# A State-Wide Automated Web-Based Tool for Estimating Injectate Migration from for Class II Wells in Texas

**TWDB Contract # 2000012453**

**GWPC Forum June 23, 2022**

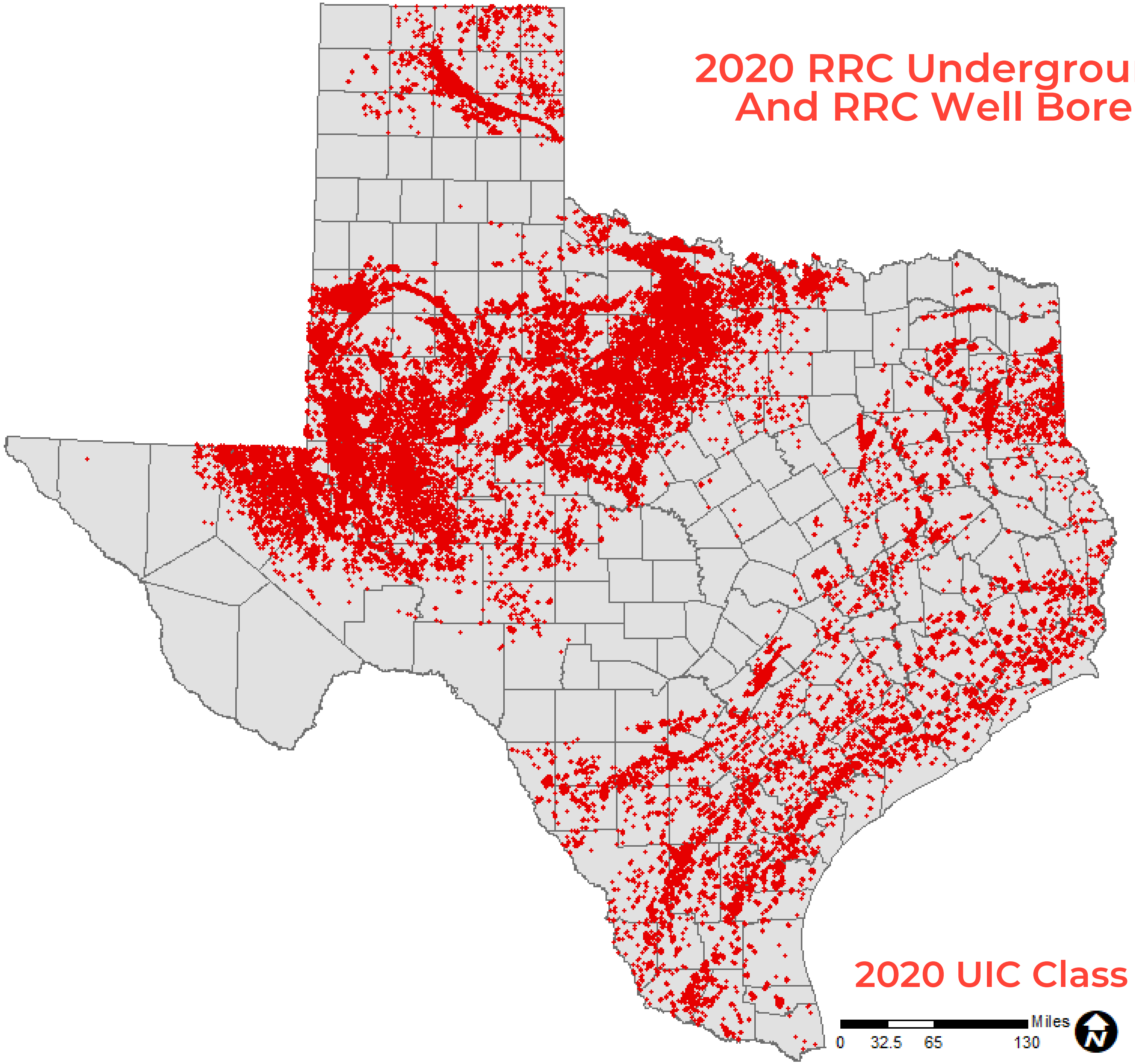
Rohit R. Goswami, PhD, PE
RRG Professional Engineering, LLC

# Acknowledgements

- Vivek Bedekar[1]
- Chris Neville[1]
- Chris Bente[2]
- Juan Acevedo[2, 3(formerly)]
- Alysa Suydam[3]
- Evan Strickland[3]
- Jack Sharp, PhD[4]
- Technical Advisory Group[5]

- 1 S.S. Papadopulos & Associates, Inc., Rockville, MD 20852
- 2 WSP USA, Inc.
- 3 Texas Water Development Board, Austin TX, 78701
- 4 Consulting Hydrogeologist, Austin, TX 78759
- 5 Acknowledged in the final report submitted to the TWDB

# 2020 RRC Underground Injection Control And RRC Well Bore Database Update



# Background

- Brackish Groundwater Production Zones (BGPZs)

- Objective
  - *Injectate migration from Class II wastewater injection wells*
  - *30 to 50 year periods*

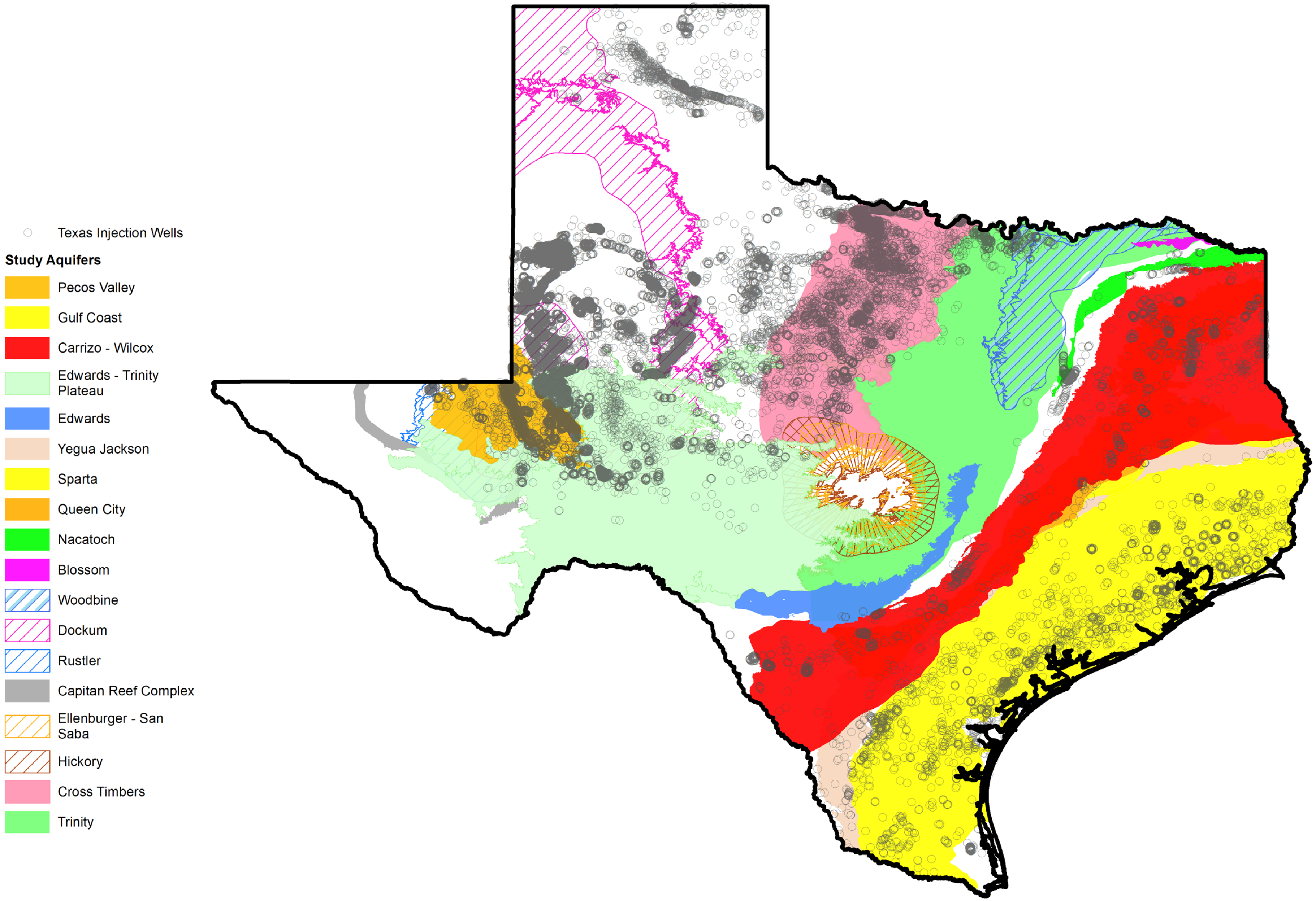
- Criteria
  - *Scientifically defensible*
  - *Reproducible*

- Technical advisory group (Workgroup)

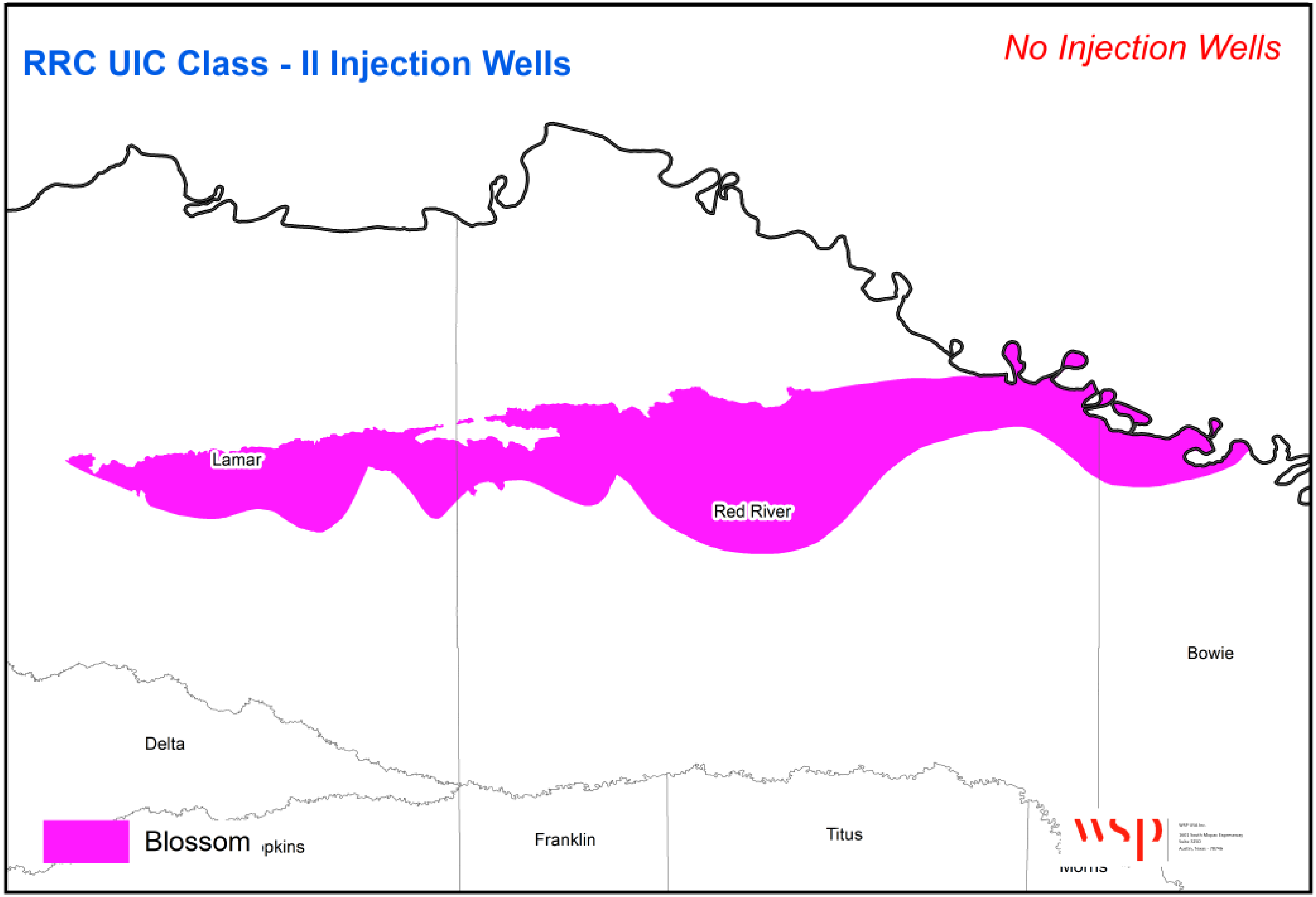
# Literature Review

- Few studies addressing specific questions
  - *General background*
  - *Suggestions from TWDB/Workgroup*
- Reviewed 150+ articles
- Key issues
  - *protection of aquifers*
  - *seismic activity impacts*
  - *Injectate clogging formation*
- Wide variety of strata suitable for wastewater injection.

