GULF 2023 Model CSUB Package Update for the GMA 14 Model

Groundwater Management Area 14 Meeting

Agenda Item 7

May 14, 2024

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GULF 2023 CSUB Package

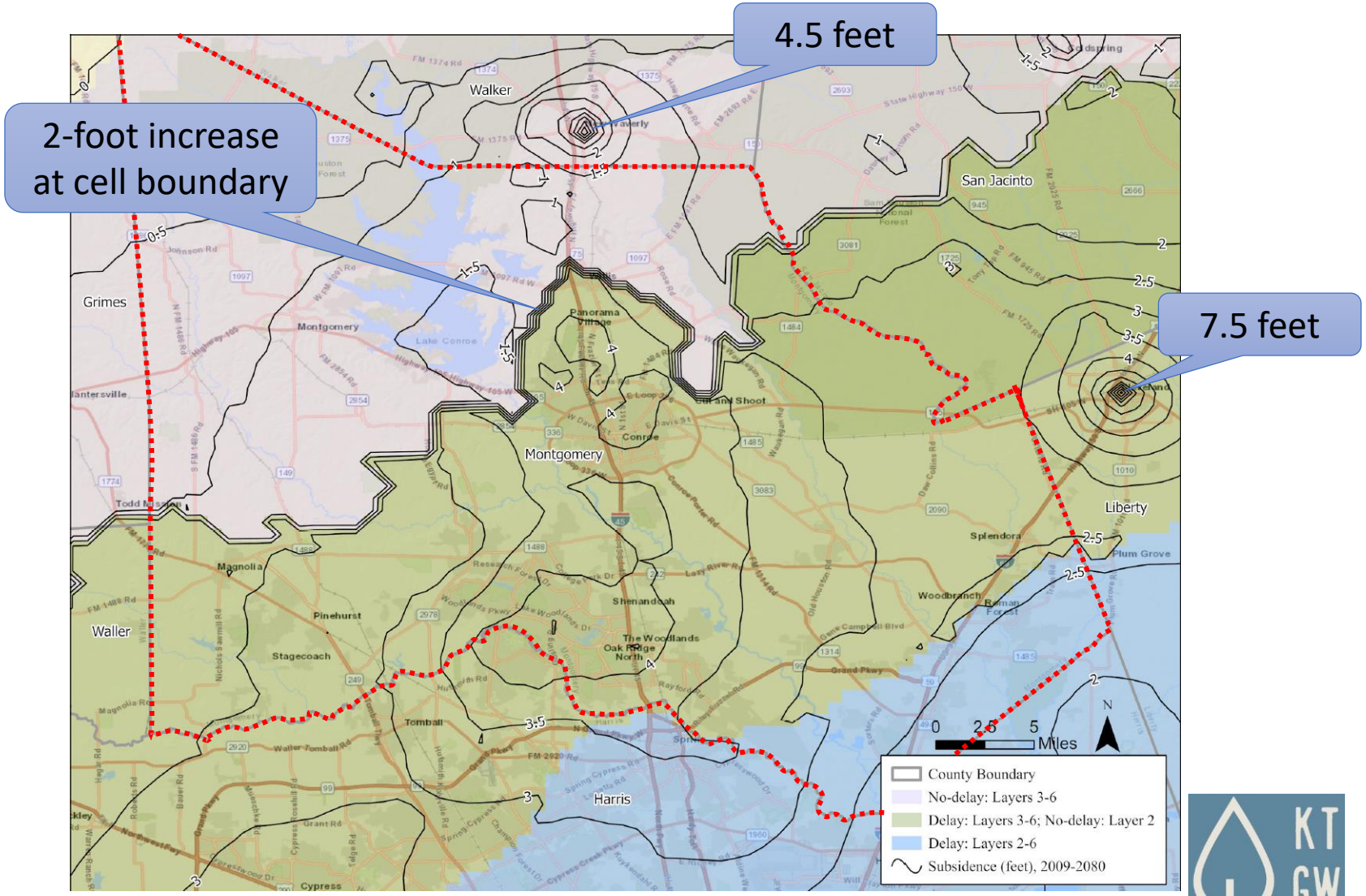
- "…simulates elastic compaction in coarse-grained sediment and both elastic and inelastic compaction in fine-grained sediment…" (Hughes and others, 2022)
- "[Compaction] in the GULF model was simulated for the Chicot, Evangeline, and Jasper aquifers and the Burkeville confining unit." (Ellis and others, 2023)
- Simulation Purposes
  - Subsidence District Regulatory Plan
  - GMA 14 Joint Planning
  - Stakeholder Investigations

Comments on Draft Model

- "**20-year predictive period included, but not representative of GMA 14 planning.** Recommend development of a predictive period with inputs that are representative of the most recent round of joint planning for a more direct comparison with work conducted by GMA 14 member districts using the current GAM." *emphasis added* (Hutchison and Beach, 2023)
- "Using the base model, we set up a predictive model to simulate the same county-aquifer pumping amounts defined in the GMA 14 DFC Run …"(Drabek and Keester, 2023)

Comments on Draft Model

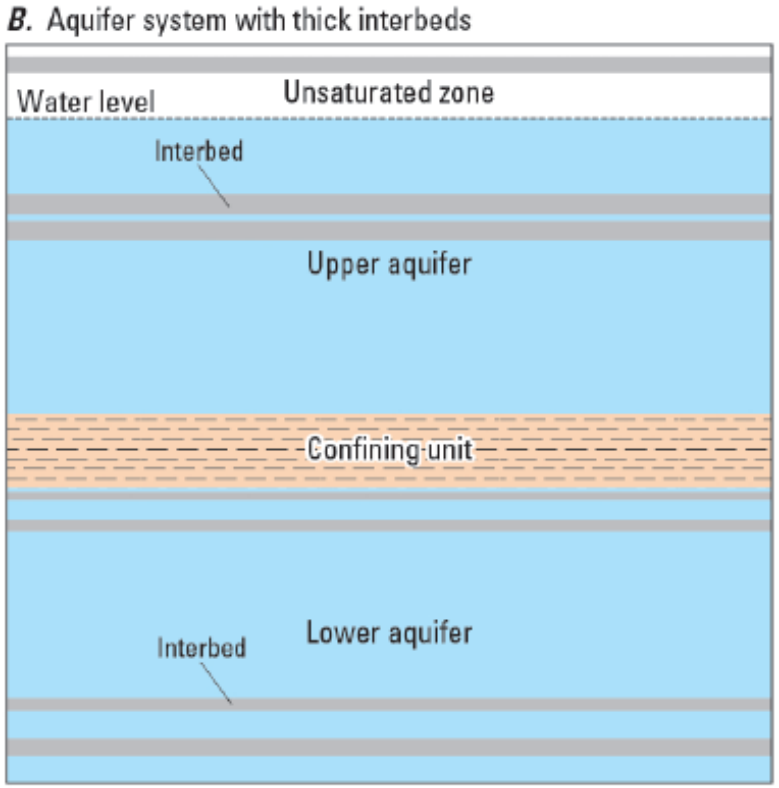
- Map of predicted subsidence in 2080
- Sharp change at model cells
- Focused predicted subsidence



