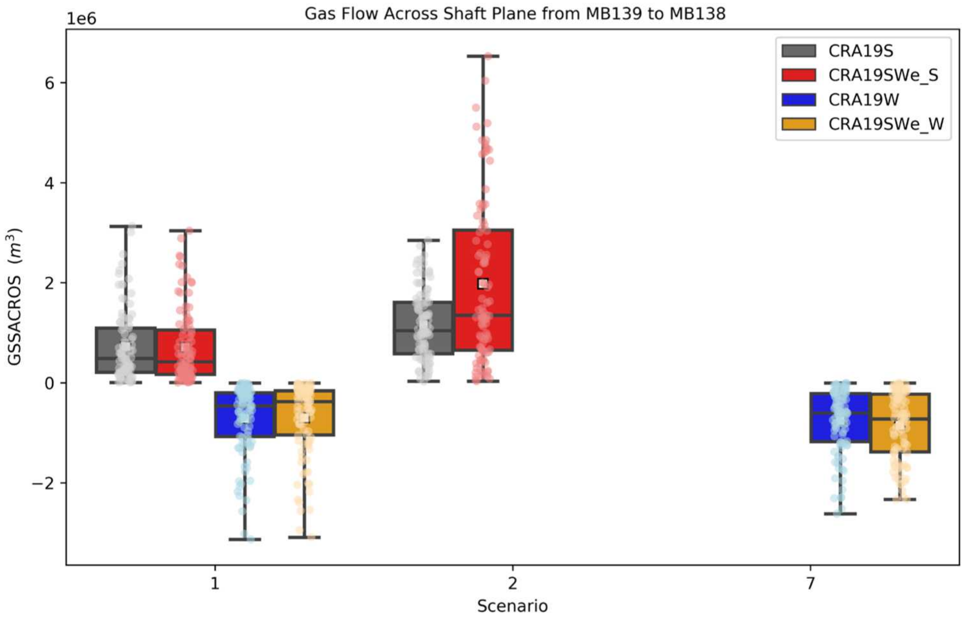


Note that sign of CRA19W across shaft flows are artificially reversed for ease of comparison with CRA19SWe_W results

Across Shaft Plane Brine Flow

- S1
  - Integrated grid model predicts lower brine flow from the experimental area toward the "south" waste panel and lower brine flow from the experimental area toward the "west" waste panel due to lower experimental area brine saturation
- S2/7
  - Integrated grid model predicts lower brine flow from the experimental area toward the "south" waste panel and lower brine flow from the experimental area toward the "west" waste panel due to lower experimental area brine saturation