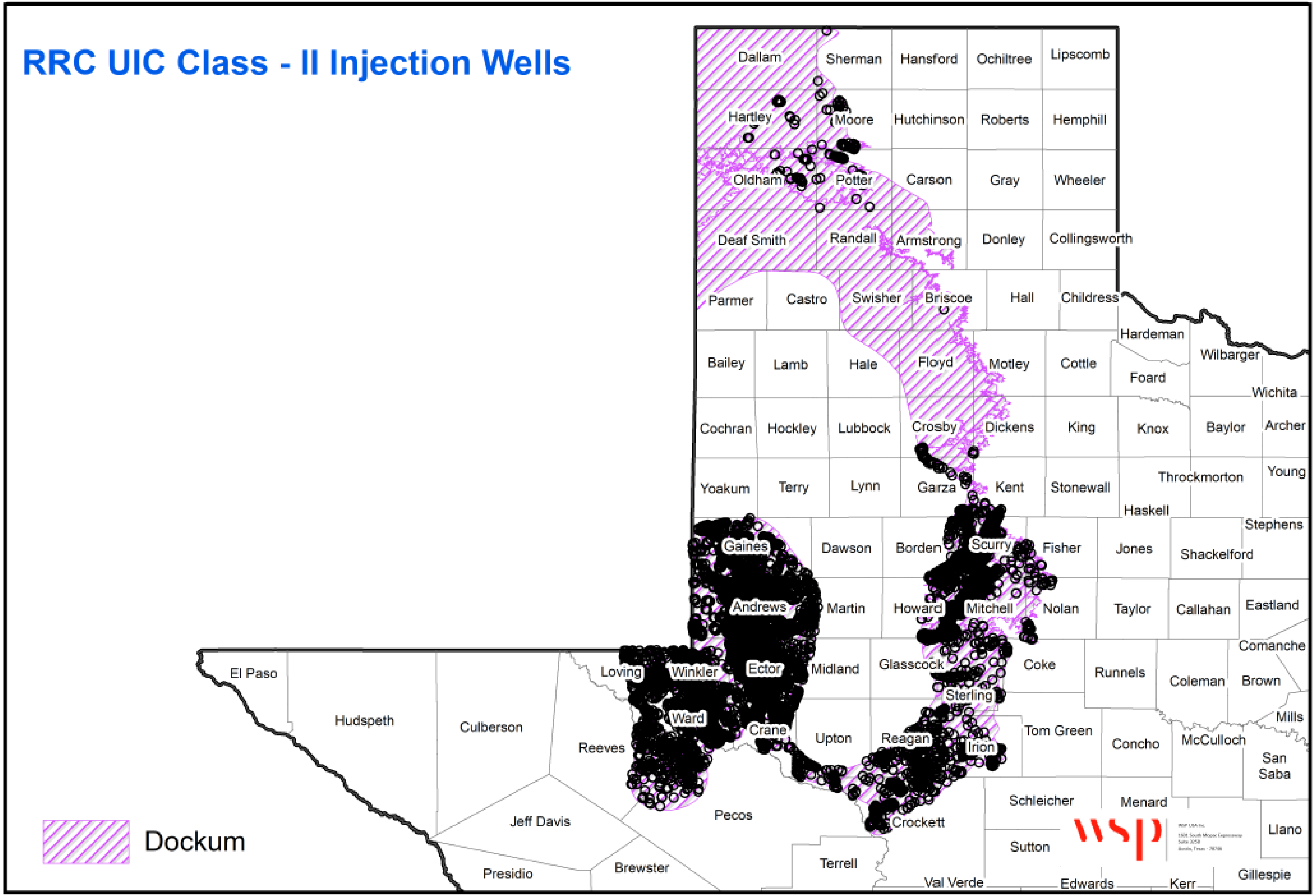
# Aquifer Assessment



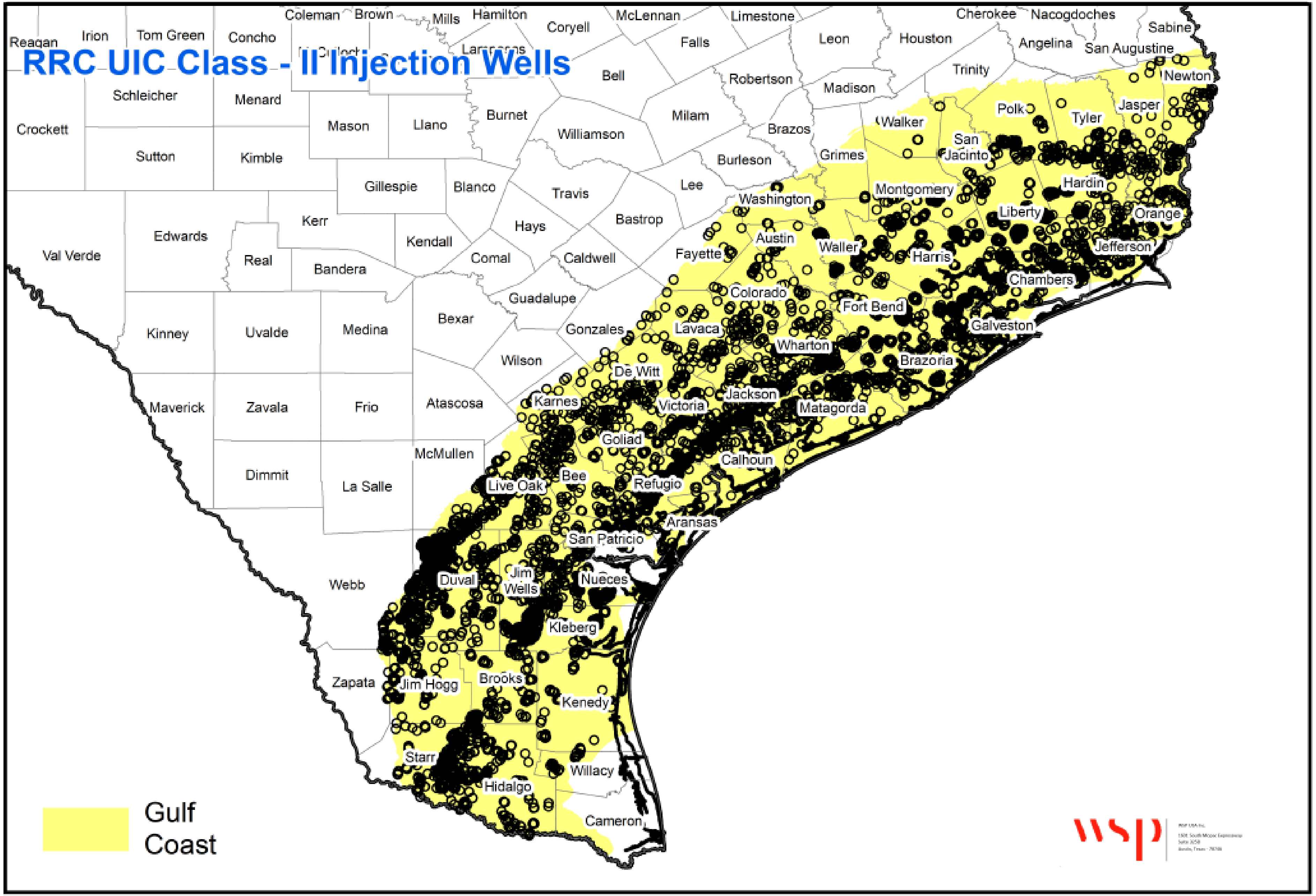
# Aquifer Assessment Maps



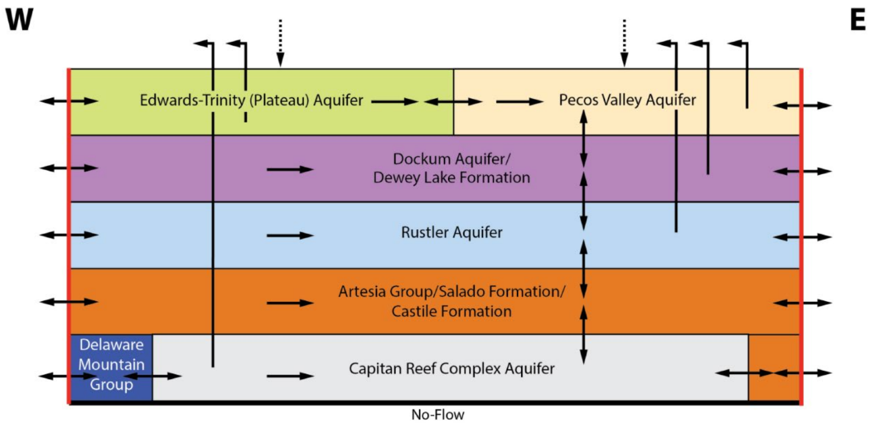
# Aquifer Assessment Maps

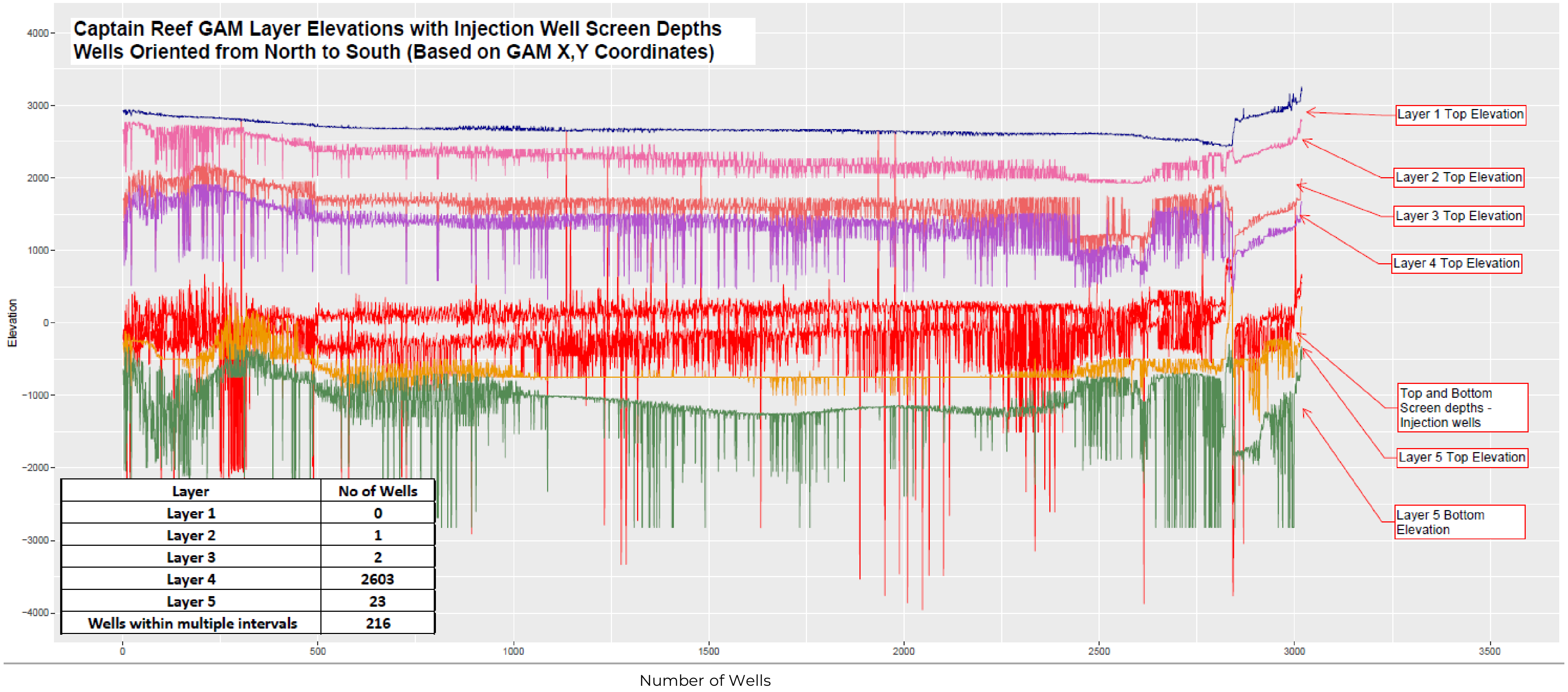


# Aquifer Assessment Maps



# Aquifer Assessment
## Capitan Reef Complex GAM




| Layer | No of Wells |
|---|---|
| Layer 1 | 0 |
| Layer 2 | 1 |
| Layer 3 | 2 |
| Layer 4 | 2603 |
| Layer 5 | 23 |
| Wells within multiple intervals | 216 |

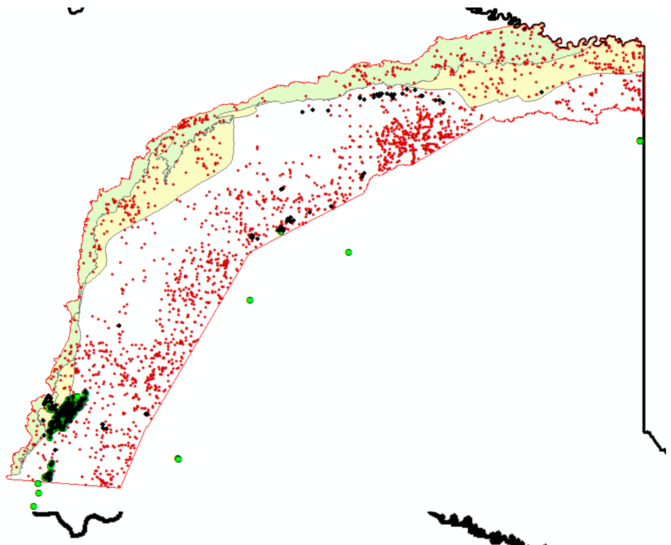
# Groundwater Database (GWDB)

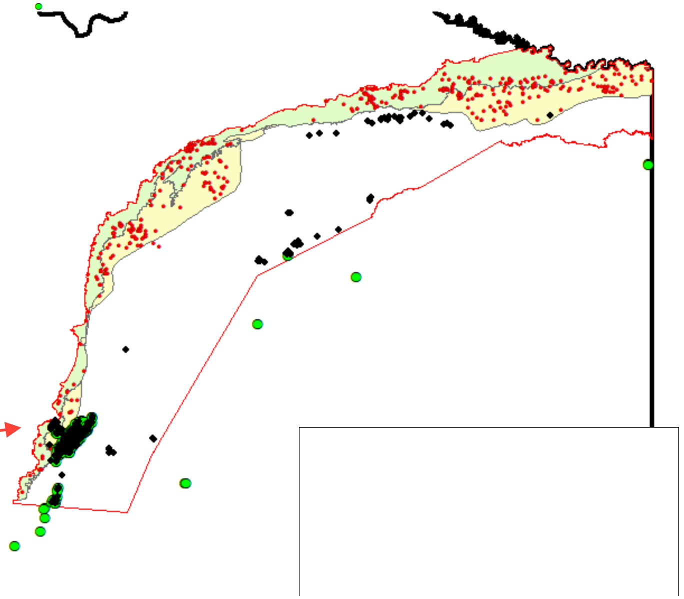
https://www.twdb.texas.gov/groundwater/data/gwdbrpt.asp

- **Fields**
  - *Well ID*
  - *Coordinates*
  - *Aquifer screened*
    - Method of determining which aquifer well is screened in
    - No blank entries, but some cells have values of “Unassigned” or “Other”
  - *Land surface Elevation*
    - Method of determining land surface elevation (DEM, interpolated from topo, etc)
    - No blank entries
  - *Well depth*
  - *Well Type*
  - *Well Use*
  - *Water Quality*
  - *Water Levels*
  - *Many Others*
- **Total GWDB Wells**
  - *140,458 wells in provided database (.txt file)*
    - 22,507 wells have aquifer “Unassigned” or “Other”
  - *140,458 wells in provided shapefile*
- **Wells in Nacatoch Study Area**
  - *2,352 wells in Nacatoch study area*
  - *410 with aquifer = “Nacatoch Sand”*
  - *321 with aquifer = “Not Applicable”, “Unknown”, etc*