CSUB Settings and Parameters

- Coarse-grained material specific storage and porosity
- For each interbed model cell
  - "*Delay*" or "*NoDelay*" interbed
  - Preconsolidation stress variable as "*pcs0*"
  - Interbed thickness (b) or equivalent thickness (b_{equiv}) as "*thick_frac*"
  - Number of interbeds (n_{equiv}) as "*rnb*"
  - Inelastic and elastic specific storage as "*ssv_cc*" and "*sse_cr*"
  - Initial porosity as "*theta*"
  - Vertical hydraulic conductivity as "*kv*"

Can be any value if a "NoDelay" interbed



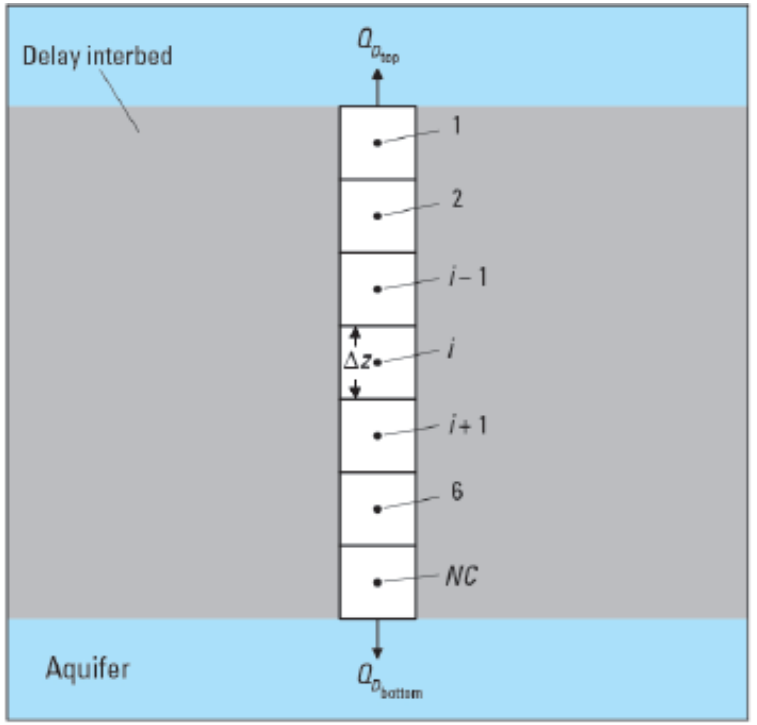
From Hughes and others (2022)

Relevant CSUB Parameters

- *thick_frac*: interbed (clay) thickness (b_{equiv})
- *rnb*: equivalent number of interbeds (n_{equiv})

Interbeds are assigned as either…

- *No-delay* interbeds: water levels between interbed and aquifer equilibrate instantaneously
- *Delay* interbeds: equilibrate over time



Vertical discretization implemented for delay interbeds.

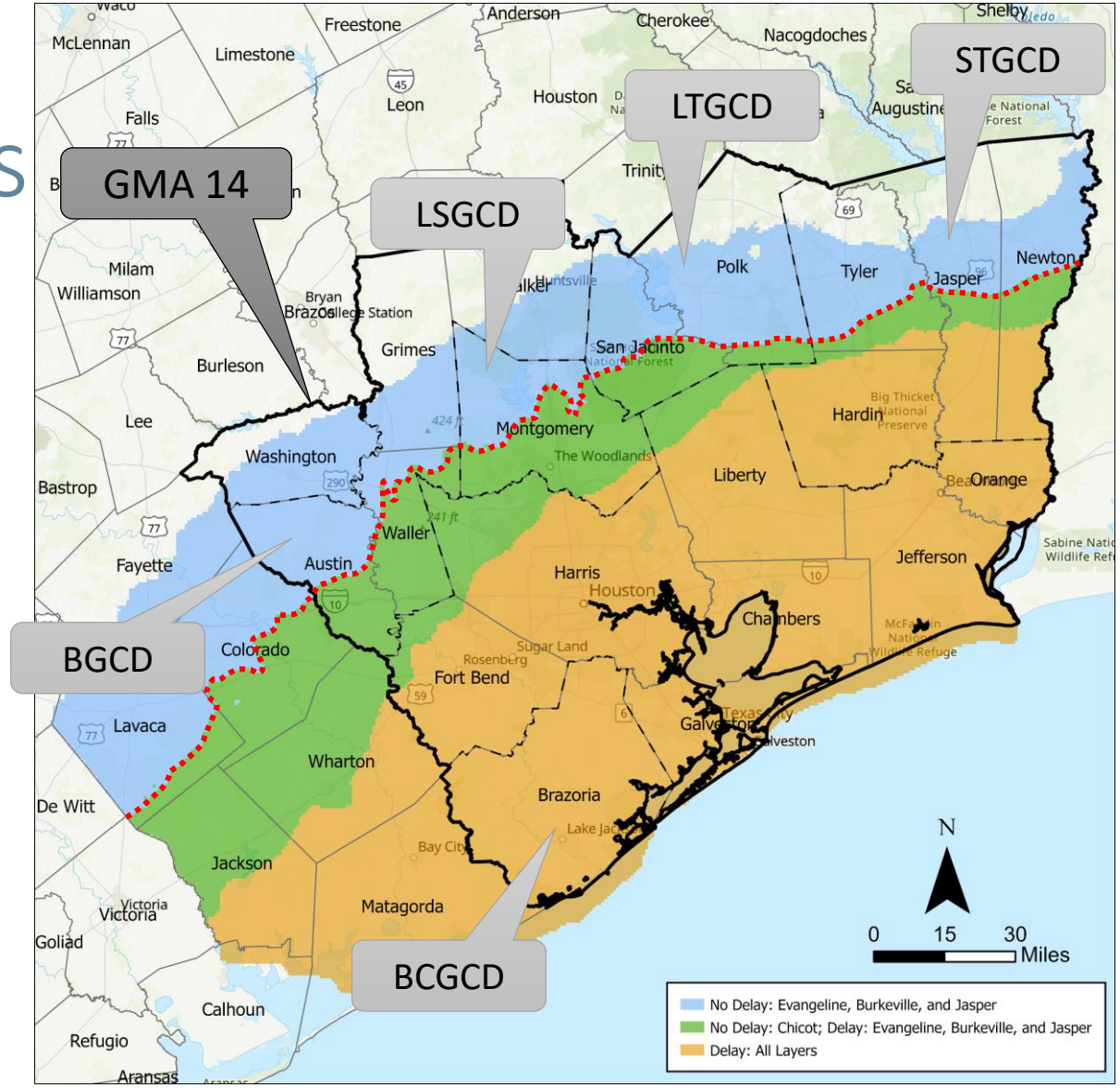
From Hughes and others (2022)