Comparison of CRA19S and CRA19W vs CRA19SWe



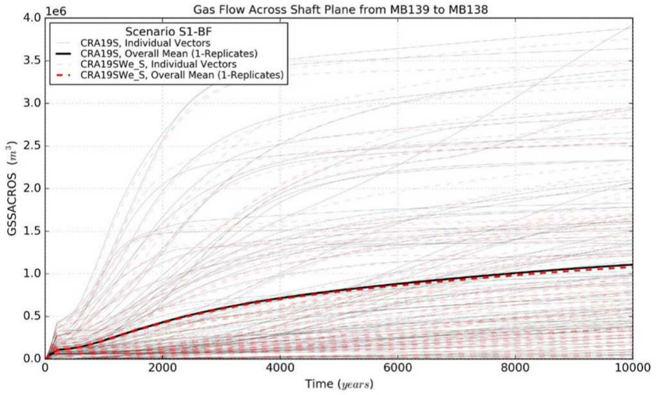
Across Shaft Plane Gas Flow

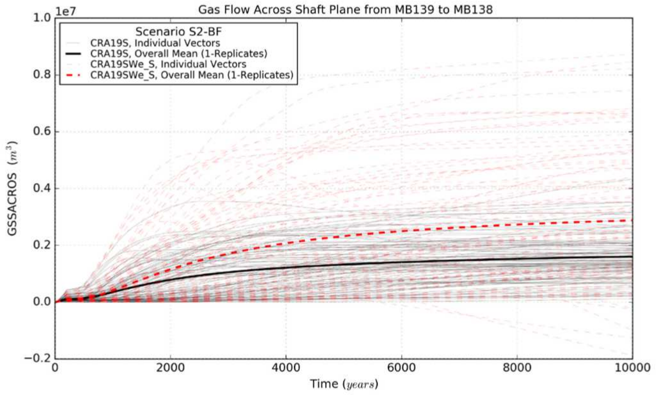
- S1
  - Integrated grid model predicts lower gas flow from the "south" waste panel toward the experimental area and lower gas flow from the "west" waste panel toward the experimental area due to lower total gas generation
- S2/7
  - Integrated grid model predicts substantially higher gas flow from the "south" waste panel toward the experimental area and higher gas flow from the "west" waste panel toward the experimental area due to higher total gas generation

Scenario 1

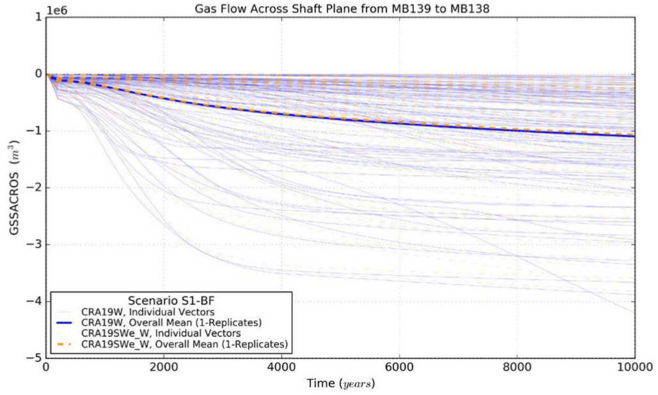
Scenario 2/7

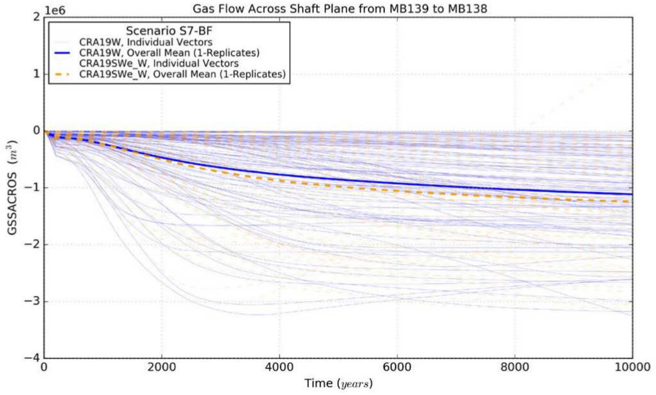
old "south"





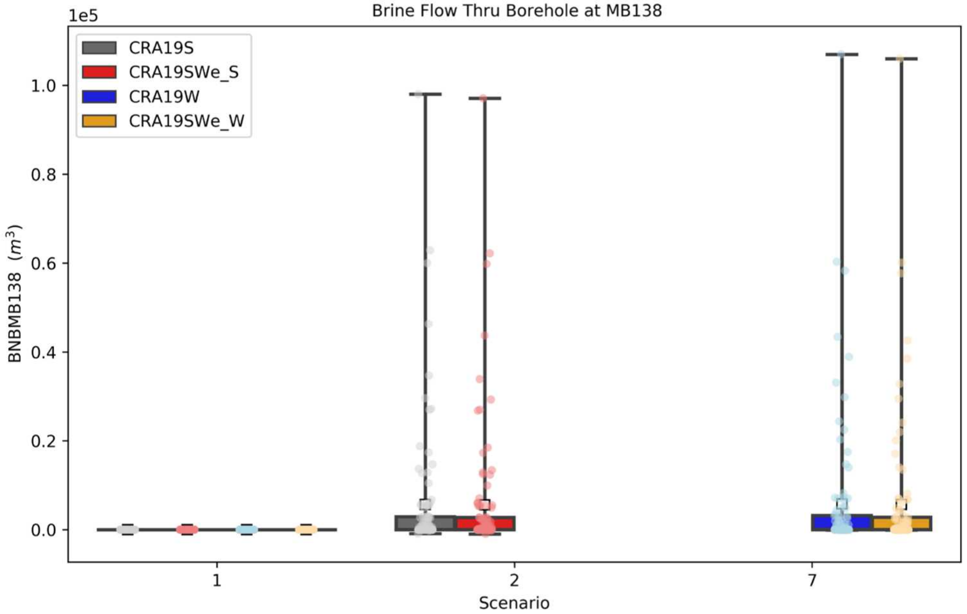
new "west"