    - *Can maybe look at “WellDepth” or other fields to see if we can make a determination*

- ☑ (Select All)
- ☑ Anode
- ☑ Drain
- ☑ Observation
- ☑ Oil or Gas
- ☑ Other (see remarks)
- ☑ Recharge
- ☑ Seismic
- ☑ Spring
- ☑ Surface Water (not a spring)
- ☑ Test Hole
- ☑ Waste Disposal
- ☑ Withdrawal of Water
- ☑ (Blanks)

- ☑ (Select All)
- ☑ Air Conditioning
- ☑ Aquaculture
- ☑ Commercial
- ☑ Desalination
- ☑ De-watering
- ☑ Domestic
- ☑ Fire
- ☑ Industrial
- ☑ Industrial (cooling)
- ☑ Institution
- ☑ Irrigation
- ☑ Monitor
- ☑ Other
- ☑ Plugged or Destroyed
- ☑ Power
- ☑ Public Supply
- ☑ Recreation
- ☑ Rig Supply
- ☑ Stock
- ☑ Unknown
- ☑ Unused
- ☑ Withdrawal of Water
- ☑ (Blanks)



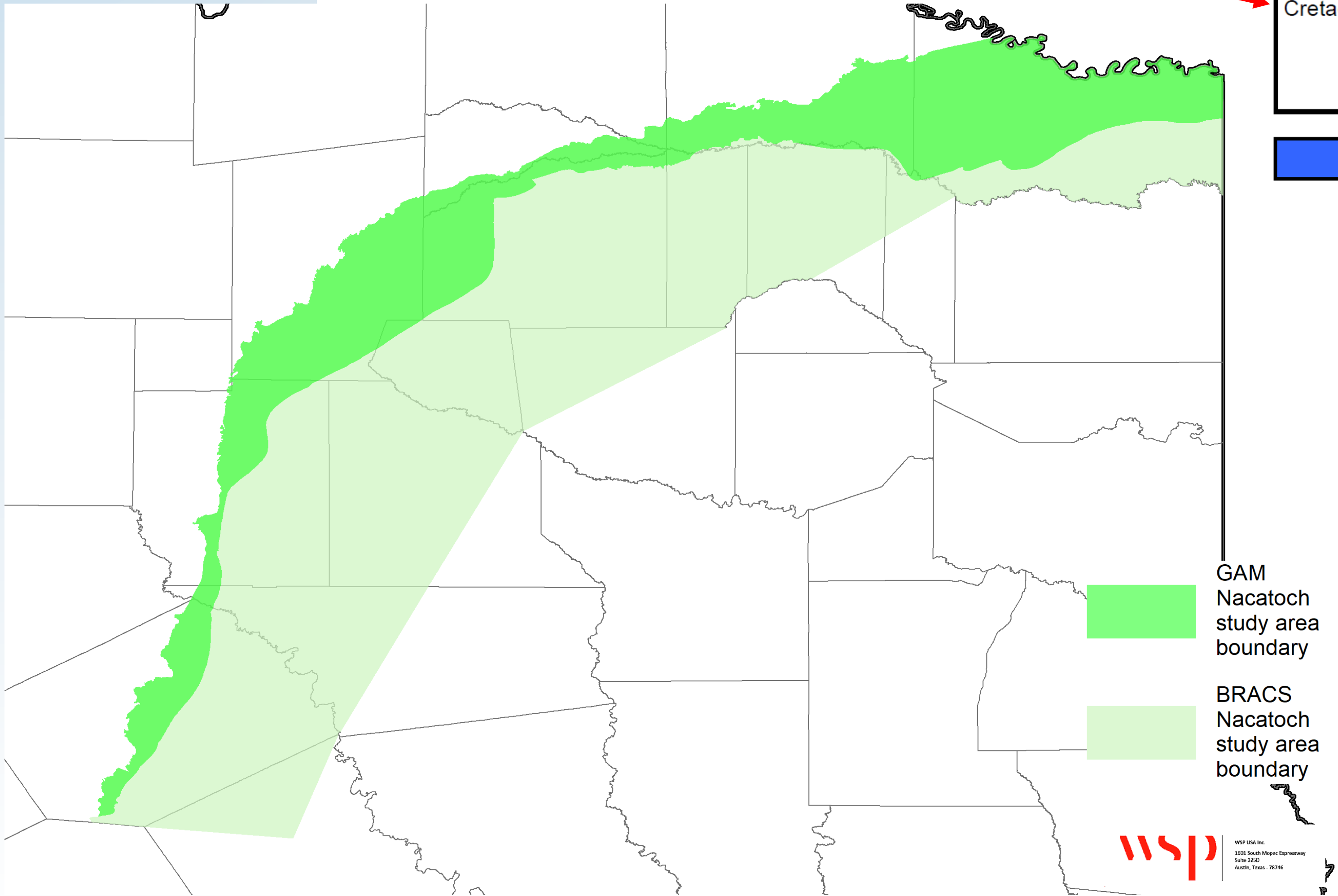


# Aquifer Parameters Assessment

## Aquifer: Nacatoch

## Model: GAM

## No of Layers: 2
## (Layer 2 – Nacatoch Sand)




| System | Group | Stratigraphic Units: Texas | | Stratigraphic Units: Arkansas | Model Layer |
|---|---|---|---|---|---|
| Quaternary | | Alluvium and fluviatile terrace deposits | | | $1^{\dagger}$ |
| Tertiary | Midway | Willis Point Formation | Midway, undifferentiated | Midway | |
| | | Kincaid Formation | | | |
| Cretaceous | Navarro | *Upper Navarro Clay | Kemp Clay | Arkadelphia Marl | |
| | | *Upper Navarro Marl | | | |
| | | Nacatoch Sand | | | 2 |
| | | *Lower Navarro Clay | Neylandville Formation | Saratoga Chalk | |
| | Taylor | Marlbrook Marl | | | |