Delay and No-Delay Beds

- Chicot: no-delay where thickness less than about 650 feet
- Older: no-delay updip of Chicot outcrop
- All other cells are delay
- Recall for No-Delay interbeds:
  - Number of interbeds (*rnb*) can be any number
  - Vertical hydraulic conductivity (*kv*) can be any number

thick_frac—is the interbed thickness or cell fraction of the interbed. Interbed thickness is specified as a fraction of the cell thickness if CELL_FRACTION is specified in the OPTIONS block.
rnb—is the interbed material factor equivalent number of interbeds in the interbed system represented by the interbed. RNB must be greater than or equal to 1 if CDELAY is DELAY. Otherwise, RNB can be any value.
kv—is the vertical hydraulic conductivity of the delay interbed. KV must be greater than 0 if CDELAY is DELAY. Otherwise, KV can be any value.

From MODFLOW 6 – Description of Input and Output (version mf6.4.1)



Delay and no-delay assignments for the Chicot, Evangeline, Burkeville, and Jasper layers.

Modflow 6 Source Code (gwf3csub8.f90)

Thick_frac and *rnb* being read from the subroutine **csub_read_packagedata**

```
1495        ! -- get thickness or cell fraction
1496        rval = this%parser%GetDouble()
1497        if (this%icellf == 0) then
1498          if (rval < DZERO .or. rval > baq) then
1499            write (errmsg, '(a,g0,2(a,1x),g0,1x,a,1x,i0,a)') &
1500              'THICK (', rval, ') MUST BE greater than or equal to 0 ', &
1501              'and less than or equal to than', baq, &
1502              'for packagedata entry', itmp, '.'
1503            call store_error(errmsg)
1504          end if
1505        else
1506          if (rval < DZERO .or. rval > DONE) then
1507            write (errmsg, '(a,1x,a,1x,i0,a)') &
1508              'FRAC MUST BE greater than 0 and less than or equal to 1', &
1509              'for packagedata entry', itmp, '.'
1510            call store_error(errmsg)
1511          end if
1512          rval = rval*baq
1513        end if
1514        this%thickini(itmp) = rval
1515        if (this%iupdatematprop /= 0) then
1516          this%thick(itmp) = rval
1517        end if
1518        !
1519        ! -- get rnb
1520        rval = this%parser%GetDouble()
1521        if (idelay > 0) then
1522          if (rval < DONE) then
1523            write (errmsg, '(a,g0,a,1x,a,1x,i0,a)') &
1524              'RNB (', rval, ') must be greater than or equal to 1', &
1525              'for packagedata entry', itmp, '.'
1526            call store_error(errmsg)
1527          end if
1528        else
1529          rval = DONE
1530        end if
1531        this%rnb(itmp) = rval
```

If the cell is a **delay** cell (idelay > 0) then
set *rnb* to the input value.

If the cell is a **no-delay** then
set *rnb* to 1 (DONE).

Calculating interbed thickness

- If the cell is a **delay** cell, then
  interbed thickness = *thick_frac X rnb*
- If the cell is **no-delay** (idelay == 0), then
  interbed thickness = *thick_frac*

```
3343        !
3344        ! -- calculate interbed thickness
3345        ! -- no delay interbeds
3346        if (idelay == 0) then
3347          b = this%thick(ib)
3348          ! -- delay interbeds
3349        else
3350          b = this%thick(ib)*this%rnb(ib)
3351        end if
```

No-delay bed

Delay bed

Modflow 6 Source Code (gwf3csub8.f90)