Note that sign of CRA19W across shaft flows are artificially reversed for ease of comparison with CRA19SWe_W results

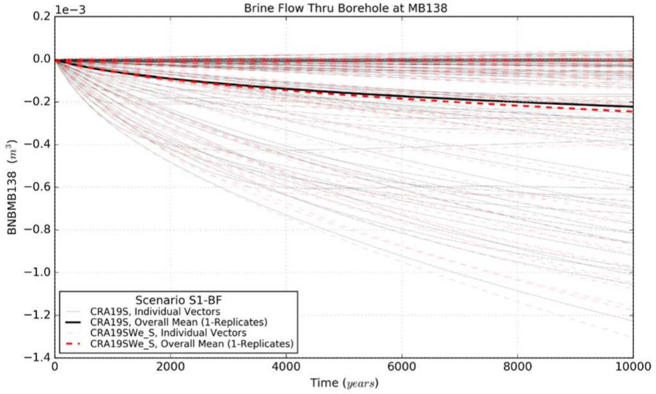
Comparison of CRA19S and CRA19W vs CRA19SWe

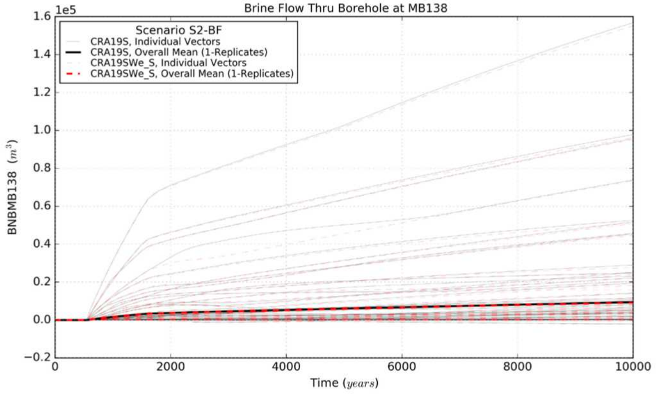


Scenario 1

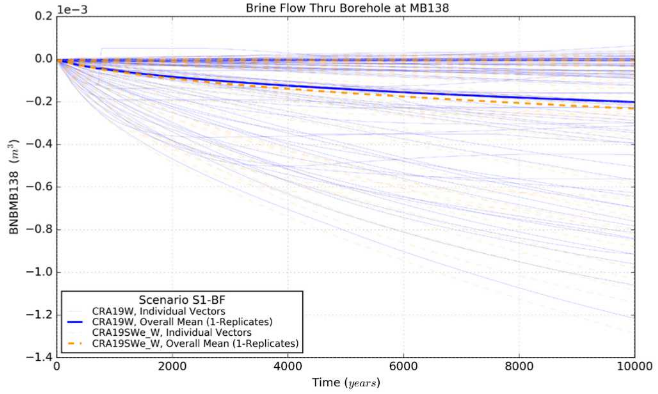
Scenario 2/7

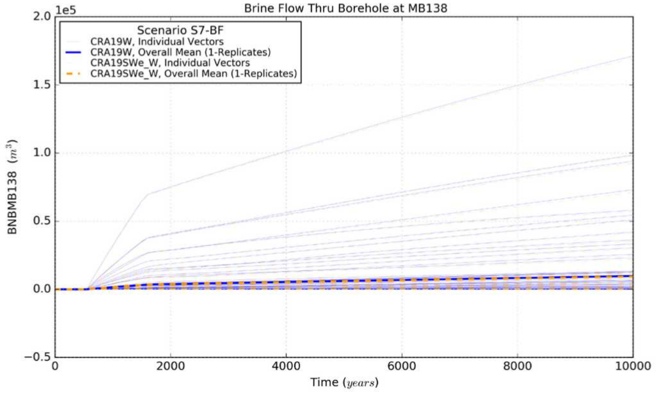
old "south"





new "west"