*Water-bearing units*

# Aquifer Parameters Assessment:
# Summary of Hydraulic Properties used in the GAM Model

## Aquifer: Nacatoch

## Model: GAM

| | Specific Capacity (gpm/ft) | Transmissivity (gal/day-ft) | Hydraulic Conductivity (ft/day) |
|---|---|---|---|
| **Average** | 1.22 | 1,686 | 4.98 |
| **Maximum** | 13.80 | 13,127 | 56.60 |
| **Minimum** | 0.04 | 206 | 0.49 |
| **Median** | 0.50 | 1,220 | 2.95 |

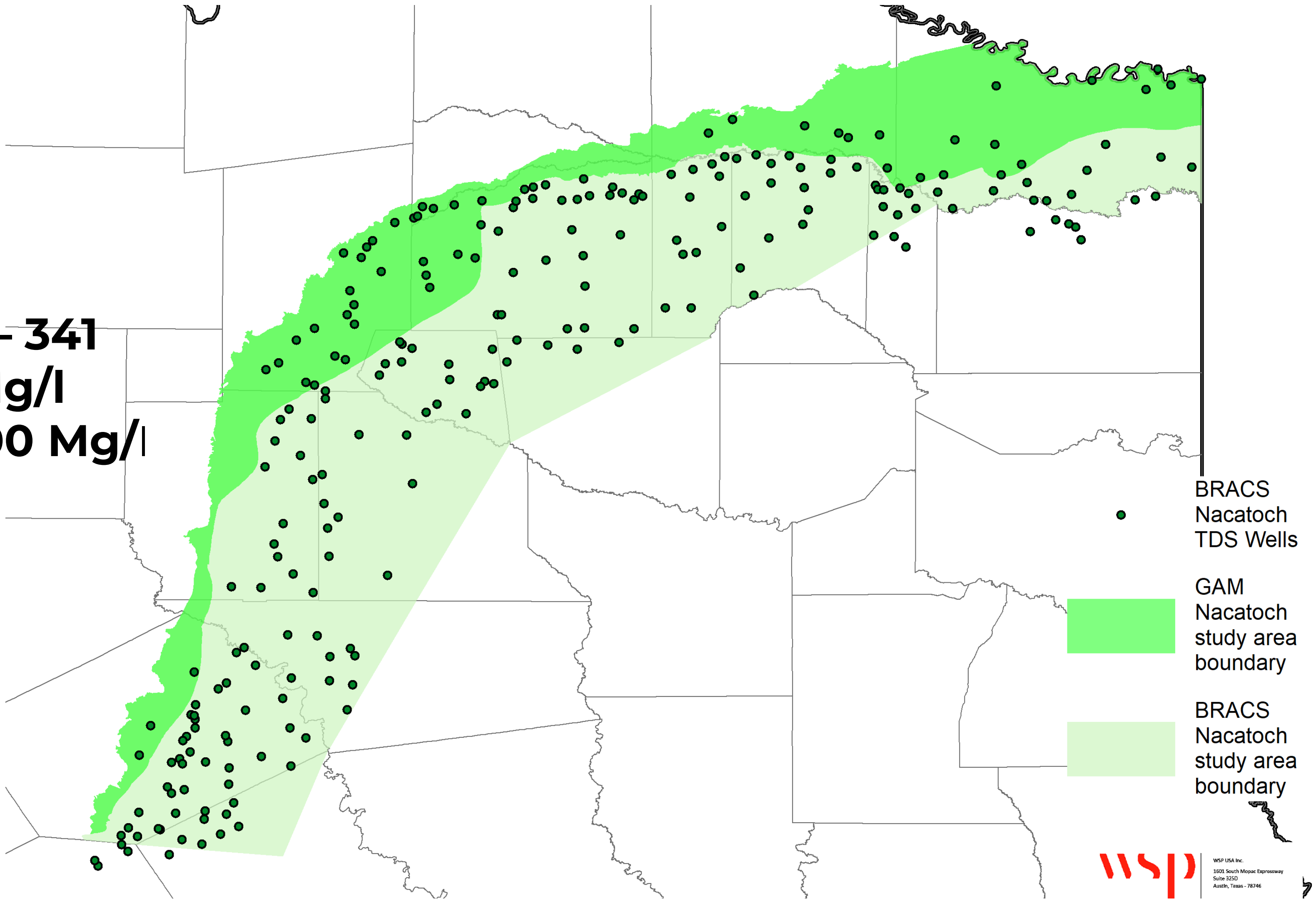
| Layer | Horizontal Hydraulic Conductivity (ft/day) | Vertical Hydraulic Conductivity (ft/day) | Specific yield (-) | Specific Storage (-) |
|---|---|---|---|---|
| 1 | 0.01 - 1 | $1x10^{-4}$ – $1x10^{-3}$ | 0.01 - 0.03 | $1x10^{-8}$ – $1x10^{-5}$ |
| 2 | 0.1 – 9.5 | $1x10^{-3}$ – 0.9 | 0.01 – 0.03 | $1x10^{-7}$ – $1x10^{-5}$ |

# Aquifer Parameters Assessment: Water Quality TDS

Aquifer:
Nacatoch

Model:
BRACS

**Total no of wells – 341**
**Minimum – 832 Mg/l**
**Maximum – 28,000 Mg/l**



# 2020 RRC UIC Data Update

- UIC Inventory Permit Information
- UIC Permit Remarks
- UIC Monitor Information
- H-10 (Monthly Monitor) Information
- H-10H (Monthly Monitor) Information
- Monitor Remarks
- H-5 (Pressure Testing) Information
- H-5 Remarks
- UIC Enforcement Information
- Enforcement Action Information
- Enforcement Action Other Data
- Enforcement Remarks
- H-10H Monitor Annual Information
- H-10 Violation Information

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 1 | Table Name: | gClass2InjWell | uif700a_root | uif700a_rmk | uif700a_montr | uif700a_monH10H | uif700a_mon_rmk |
| 2 | Dictionary Key (RRC_TAPE_RECORD_ID): | N/A (this table is an assemblage of relevant fields from other existing tables. This is the "primary" table used to create the Class II well shapefile) | 01 | 02 | 03 | 04/05 | (empty) 06 |
| 3 | Fields: | API_FULL | RRC_TAPE_RECORD_ID | RRC_TAPE_RECORD_ID | RRC_TAPE_RECORD_ID | RRC_TAPE_RECORD_ID | RRC_TAPE_RECORD_ID |
| 4 | | TYPE_INJ | UIC_CNTL_NO | UIC_CNTL_NO | UIC_CNTL_NO | UIC_CNTL_NO | UIC_CNTL_NO |
| 5 | | INJ_ZNE_TD | UIC_O_G_TYPE | UIC_O_G_TYPE | UIC_O_G_TYPE | UIC_O_G_TYPE | UIC_O_G_TYPE |
| 6 | **Legend** | INJ_ZNE_BD | UIC_LEASE_ID | UIC_LEASE_ID | UIC_LEASE_ID | UIC_LEASE_ID | UIC_LEASE_ID |
| 7 | No highlight indicates table already exists with | T_Z_BD | UIC_DIST | UIC_DIST | UIC_DIST | UIC_DIST | UIC_DIST |
| 8 | displayed fields in Access database | S_Z_TD | UIC_WELL_NO | UIC_WELL_NO | UIC_WELL_NO | UIC_WELL_NO | UIC_WELL_NO |
| 9 | Data exists in .csv file, but has not been analyzed | S_Z_BD | UIC_OPER | UIC_API_FULL | UIC_API_FULL | UIC_API_FULL | UIC_API_FULL |
| 10 | or imported into Access database | ACTIVE | UIC_CNTY_NO | UIC_REMARKS_RMK | UIC_MONTR_W_STATUS | MN_H10H_CCYY | MN_REMARKS_TYPE |
| 11 | | LETTER_DT | UIC_API_NO | UIC_REMARKS_LINE | UIC_MONTR_SW | MN_H10H_MONTH | MN_REMARKS |
| 12 | | CANCEL_DT | UIC_API_FULL | UIC_REMARKS_TYPE | UIC_MONTR_FW | MN_H10H_MAX_HYDROCARB_PSIG | |
| 13 | | W3_DATE | UIC_FIELD_NO | UIC_REMARKS | UIC_MONTR_FRAC_WATER | MN_H10H_MAX_BRINE_PSIG | |
| 14 | | LATDD | UIC_CLASS | UIC_REMARK_ID | UIC_MONTR_NRM | MN_H10H_INJ_BRINE_BBLS_SIGN | |
| 15 | | LONGDD | UIC_APPR_DATE | UIC_REMARK_DATE | UIC_MONTR_CO2 | MN_H10H_INJ_BRINE_BBLS | |
| 16 | | INJ_SW | UIC_APPR_CC | UIC_REMARK_CCYY | UIC_MONTR_CO2A | $MN_H10H_INJ_HYDRO_BBLS_SIGN | |
| 17 | | INJ_FW | UIC_APPR_YY | UIC_REMARK_MM | UIC_MONTR_GAS | MN_H10H_INJ_HYDROCARB_BBLS | |
| 18 | | INJ_FRAC_W | UIC_APPR_MONTH | UIC_REMARK_DD | UIC_MONTR_H2S | MN_H10H_INJ_GAS_MCF_SIGN | |
| 19 | | INJ_NORM | UIC_APPR_DAY | | UIC_MONTR_POLYMER | MN_H10H_INJ_GAS_MCF | |
| 20 | | INJ_CO2 | UIC_W14_DATE | | UIC_MONTR_STEAM | MN_H10H_DOCUMENT_CYCLE | |
| 21 | | INJ_GAS | UIC_W14_CC | | UIC_MONTR_AIR | MN_H10H_DOCUMENT_BATCH | |
| 22 | | INJ_H2S | UIC_W14_YY | | UIC_MONTR_NITROGEN | MN_H10H_DOCUMENT_ITEM | |
| 23 | | INJ_POLYM | UIC_W14_MONTH | | UIC_MONTR_OTH | | |
| 24 | | INJ_STEAM | UIC_W14_DAY | | UIC_MONTR_BW | | |
| 25 | | INJ_AIR | UIC_H1_DATE | | UIC_MONTR_LPG | | |
| 26 | | INJ_N | UIC_H1_CC | | UIC_MONTR_SW_PCT | | |
| 27 | | INJ_OTHER | UIC_H1_YY | | UIC_MONTR_FW_PCT | | |
| 28 | | INJ_BW | UIC_H1_MONTH | | UIC_MONTR_FRAC_WATER_PCT | | |
| 29 | | INJ_LPG | UIC_H1_DAY | | UIC_MONTR_NORM_PCT | | |
| 30 | | PERF_Z_TD | UIC_LETTER_DATE | | UIC_MONTR_CO2_PCT | | |