Subroutine **csub_delay_calc_comp** calculates **delay** interbed compaction

```
6688    ! -- initialize variables
6689    idelay = this%idelay(ib)
6690    ielastic = this%ielastic(ib)
6691    node = this%nodelist(ib)
6692    comp = DZERO
6693    compi = DZERO
6694    compe = DZERO
6695    !
6696    ! -- calculate cell saturation
6697    call this%csub_calc_sat(node, hcell, hcellold, snnew, snold)
6698    !
6699    ! -- calculate compaction
6700    if (this%thickini(ib) > DZERO) then
6701      fmult = this%dbdzini(1, idelay)
6702      do n = 1, this%ndelaycells
6703        h = this%dbh(n, idelay)
6704        h0 = this%dbh0(n, idelay)
6705        call this%csub_delay_calc_sat(node, idelay, n, h, h0, dsn, dsn0)
6706        call this%csub_delay_calc_ssksske(ib, n, hcell, ssk, sske)
6707        if (ielastic /= 0) then
6708          v1 = dsn*ssk*this%dbes(n, idelay) - sske*this%dbes0(n, idelay)
6709          v2 = DZERO
6710        else
6711          v1 = dsn*ssk*(this%dbes(n, idelay) - this%dbpcs(n, idelay))
6712          v2 = dsn0*sske*(this%dbpcs(n, idelay) - this%dbes0(n, idelay))
6713        end if
6714        v = (v1 + v2)*fmult
6715        comp = comp + v
6716        !
6717        ! -- save compaction data
6718        this%dbcomp(n, idelay) = v*snnew
6719        !
6720        ! -- calculate inelastic and elastic storage components
6721        if (this%idbconvert(n, idelay) /= 0) then
6722          compi = compi + v1*fmult
6723          compe = compe + v2*fmult
6724        else
6725          compe = compe + (v1 + v2)*fmult
6726        end if
6727      end do
6728    end if
6729    !
6730    ! -- fill compaction
6731    comp = comp*this%rnb(ib)
6732    compi = compi*this%rnb(ib)
6733    compe = compe*this%rnb(ib)
6734    !
6735    ! -- return
6736    return
6737  end subroutine csub_delay_calc_comp
```

Final step is to multiply the calculated compaction by the number of interbeds (*rnb)*

Subroutine **csub_nodelay_calc_comp** calculates **no-delay** interbed compaction

```
4253  subroutine csub_nodelay_calc_comp(this, ib, hcell, hcellold, comp, rho1, rho2)
4254    ! -- dummy variables
4255    class(GwfCsubType) :: this
4256    integer(I4B), intent(in) :: ib          !< interbed number
4257    real(DP), intent(in) :: hcell           !< current head for the cell
4258    real(DP), intent(in) :: hcellold        !< previous head for the cell
4259    real(DP), intent(inout) :: comp         !< no-delay interbed compaction
4260    real(DP), intent(inout) :: rho1         !< current storage coefficient based on Sske
4261    real(DP), intent(inout) :: rho2         !< current storage coefficient based on Ssk
4262    ! -- local variables
4263    integer(I4B) :: node
4264    real(DP) :: es
4265    real(DP) :: es0
4266    real(DP) :: pcs
4267    real(DP) :: tled
4268    real(DP) :: rhs
4269    !
4270    ! -- initialize variables
4271    node = this%nodelist(ib)
4272    tled = DONE
4273    es = this%cg_es(node)
4274    es0 = this%cg_es0(node)
4275    pcs = this%pcs(ib)
4276    !
4277    ! -- calculate no-delay interbed rho1 and rho2
4278    call this%csub_nodelay_fc(ib, hcell, hcellold, rho1, rho2, rhs, argtled=tled)
4279    !
4280    ! -- calculate no-delay interbed compaction
4281    if (this%ielastic(ib) /= 0) then
4282      comp = rho2*es - rho1*es0
4283    else
4284      comp = -pcs*(rho2 - rho1) - (rho1*es0) + (rho2*es)
4285    end if
4286    !
4287    ! -- return
4288    return
4289
4290  end subroutine csub_nodelay_calc_comp
```

Number of interbeds (*rnb)* is not relevant for no-delay beds

Delay and No-Delay Beds

Delay and no-delay assignments

- Chicot: no-delay where thickness less than about 650 feet
- Older: no-delay updip of Chicot outcrop
- All other cells are delay