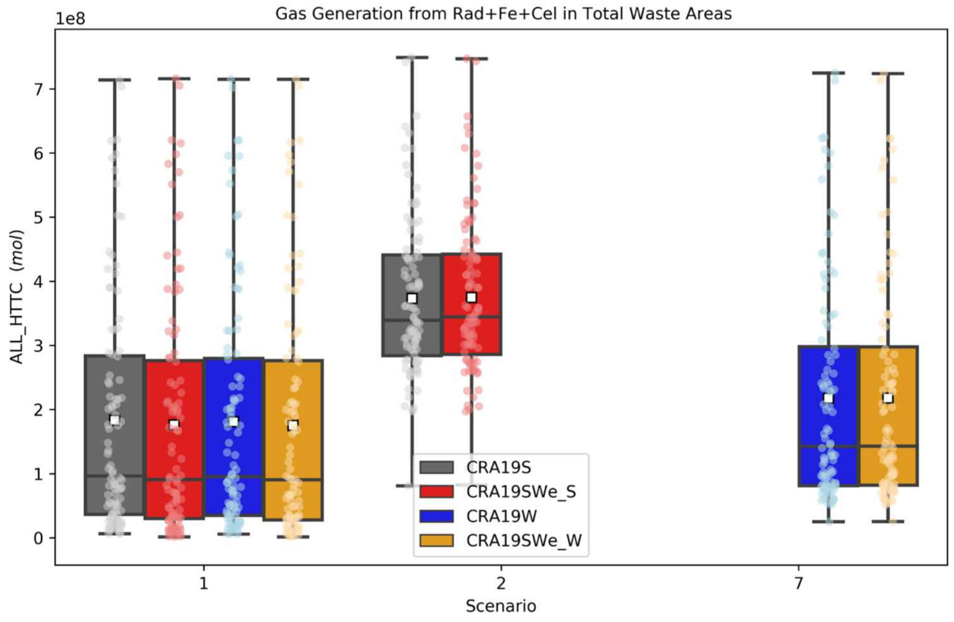




Brine Flow Thru Borehole

- S1
  - Essentially no flow
- S2/7
  - Integrated grid model predicts lower brine flow thru the borehole in the "south" and lower brine flow thru the borehole in the "west" due to lower waste panel brine pressures