| | 1 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Table Name: | uif700a_H5 | uif700a_H5_rmk | uif700a_enf | uif700a_enfact | uif700a_enfoth | uif700a_enfrmk | uif700a_mon10H | uif700a_H10vio |
| 2 | Dictionary Key (RRC_TAPE_RECORD_ID): | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 |
| 3 | Fields: | RRC_TAPE_RECORD_ID | RRC_TAPE_RECORD_ID | RRC_TAPE_RECORD_ID | RRC_TAPE_RECORD_ID | RRC_TAPE_RECORD_ID | RRC_TAPE_RECORD_ID | RRC_TAPE_RECORD_ID | RRC_TAPE_RECORD_ID |
| 4 | | UIC_CNTL_NO | UIC_CNTL_NO | UIC_CNTL_NO | UIC_CNTL_NO | UIC_CNTL_NO | UIC_CNTL_NO | UIC_CNTL_NO | UIC_CNTL_NO |
| 5 | | UIC_O_G_TYPE | UIC_O_G_TYPE | UIC_O_G_TYPE | UIC_O_G_TYPE | UIC_O_G_TYPE | UIC_O_G_TYPE | UIC_O_G_TYPE | UIC_O_G_TYPE |
| 6 | **Legend** | UIC_LEASE_ID | UIC_LEASE_ID | UIC_LEASE_ID | UIC_LEASE_ID | UIC_LEASE_ID | UIC_LEASE_ID | UIC_LEASE_ID | UIC_LEASE_ID |
| 7 | No highlight indicates table already exists with | UIC_DIST | UIC_DIST | UIC_DIST | UIC_DIST | UIC_DIST | UIC_DIST | UIC_DIST | UIC_DIST |
| 8 | displayed fields in Access database | UIC_WELL_NO | UIC_WELL_NO | UIC_WELL_NO | UIC_WELL_NO | UIC_WELL_NO | UIC_WELL_NO | UIC_WELL_NO | UIC_WELL_NO |
| 9 | Data exists in .csv file, but has not been analyzed | UIC_API_FULL | UIC_API_FULL | UIC_API_FULL | UIC_API_FULL | UIC_API_FULL | UIC_API_FULL | UIC_API_FULL | UIC_API_FULL |
| 10 | or imported into Access database | UIC_H5_TEST_DATE_KEY | H5_REMARKS_TYPE | UIC_ENF_KEY | ENF_ACT_VIOL_DATE | ENF_OTH_COMP_METHOD | ENF_REMARKS_TYPE | UIC_H10H_MONTR_KEY | UIC_H10_VIOL_BEGIN_YEAR |
| 11 | | UIC_H5_TEST_SEQ_NUM | H5_REMARKS | UIC_ENF_MAN_FILE_FLAG | ENF_ACT_VIOL_CC | ENF_OTH_ENFORCE_TYPE | ENF_REMARKS | UIC_H10H_MONTR_CC | UIC_H10_VIOL_BEGIN_MONTH |
| 12 | | UIC_H5_DUE_DATE | | | ENF_ACT_VIOL_YY | ENF_OTH_COMPLAINT_NUM | | UIC_H10H_MONTR_YY | UIC_H10_VIOL_END_YEAR |
| 13 | | UIC_H5_DUE_CC | | | ENF_ACT_VIOL_MM | | | UIC_H10H_MONTR_MM | UIC_H10_VIOL_END_MONTH |
| 14 | | UIC_H5_DUE_YY | | | ENF_ACT_VIOL_DD | | | UIC_H10H_MONTR_W_STATUS | UIC_H10_VIOL_CODE |
| 15 | | UIC_H5_DUE_MM | | | ENF_ACT_VIOL_CODE | | | UIC_H10H_MONTR_CRUDE | UIC_H10_VIOL_LETTER_KEY |
| 16 | | UIC_H5_DUE_DD | | | ENF_ACT_NOTICE_DATE | | | UIC_H10H_MONTR_GAS | UIC_H10_VIOL_LETTER_DATE |
| 17 | | UIC_H5_RECEIVED_DATE | | | ENF_ACT_NOTICE_CC | | | UIC_H10H_MONTR_LPG | UIC_H10_VIOL_LETTER_YEAR |
| 18 | | UIC_H5_RECEIVED_CC | | | ENF_ACT_NOTICE_YY | | | UIC_H10H_MONTR_OTHER | UIC_H10_VIOL_LETTER_MONTH |
| 19 | | UIC_H5_RECEIVED_YY | | | ENF_ACT_NOTICE_MM | | | UIC_H10H_MONTR_PRESS_GT_ZERO | UIC_H10_VIOL_LETTER_DAY |
| 20 | | UIC_H5_RECEIVED_MM | | | ENF_ACT_NOTICE_DD | | | UIC_H10H_MONTR_SURFACE_VESSEL | UIC_H10_VIOL_RESOLVE_DATE |
| 21 | | UIC_H5_RECEIVED_DD | | | ENF_ACT_NOTICE_TYPE | | | UIC_H10H_MONTR_REC_FLG | UIC_H10_VIOL_RESOLVE_YEAR |
| 22 | | UIC_H5_SCHEDULE_TYPE | | | ENF_ACT_COMP_DATE | | | UIC_H10H_MULT_WELL_CAVERN_FLAG | UIC_H10_VIOL_RESOLVE_MONTH |
| 23 | | UIC_H5_SCHEDULE_FLAG | | | ENF_ACT_COMP_CC | | | UIC_H10H_MONTR_ISS_DATE | UIC_H10_VIOL_RESOLVE_DAY |
| 24 | | UIC_H5_SCHEDULED_DATE | | | ENF_ACT_COMP_YY | | | UIC_H10H_MONTR_ISS_CC | UIC_H10_VIOL_RESOLVE_BY_FLAG |
| 25 | | UIC_H5_SCHEDULED_CC | | | ENF_ACT_COMP_MM | | | UIC_H10H_MONTR_ISS_YY | UIC_H10_VIOL_P4_CERT_DTE_KEY |
| 26 | | UIC_H5_SCHEDULED_YY | | | ENF_ACT_COMP_DD | | | UIC_H10H_MONTR_ISS_MM | UIC_H10_VIOL_P4_CERT_SECTION |
| 27 | | UIC_H5_SCHEDULED_MM | | | ENF_ACT_COMP_METHOD | | | UIC_H10H_MONTR_ISS_DD | UIC_H10_VIOL_P4_CERT_REASON |
| 28 | | UIC_H5_SCHEDULED_DD | | | ENF_ACT_SNC_FLAG | | | UIC_H10H_MONTR_REC_DATE | UIC_H10_VIOL_SEVER_LTR_DATE |
| 29 | | UIC_H5_2ND_NOTICE_DATE | | | ENF_ACT_VIOL_ON_HOLD | | | UIC_H10H_MONTR_REC_CC | UIC_H10_VIOL_SEVER_LTR_YEAR |
| 30 | | UIC_H5_2ND_NOTICE_CC | | | | | | UIC_H10H_MONTR_REC_YY | UIC_H10_VIOL_SEVER_LTR_MONTH |

# 2020 RRC Well Bore Data Update

- Well Bore Technical Data Root Segment
- Well Bore Completion Information Segment
- Well Bore Technical Data Forms File Data
- Well Bore Remarks Segment
- Well Bore Tubing Segment
- Well Bore Casing Segment
- Well Bore Perf Segment
- Well Bore Liner Segment
- Well Bore Formation Data Segment
- Well Bore Squeeze Segment
- Well Bore Usable Quality Water Protection
- Well Bore Old Location Segment
- Well Bore New Location Segment
- Well Bore Plugging Data Segment
- Well Bore Plugging Remarks Segment
- Well Bore Plugging Record Segment
- Well Bore Plugging Data Casing-Tubing record
- Well Bore Plugging Perfs Segment
- Well Bore Plugging Data Nomenclature Segment
- Well Bore Drilling Permit Number
- Well Bore Well-ID Segment
- 14B2 Well Segment
- H-15 Report Segment
- H-15 Remark Segment
- Senate Bill 126 (2-Yr Inactive Program) Segment
- Well Bore - Drilling Permit Status Segment

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1 | Table Name: | dbf900_01root | dbf900_02compl | dbf900_03date | dbf900_04rmks | dbf900_05tube | dbf900_06case | dbf900_07perf |
| 2 | Dictionary Key (RRC_TAPE_RECORD_ID): | 01 | 02 | 03 | 04 | 05 | 06 | 07 |
| 3 | Fields: | RRC_TAPE_RECORD_ID | RRC_TAPE_RECORD_ID | RRC_TAPE_RECORD_ID | RRC_TAPE_RECORD_ID | RRC_TAPE_RECORD_ID | RRC_TAPE_RECORD_ID | RRC_TAPE_RECORD_ID |
| 4 | | WB_API_NUMBER | WB_API_NUMBER | WB_API_NUMBER | WB_API_NUMBER | WB_API_NUMBER | WB_API_NUMBER | WB_API_NUMBER |
| 5 | | WB_NXT_AVAIL_SUFFIX | WB_OIL_CODE | WB_FILE_KEY | WB_FILE_KEY | WB_FILE_KEY | WB_FILE_KEY | WB_FILE_KEY |
| 6 | **Legend** | WB_NXT_AVAIL_HOLE_CHGE_NBR | WB_OIL_DIST | WB_FILE_DATE | WB_RMK_LNE_CNT | WB_SEGMENT_COUNTER | WB_CASING_COUNT | WB_PERF_COUNT |
| 7 | No highlight indicates table already exists with | WB_FIELD_DISTRICT | WB_OIL_LSE_NBR | WB_EXCEPT_RULE_11 | WB_RMK_TYPE_CODE | WB_TUBING_INCHES | WB_CAS_INCH | WB_FROM_PERF |
| 8 | displayed fields in Access database | WB_RES_CNTY_CODE | WB_OIL_WELL_NBR | WB_CEMENT_AFFIDAVIT | WB_REMARKS | WB_FR_NUMERATOR | WB_CAS_FRAC_NUM | WB_TO_PERF |
| 9 | Data exists in .csv file, but has not been | WB_ORIG_COMPL_CC | WB_GAS_CODE | WB_G_5 | | WB_FR_DENOMINATOR | WB_CAS_FRAC_DENOM | WB_OPEN_HOLE_CODE |
| 10 | analyzed or imported into Access database | WB_ORIG_COMPL_DATE | WB_GAS_RRC_ID | WB_W_12 | | WB_DEPTH_SET | WB_CAS_WT_TABLE | |
| 11 | | WB_ORIG_COMPL_CENT | WB_GAS_DIST | WB_DIR_SURVEY | | WB_PACKER_SET | WB_WGT_WHOLE1 | |
| 12 | | WB_ORIG_COMPL_YY | WB_GAS_WELL_NO | WB_W2_G1_DATE | | | WB_WGT_TENTHS1 | |
| 13 | | WB_ORIG_COMPL_MM | WB_MULTI_WELL_REC_NBR | WB_COMPL_DATE | | | WB_WGT_WHOLE2 | |
| 14 | | WB_ORIG_COMPL_DD | WB_API_SUFFIX | WB_COMPL_CENTURY | | | WB_WGT_TENTHS2 | |
| 15 | | WB_TOTAL_DEPTH | WB_ACTIVE_INACTIVE_CODE | WB_COMPL_YEAR | | | WB_CASING_DEPTH_SET | |
| 16 | | WB_VALID_FLUID_LEVEL | WB_DWN_HOLE_COMMINGLE_CODE | WB_COMPL_MONTH | | | WB_MLTI_STG_TOOL_DPTH | |
| 17 | | WB_CERT_REVOKED_DATE | WB_CREATED_FROM_PI_FLAG | WB_COMPL_DAY | | | WB_AMOUNT_OF_CEMENT | |
| 18 | | WB_CERT_REVOKED_CC | WB_RULE_37_NBR | WB_DRL_COMPL_DATE | | | WB_CEMENT_MEASUREMENT | |
| 19 | | WB_CERT_REVOKED_YY | WB_P_15 | WB_PLUGB_DEPTH1 | | | WB_HOLE_INCH | |
| 20 | | WB_CERT_REVOKED_MM | WB_P_12 | WB_PLUGB_DEPTH2 | | | WB_HOLE_FRAC_NUM | |
| 21 | | WB_CERT_REVOKED_DD | WB_PLUG_DATE_POINTER | WB_WATER_INJECTION_NBR | | | WB_HOLE_FRAC_DENOM | |
| 22 | | WB_CERTIFICATION_DENIAL_DATE | | WB_SALT_WTR_NBR | | | WB_TOP_OF_CEMENT_CASING | |
| 23 | | WB_CERTIFICATION_DENIAL_CC | | WB_REMARKS_IND | | | WB_AMOUNT_CASING_LEFT | |
| 24 | | WB_CERTIFICATION_DENIAL_YY | | WB_ELEVATION | | | | |
| 25 | | WB_CERTIFICATION_DENIAL_MM | | WB_ELEVATION_CODE | | | | |
| 26 | | WB_CERTIFICATION_DENIAL_DD | | WB_LOG_FILE_RBA | | | | |
| 27 | | WB_DENIAL_REASON_FLAG | | WB_DOCKET_NBR | | | | |
| 28 | | WB_ERROR_API_ASSIGN_CODE | | | | | | |
| 29 | | WB_REFER_CORRECT_API_NBR | | | | | | |
| 30 | | WB_DUMMY_API_NUMBER | | | | | | |
| 31 | | WB_DATE_DUMMY_REPLACED | | | | | | |
| 32 | | WB_NEWEST_DRL_PMT_NBR | | | | | | |
| 33 | | WB_CANCEL_EXPIRE_CODE | | | | | | |
| 34 | | WB_EXCEPT_13_A | | | | | | |
| 35 | | WB_FRESH_WATER_FLAG | | | | | | |