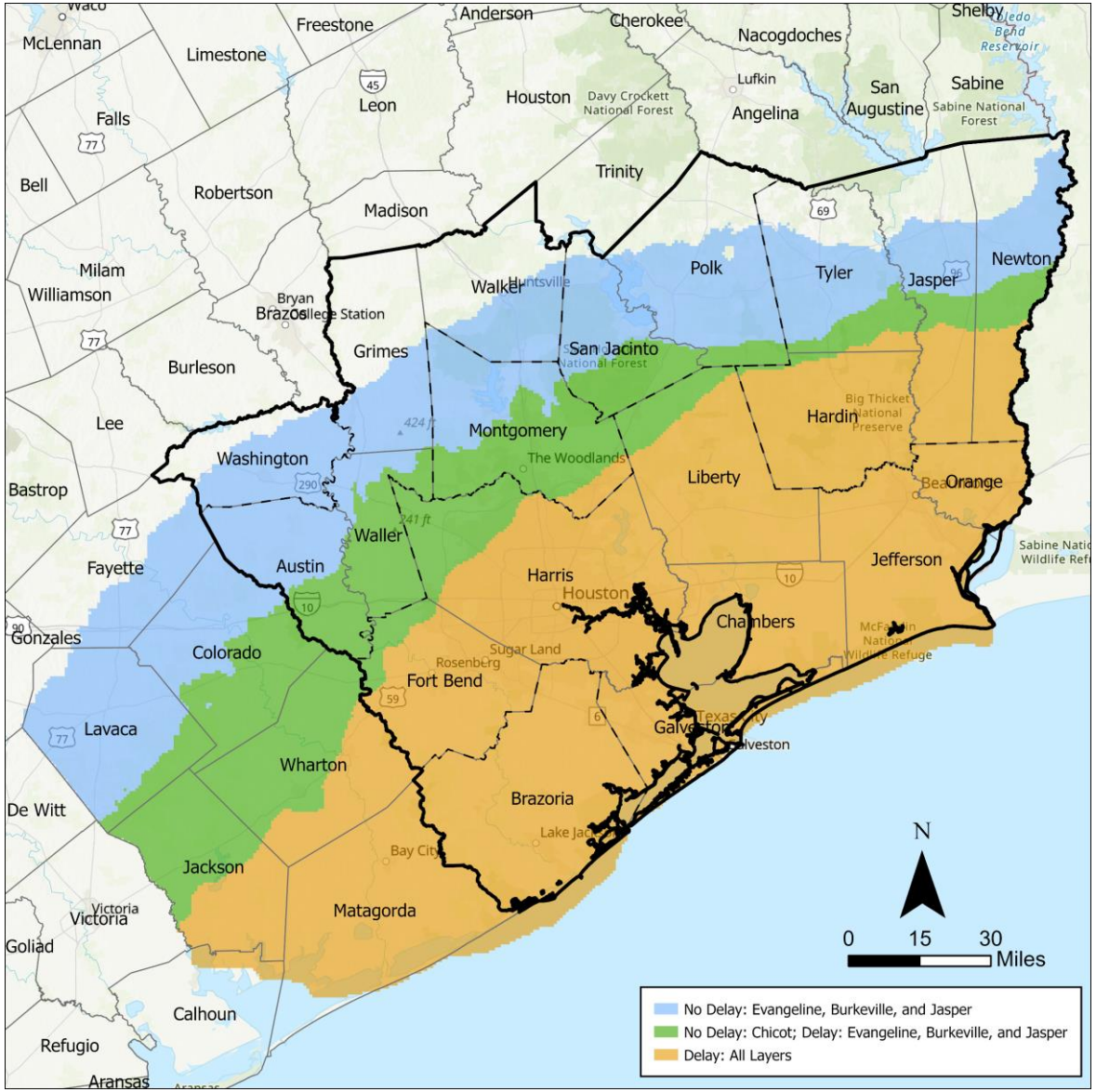
Total Interbed (clay) thickness

- For no-delay interbeds:

  Clay thickness = *thick_frac*

- For delay interbeds:

  Clay thickness = *thick_frac* X *rnb*

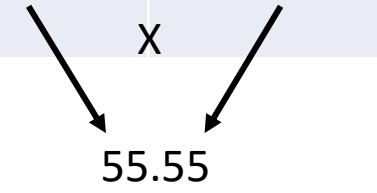


Delay and no-delay assignments for the Chicot, Evangeline, Burkeville, and Jasper layers.

CSUB Input Parameters

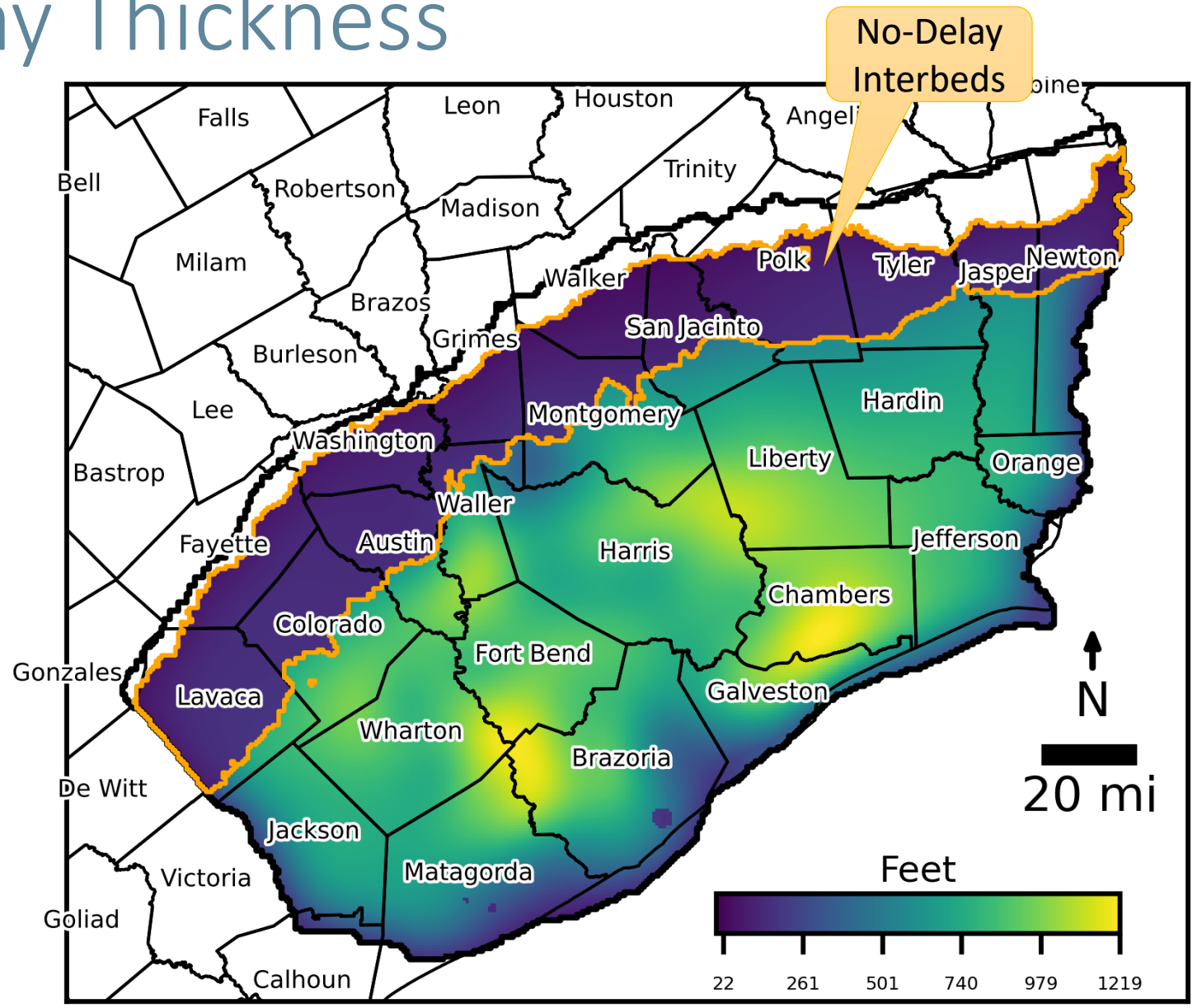
icsubno	ilay	ir	ic	cdelay	pcs0	thick_frac	rnb	ssv_cc	sse_cr	theta	kv
889	2	84	321	nodelay	12.9639	23.7234	2.3393	0.000284	8.96E-06	0.448987	2.04E-06
890	2	84	322	delay	12.6559	23.7071	2.3432	0.000282	8.61E-06	0.443674	1.96E-06