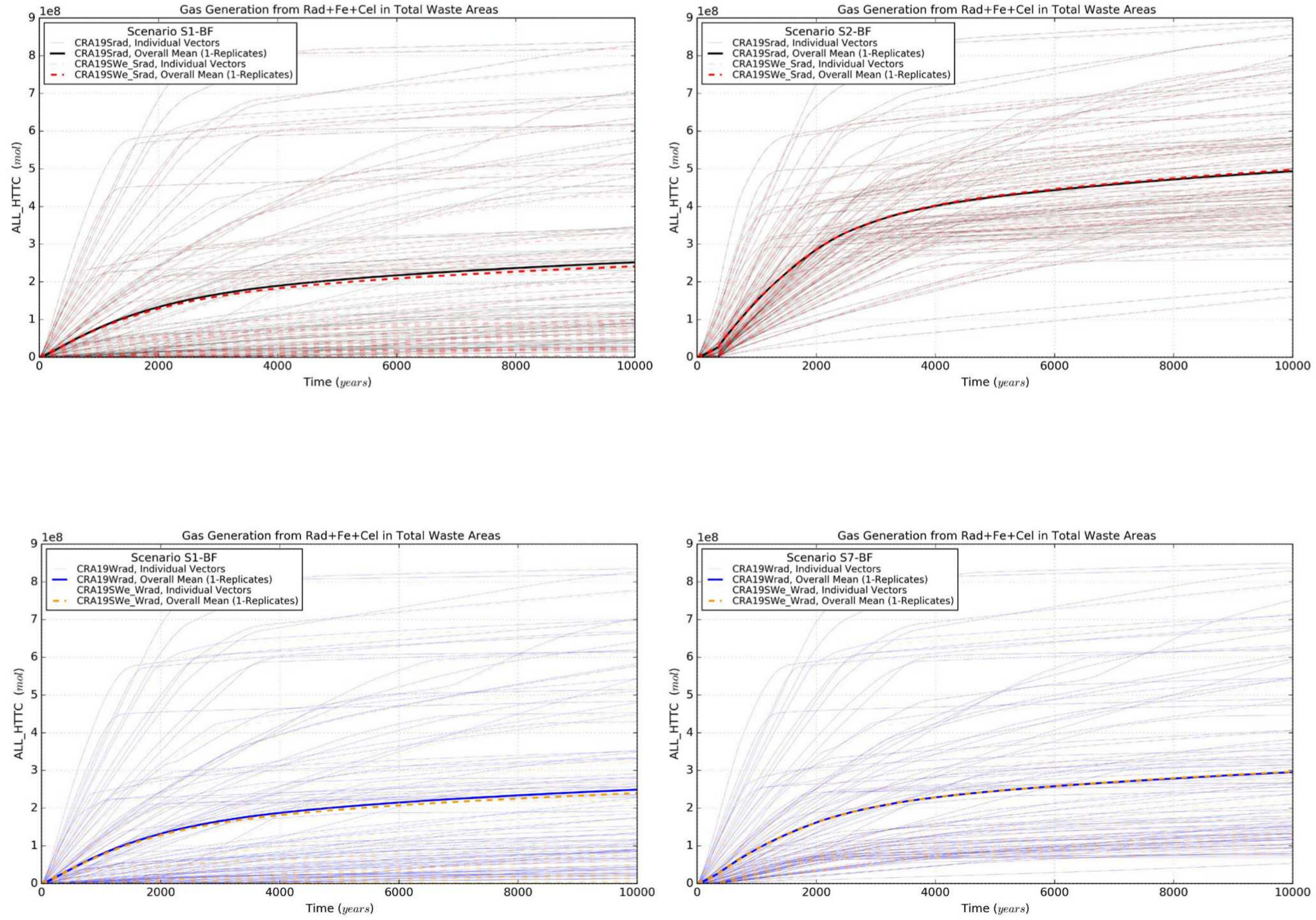
Comparison of CRA19S and CRA19W vs CRA19SWe



Scenario 1
Scenario 2/7

old "south"

new "west"



Total Gas Generation

- S1
  - Integrated grid model predicts lower total gas generation in the "south" and lower total gas generation in the "west" due to lower waste area brine saturation
- S2/7
  - Integrated grid model predicts slightly higher total gas generation in the "south" and equivalent total gas generation in the "west" due to associated waste area brine saturation

Conclusions

The primary impact on results predicted by a single "integrated" repository grid vs two "isolated" repository grids to model expansion are scenario specific

- Scenario 1 – greatest impact is to waste panel brine saturations as influenced by the flared grid implementation and associated selection of the "center of flow" and cell sizes adjacent to the excavations necessary to conserve volume surrounding the excavations
- Scenario 2/7 – greatest impact to waste area pressures is influenced by the degree to which gas generated within the waste areas flows towards the common experimental area

The comparison between a single "integrated" and two "isolated" repository BRAGFLO models clearly establishes that significant quantities of brine and gas communicate across the planes defined by the old "south" and new "west" shafts

- Greater quantities of gas generation in the "old" south waste areas (due to intrusion events that flood multiple panels without separating panel closures) results in ~2 million cubic meters (temporal average for replicate 1) of gas flowing across the old "south" shaft plane and influencing pressures and saturations within the new "west" repository

A single "integrated" grid model is recommended to support expansion

- A single-grid model will require an increase to at least 11 total BRAGFLO scenarios in order to model borehole intrusion under E1, E2, and E2E1 conditions at different times in the two borehole locations (i.e., the old "south" waste panel and the new "west" waste panel)

Further development of the "integrated" grid approach, if pursued at this time, will require substantial rework when a final expanded repository design becomes available, but infrastructure development to address Solaris run-control changes and required CUTTINGS_S and CCDFGF code development needed to handle the expanded scenarios could proceed now without substantial risk