| | 1 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|
| 1 | Table Name: | dbf900_08line | dbf900_09form | dbf900_10sqeze | dbf900_11fresh | dbf900_12oldloc | dbf900_13newloc | dbf900_14plug |
| 2 | Dictionary Key (RRC_TAPE_RECORD_ID): | 08 | 09 | 10 | 11 | 12 | 13 | 14 |
| 3 | Fields: | RRC_TAPE_RECORD_ID | RRC_TAPE_RECORD_ID | RRC_TAPE_RECORD_ID | RRC_TAPE_RECORD_ID | RRC_TAPE_RECORD_ID | RRC_TAPE_RECORD_ID | RRC_TAPE_RECORD_ID |
| 4 | | WB_API_NUMBER | WB_API_NUMBER | WB_API_NUMBER | WB_API_NUMBER | WB_API_NUMBER | WB_API_NUMBER | WB_API_NUMBER |
| 5 | | WB_FILE_KEY | WB_FILE_KEY | WB_FILE_KEY | WB_FILE_KEY | WB_LEASE_NAME | WB_LOC_COUNTY | WB_DATE_W3_FILED |
| 6 | **Legend** | WB_LINE_COUNT | WB_FORMATION_CNTR | WB_SQUEEZE_CNTR | WB_FRESH_WATER_CNTR | WB_SEC_BLK_SURVEY_LOC | WB_ABSTRACT | WB_DATE_WELL_BORE_PLUGGED |
| 7 | No highlight indicates table already exists with | WB_LIN_INCH | WB_FORMATION_NAME | WB_SQUEEZE_UPPER_DEPTH | WB_TWDB_DATE | WB_WELL_LOC_MILES | WB_SURVEY | WB_PLUG_TOTAL_DEPTH |
| 8 | displayed fields in Access database | WB_LIN_FRAC_NUM | WB_FORMATION_DEPTH | WB_SQUEEZE_LOWER_DEPTH | WB_SURFACE_CASING_DETER_CODE | WB_WELL_LOC_DIRECTION | WB_BLOCK_NUMBER | WB_PLUG_CEMENT_COMP |
| 9 | Data exists in .csv file, but has not been | WB_LIN_FRAC_DENOM | | WB_SQUEEZE_KIND_AMOUNT | WB_UQWP_FROM | WB_WELL_LOC_NEAREST_TOWN | WB_SECTION | WB_PLUG_MUD_FILLED |
| 10 | analyzed or imported into Access database | WB_SACKS_OF_CEMENT | | | WB_UQWP_TO | WB_DIST_FROM_SURVEY_LINES | WB_ALT_SECTION | WB_PLUG_MUD_APPLIED |
| 11 | | WB_TOP_OF_LINER | | | | WB_DIST_DIRECT_NEAR_WELL | WB_ALT_ABSTRACT | WB_PLUG_MUD_WEIGHT |
| 12 | | WB_BOTTOM_OF_LINER | | | | | WB_FEET_FROM_SUR_SECT_1 | WB_PLUG_DRIL_PERM_DATE |
| 13 | | | | | | | WB_DIREC_FROM_SUR_SECT_1 | WB_PLUG_DRIL_PERM_NO |
| 14 | | | | | | | WB_FEET_FROM_SUR_SECT_2 | WB_PLUG_DRIL_COMP_DATE |
| 15 | | | | | | | WB_DIREC_FROM_SUR_SECT_2 | WB_PLUG_LOG_ATTACHED |
| 16 | | | | | | | WB_WGS84_LATITUDE | WB_PLUG_LOG_RELEASED_TO |
| 17 | | | | | | | WB_WGS84_LONGITUDE | WB_PLUG_TYPE_LOG |
| 18 | | | | | | | WB_PLANE_ZONE | WB_PLUG_FRESH_WATER_DEPTH |
| 19 | | | | | | | WB_PLANE_COORDINATE_EAST | WB_PLUG_FROM_UWQP_1 |
| 20 | | | | | | | WB_PLANE_COORDINATE_NORTH | WB_PLUG_TO_UWQP_1 |
| 21 | | | | | | | WB_VERIFICATION_FLAG | WB_PLUG_FROM_UWQP_2 |
| 22 | | | | | | | | WB_PLUG_TO_UWQP_2 |
| 23 | | | | | | | | WB_PLUG_FROM_UWQP_3 |
| 24 | | | | | | | | WB_PLUG_TO_UWQP_3 |
| 25 | | | | | | | | WB_PLUG_FROM_UWQP_4 |
| 26 | | | | | | | | WB_PLUG_TO_UWQP_4 |
| 27 | | | | | | | | WB_PLUG_MATERIAL_LEFT |
| 28 | | | | | | | | WB_PLUG_OIL_CODE |
| 29 | | | | | | | | WB_PLUG_OIL_DIST |
| 30 | | | | | | | | WB_PLUG_OIL_LSE_NBR |
| 31 | | | | | | | | WB_PLUG_OIL_WELL_NBR |
| 32 | | | | | | | | WB_PLUG_GAS_CODE |
| 33 | | | | | | | | WB_PLUG_GAS_RRC_ID |
| 34 | | | | | | | | WB_PLUG_GAS_DIST |
| 35 | | | | | | | | WB_PLUG_GAS_WELL_NO |

# RRC Data Processing Summary

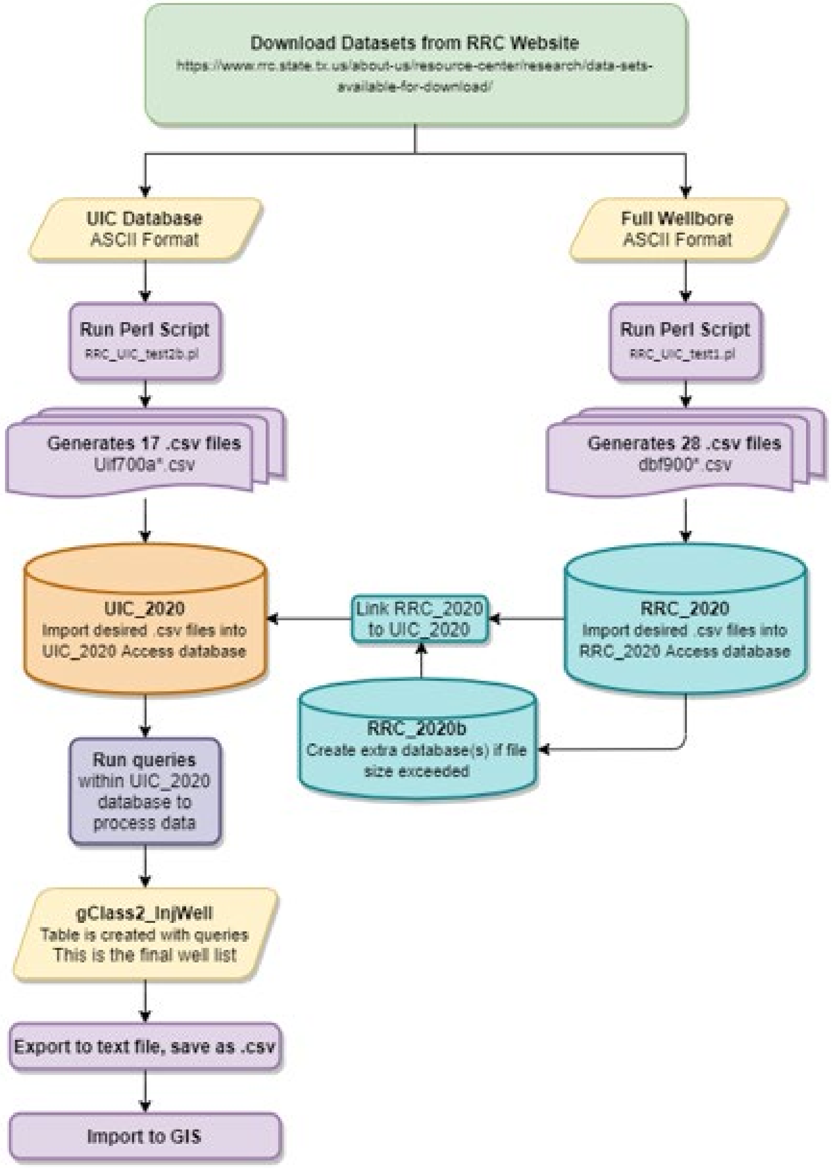
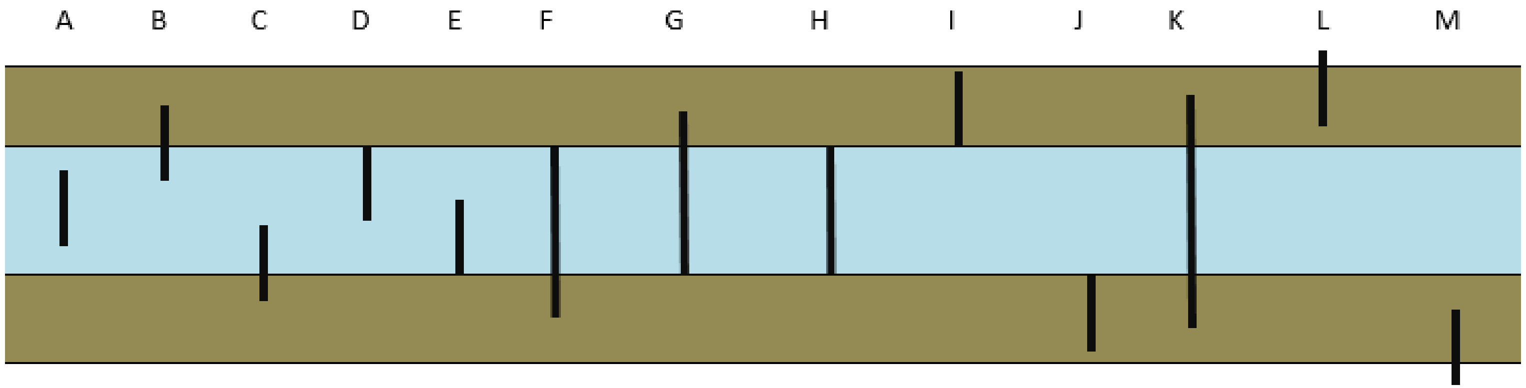