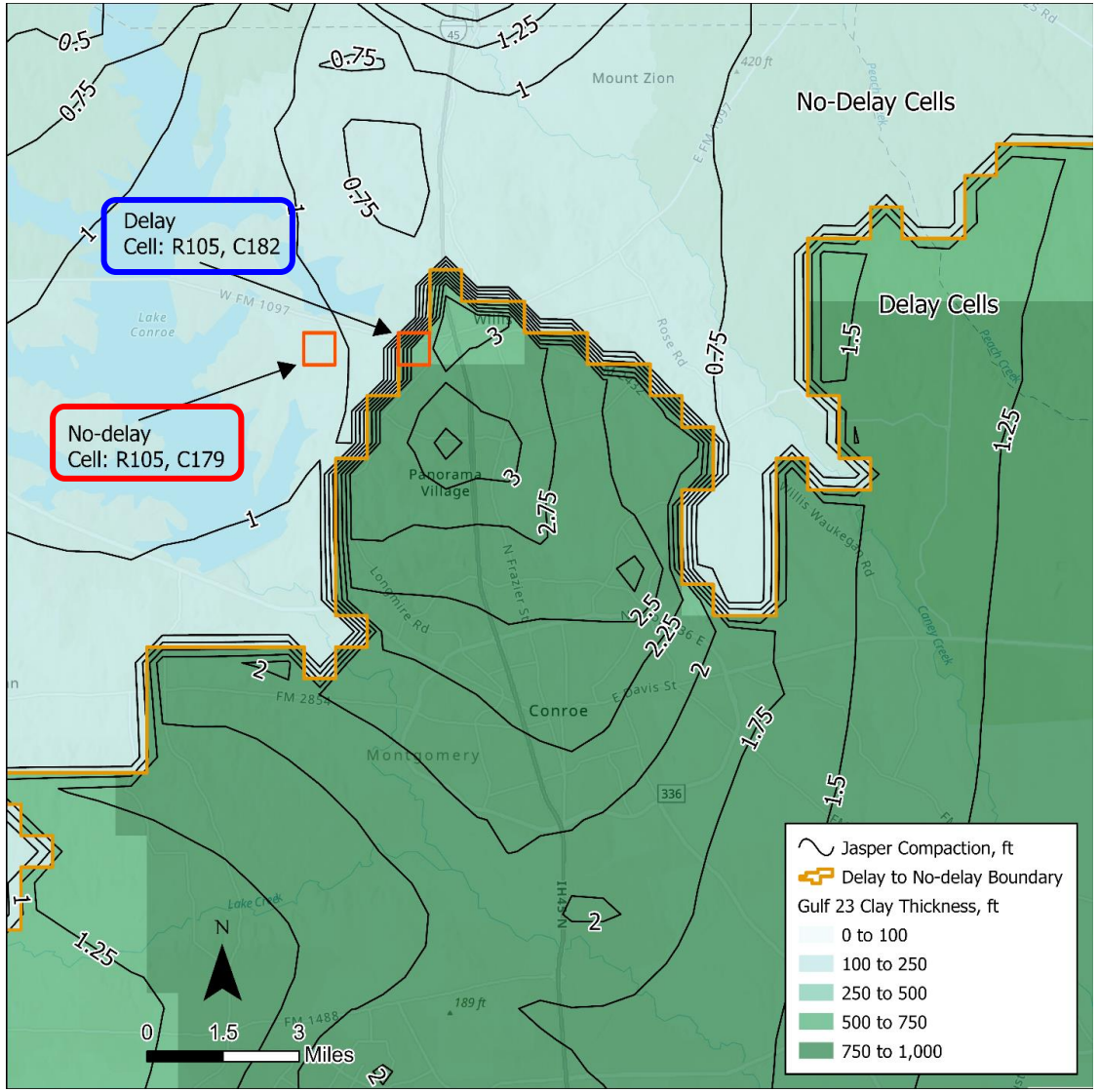
icsubno	ilay	ir	ic	cdelay	pcs0	thick_frac	rnb	ssv_cc	sse_cr	theta	kv
889	2	84	321	nodelay	12.9639	23.7234	~~2.3393~~	0.000284	8.96E-06	0.448987	2.04E-06
890	2	84	322	delay	12.6559	23.7071	2.3432	0.000282	8.61E-06	0.443674	1.96E-06