Figure 4.1.1: Database Processing Summary

# TWDB Workflow

- Reproduced existing TWDB workflow
  - *BRACS_TechTask_HB30-Criteria_Analysis_step6_InjectionWells_ClassII_for_WSP.docx*
- Considered scenarios (see image below) as outlined in workflow
- Followed logic statements provided in document (example below, left)
- Did not perform manual review and edits as outlined in document
- Flagged “data quality issues” (logic below, right)




**Queries used to identify well subsets**

Wells that intersect the formation:

A – Injection zone entirely within the formation

"INJ_ZNE_TD" > "FM_TD" AND "INJ_ZNE_BD" < "FM_BD"

B – Injection zone straddles the top of the formation

"INJ_ZNE_TD" < "kb_td_snp" AND "INJ_ZNE_BD" > "kb_td_snp" AND "INJ_ZNE_BD" < "kb_bd_snp"

C – Injection zone straddles the bottom of the formation

"INJ_ZNE_TD" > "kb_td_snp" AND "INJ_ZNE_TD" < "kb_bd_snp" AND "INJ_ZNE_BD" > "kb_bd_snp"

D – Injection zone starts at the top of the formation and ends within the formation

"INJ_ZNE_TD" = "kb_td_snp" AND "INJ_ZNE_BD" < "kb_bd_snp" AND "INJ_ZNE_BD" > "kb_td_snp"

**Flag data quality issues**

14. Queries should be run to flag poor data quality. These wells will need further analysis to determine if they intersect the formation. These queries identify wells where:
    a. the top and bottom depth of the injection zone are zero,
       i. "INJ_ZNE_TD" =0 AND "INJ_ZNE_BD" =0
    b. wells where the bottom depth is zero (top is valid), and
       i. "INJ_ZNE_BD" =0 AND "INJ_ZNE_TD" <>0
    c. wells where the top is deeper than the bottom (and the bottom is valid).
       i. B_INJ_ZONE <> 0 AND "T_INJ_ZONE" > "B_INJ_ZONE"

# Automated RRC Data Processing Tool

- Automates the process of downloading the RRC dataset for Class II injection wells and generates tables for the well intersection tool

- **Tool input**:
  - *RRC Underground Injection Control Database*
    - Raw data download of uif700a.txt file
  - *RRC Oil and Gas Full Wellbore Database*
    - Raw data download of dbf900.txt file

- **Tool Output**:
  - *Processed table containing information from both RRC datasets (gClass2_InjWell.csv)*
  - *Statistics of all injection well data in Texas - avg, min, and max injection rates (InjectionWell_Statistics.xslx)*

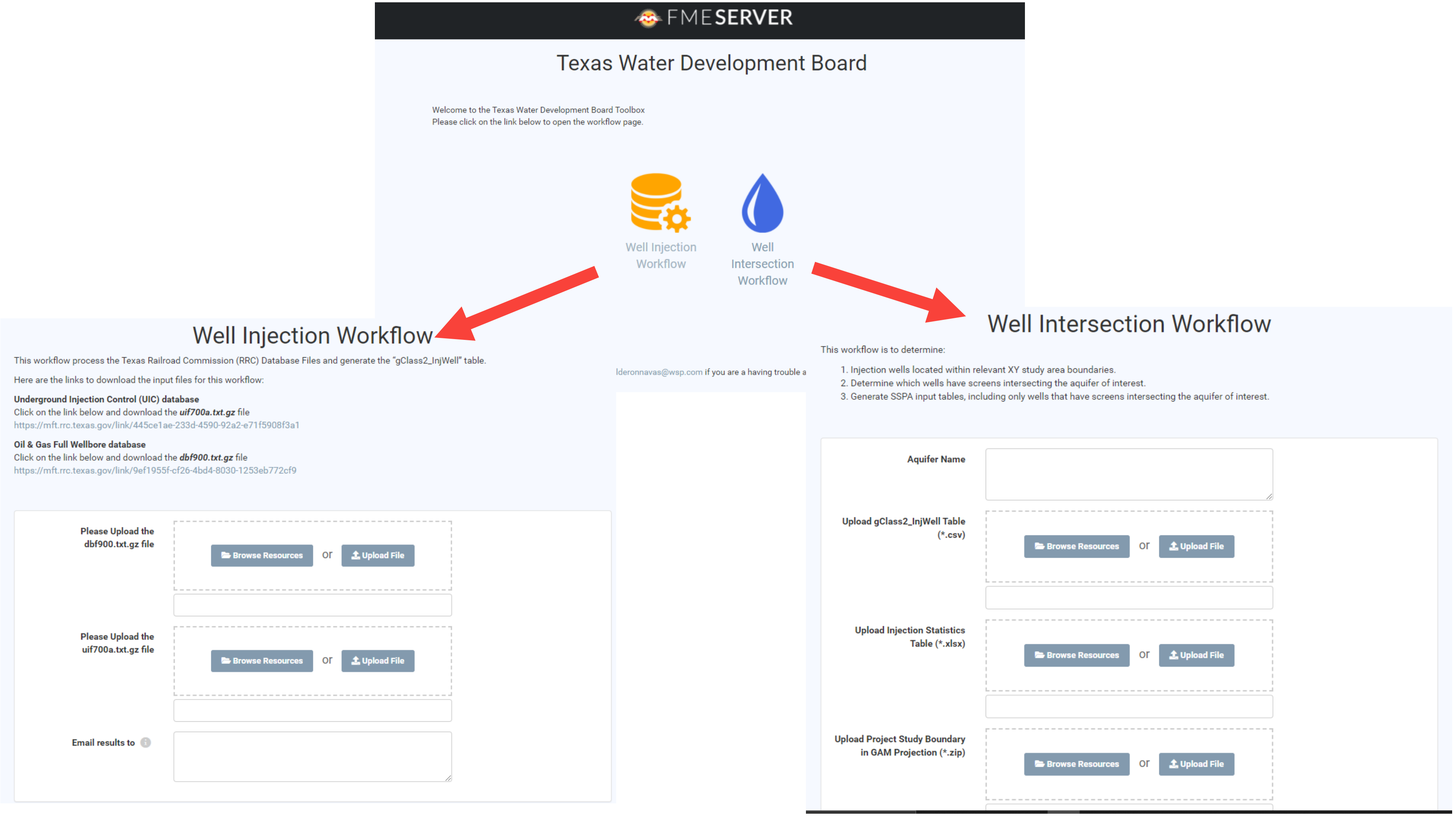
# Automated Well Intersection Tool

- Automates the process of locating the injection wells in aquifers and generates tables for the injectate mapping tool

- **Tool Input**:
  - *Aquifer study area boundaries (shapefiles)*
  - *Aquifer hydrostratigraphic surfaces (rasters)*
  - *Digital Elevation Model of Texas (raster)*
  - *Processed table with RRC datasets (gClass2_InjWell.csv)*
  - *Statistics of all injection well data (InjectionWell_Statistics.xslx)*

- **Tool Output**:
  - *Processed table containing injection well rates ($ft^3$/day), injection tops and bottoms, and injection start and stop dates*
    - Input table for Injectate Mapping Tool (AquiferName_InjectateMappingInput_Date.csv)

# Automated Tools:
# Data Processing and Well Intersection Tools



# Mapping Techniques – Processes

Simple → Complex

| Process | Modeling Technique | Data Availability | Meets Modeling Objective? |
|---|---|---|---|
| Injection flow hydraulics | Analytical solutions | Injection and aquifer data | No |
| Flow gradient | Analytical solutions | Regional flow gradients assumed | Yes |
| Advection | Analytical solutions | Basic data is available | Yes |
| Dispersion | Analytical solutions | Values need to be assumed | Yes |
| Multiple wells | Numerical solutions | Injection well locations | Yes |
| Density | Numerical solutions | Injectate and receiving water data | Yes |
| Heterogeneity | Numerical solutions | Detailed well log data | Yes |
| Geochemistry | Numerical solutions | Site-specific and well specific data | Yes |

# Mapping Techniques

1. Analytical solutions:
   - *Stable*
   - *Easy-to-use*
   - *Simplifying assumptions but exact solutions*
   - *EPA (1994), Bear & Jacobs (1965), Domenico-type*

2. Numerical solutions :
   - *Accommodate complex systems*
   - *Intensive data requirements*
   - *potentially unstable, require advanced users*
   - *Modflow 6*