GULF 2023 Clay Thickness

GULF 2023 Jasper layer total interbed thickness

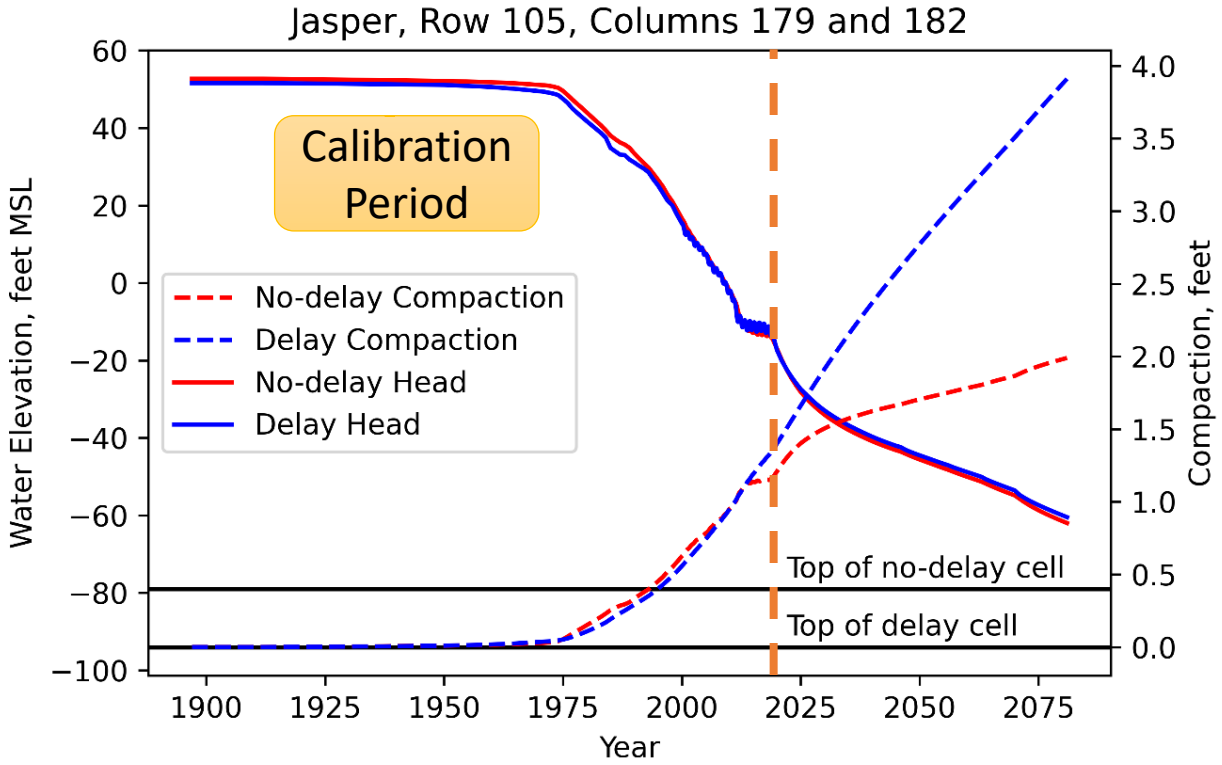




GULF 2023 Jasper clay thickness and additional compaction in 2080 from 2010 values. The compaction and water levels of the labeled cells are shown in the Figure to the right.

Gulf 2023 CSUB interbed parameter data for the Jasper layer.

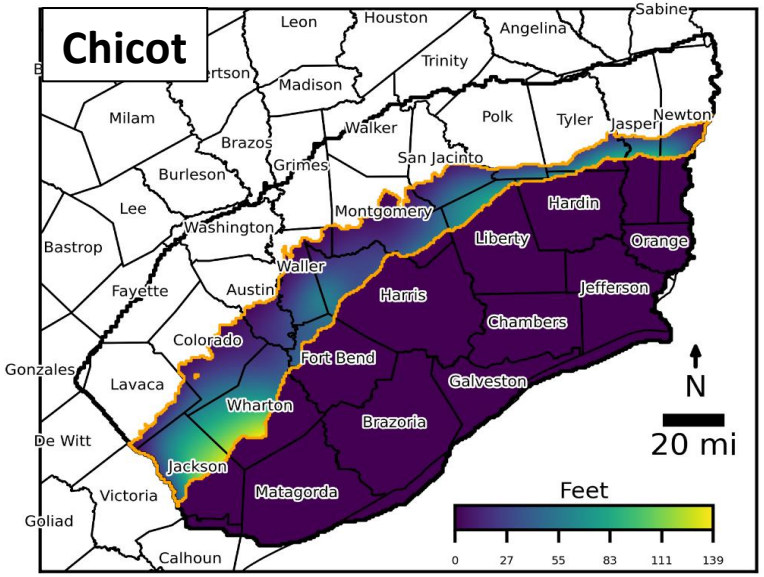
Cell	Designation	*Thick_frac*, feet		*rnb*		**Total Interbed Thickness, feet**
R105, C179	no-delay	167.82	→	~~4.36~~	→	**167.82**
R105, C182	delay	169.16	X	4.39	=	**742.62**

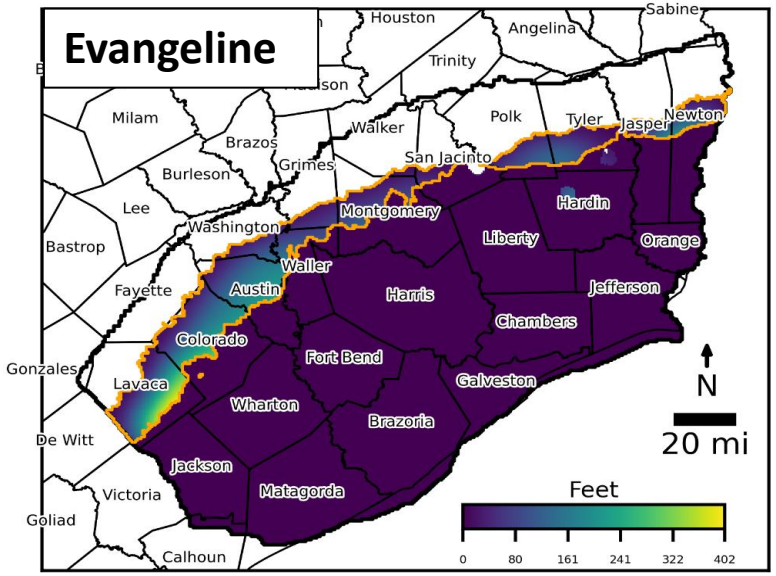


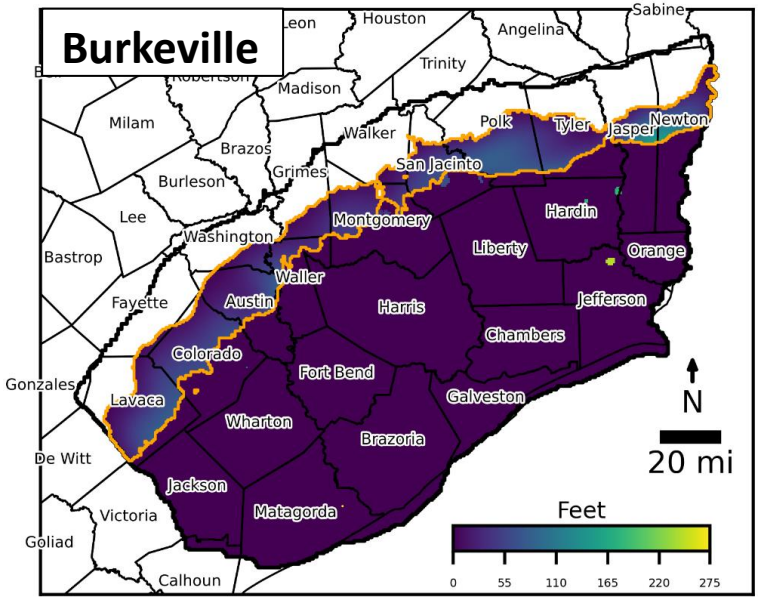
Comparison of additional compaction in the Jasper simulated by the GULF 2023 across the no-delay to delay transition along row 105.

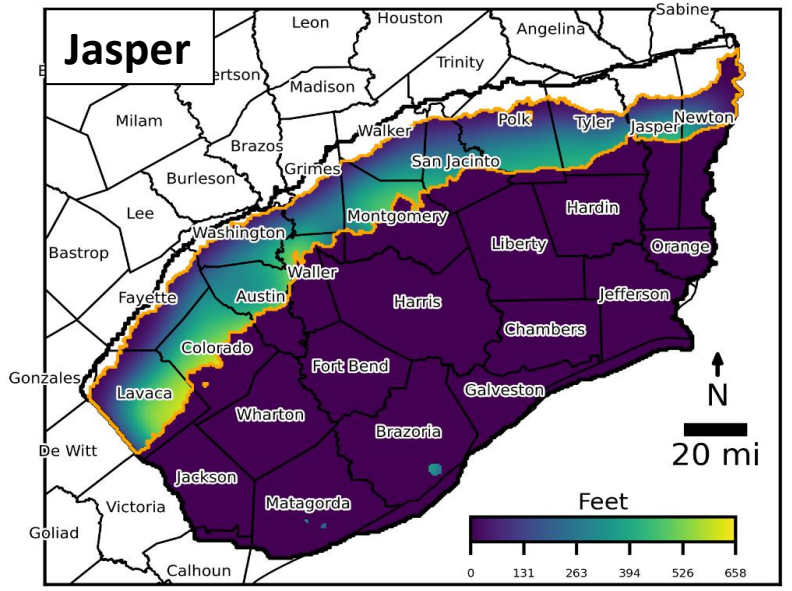
Increase in Clay Thickness

- Orange outline represents the cells designated as no delay interbeds
- Updated the clay thickness using the GULF 2023 dataset that included the *rnb* and *thick_frac*



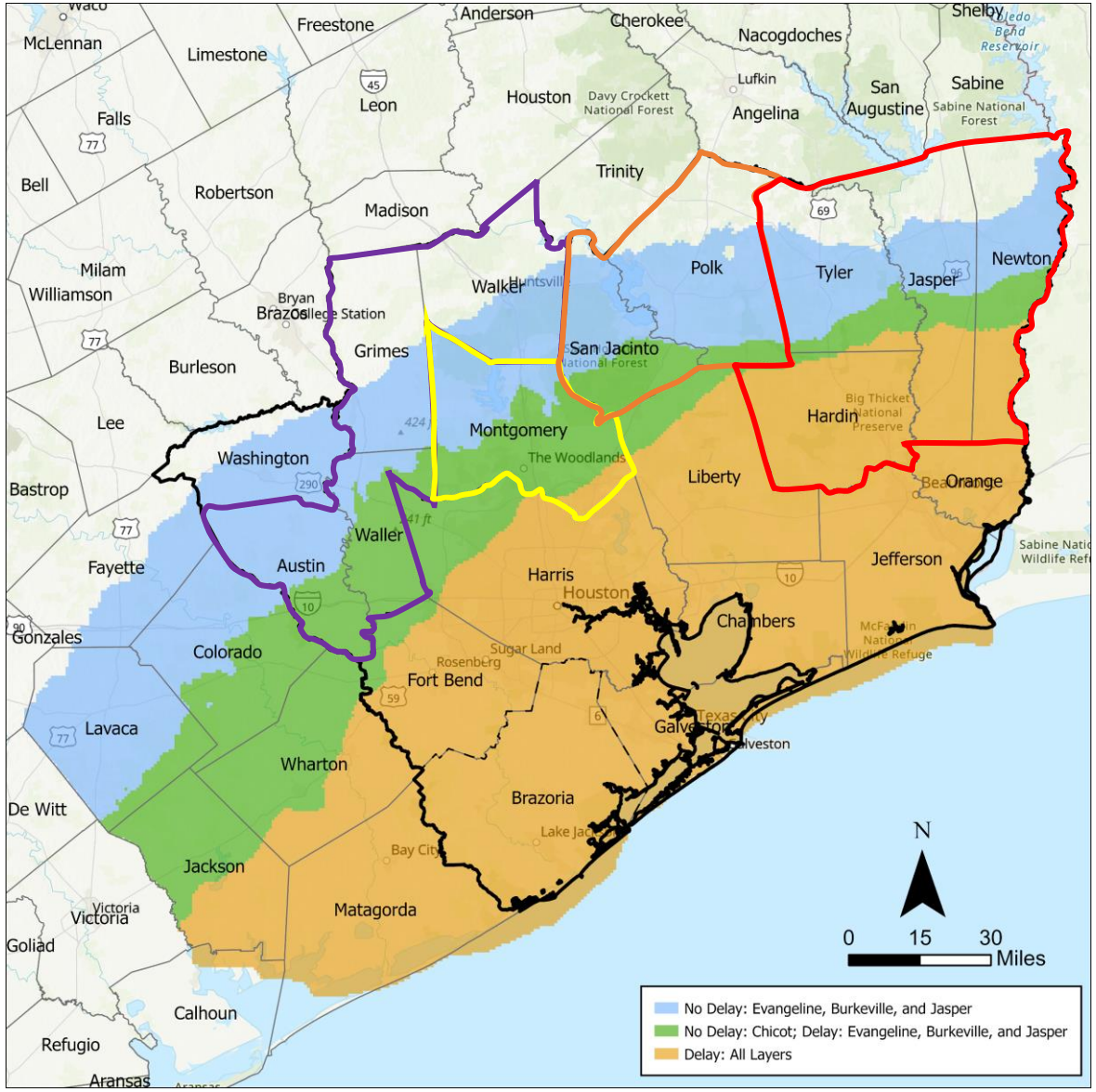






Summary

- Correction of clay thickness (*thick_frac*) for no-delay beds will affect GULF 2023 calibration
  - Simulated interbeds are much thicker in updip areas
  - Model will not provide reasonable predictions of compaction with GULF 2023 calibrated parameters
- Calibration of no-delay interbed specific storage and vertical hydraulic conductivity based on incorrect clay thickness
- Issue primarily updip GCDs



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Questions

GULF 2023 Model CSUB Package Update for the GMA 14 Model

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May 14, 2024

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