# Mapping Techniques – Processes

Simple → Complex

| Process | Modeling Technique | Data Availability | Meets Modeling Objective? |
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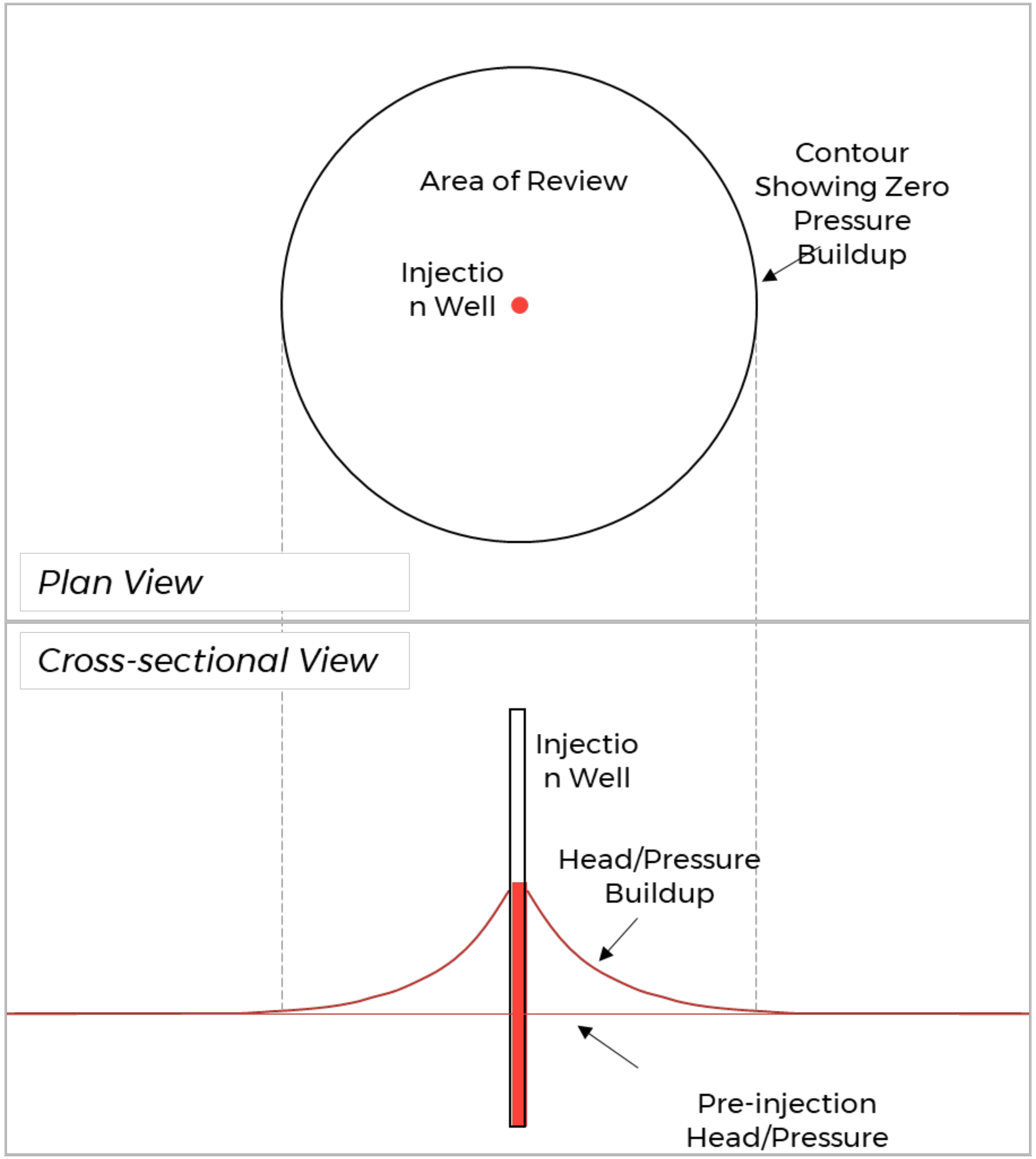
# Analytical Solutions (Drawdown/Mounding)

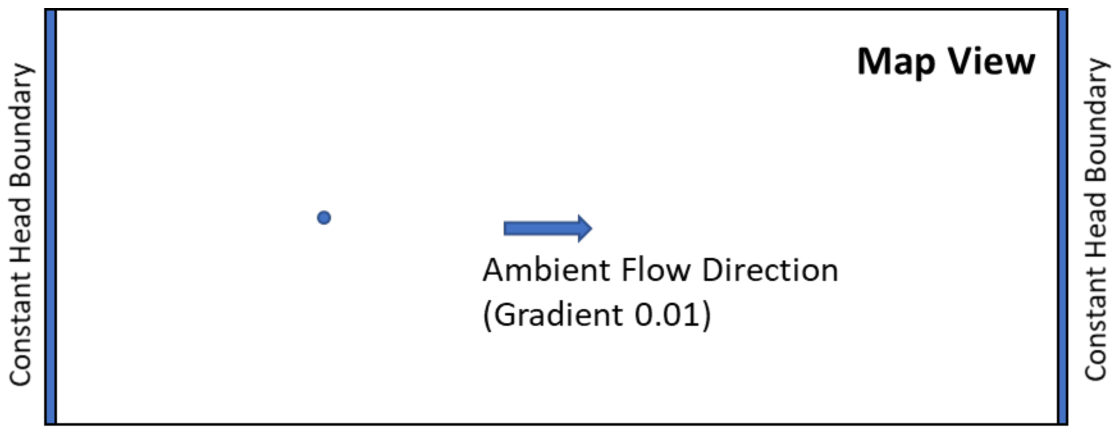
- Abundant literature on "Area of Review" or "Zone of endangering influence"

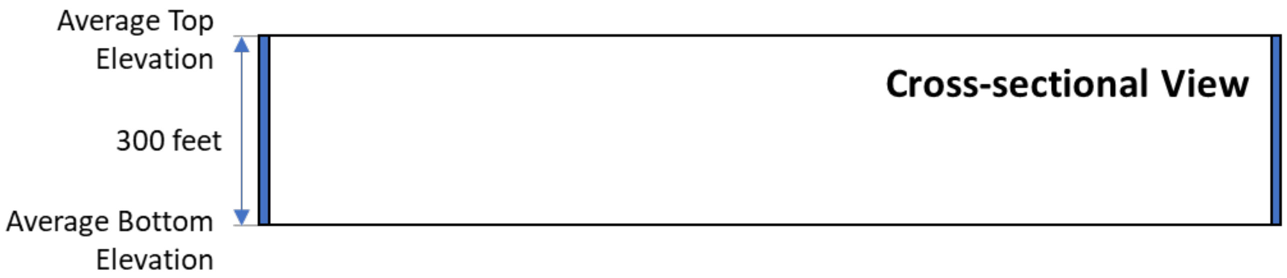
- head change, not migration



# Analytical Solutions (Drawdown/Mounding)

- Heads stabilize over time
- Injectate keeps spreading



# Analytical Solutions (Drawdown/Mounding)

# Summary: Injection mounding

- Only addresses mounding
- No injectate migration
- Does not meet mapping objectives

# Mapping Techniques – Processes

Simple → Complex

| Process | Modeling Technique | Data Availability | Meets Modeling Objective? |
|---|---|---|---|
| Injection flow hydraulics | Analytical solutions | Injection and aquifer data | No |
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| Heterogeneity | Numerical solutions | Detailed well log data | Yes |
| Geochemistry | Numerical solutions | Site-specific and well specific data | Yes |

# Analytical Solutions

– Injectate migration is key

  – *EPA (1994)*

$$r(t) = \left(\frac{Qt}{\pi \phi b}\right)^{1/2}$$

  – *Domenico-type solution (Srinivasan, et. al, 2007) or Wexler, 1992*

$$c(x,y,z,t) = \frac{c_o}{8} f_x^o(x,t) f_y(x,y) f_z(x,z),$$

$$\text{where} \quad f_x^o(x,t) = 2\exp\left(-\frac{kx}{v}\right) u\left\{t - \frac{x}{v}\right\}$$

where $u\left\{t - \frac{x}{v}\right\}$ is the step function given by,

$$u\left\{t - \frac{x}{v}\right\} = \begin{cases} 0 \text{ if } t \leq \frac{x}{v} \\ 1 \text{ if } t > \frac{x}{v} \end{cases}$$

# Analytical Solutions

– *Bear and Jacobs (1965)*

$$t_D = x_D - ln\{1 + x_D\}$$

$$t_D = \frac{2\pi q^2 b}{\phi Q} t$$

$$x_D = \frac{2\pi q b}{Q} \bar{x}$$

# Assumptions – Aquifer

- Confined
- Homogeneous
- Isotropic
- Insignificant vertical gradient
- Infinite extent
- Steady-state flow field: horizontal gradient (i)
- No recharge or other sources/sinks: lumped into (i)

# Assumptions – Injection Wells & Transport

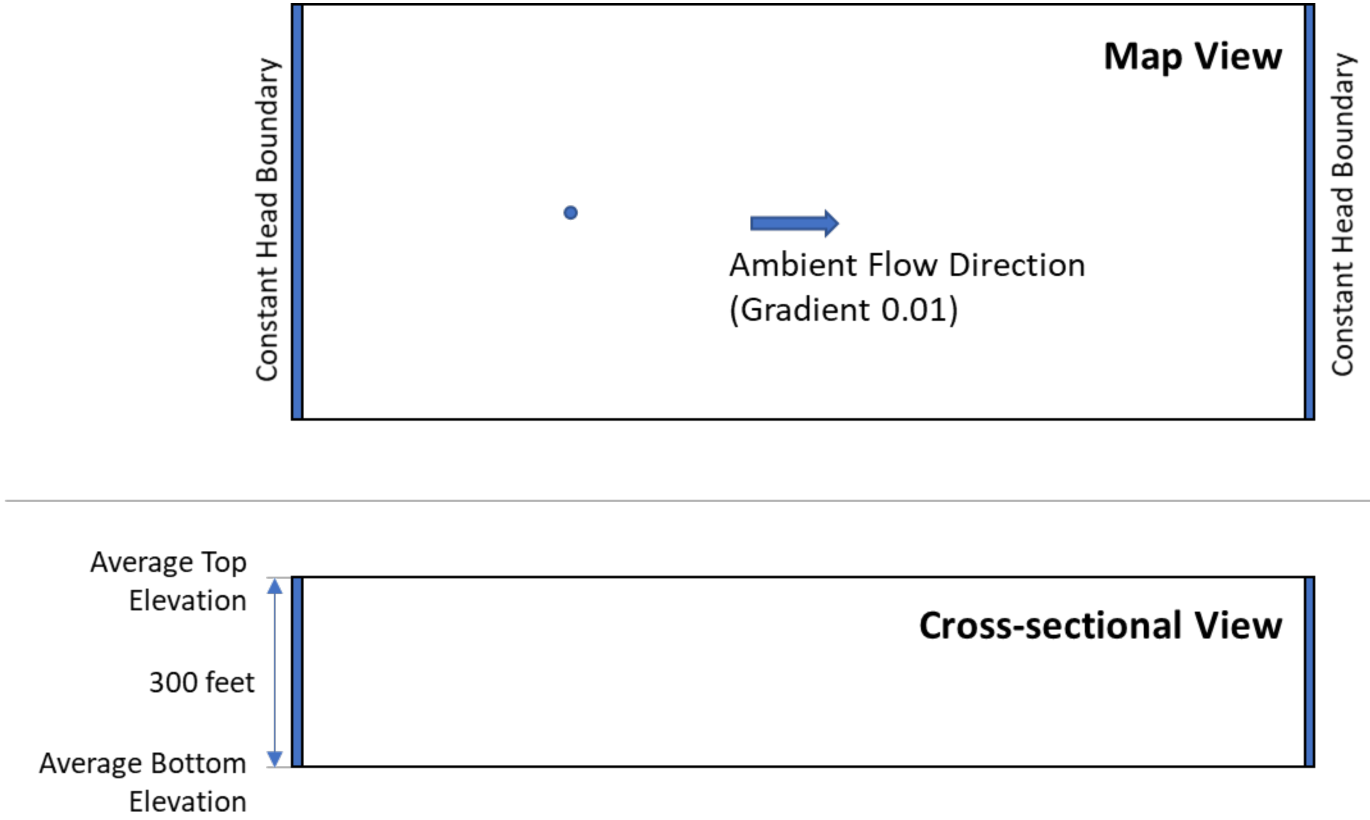
- Injection wells:
  - *fully efficient*
  - *no wellbore storage effects*
- Continuous screening only
  - *Multiple screens lumped*
- Variable-density ignored
  - *Justification in report and through simulations*
- No dispersion
- Non-reactive transport: conservative migration
- No vertical migration
- Single well analysis

# Analytical vs. Numerical Solution

– One injection well

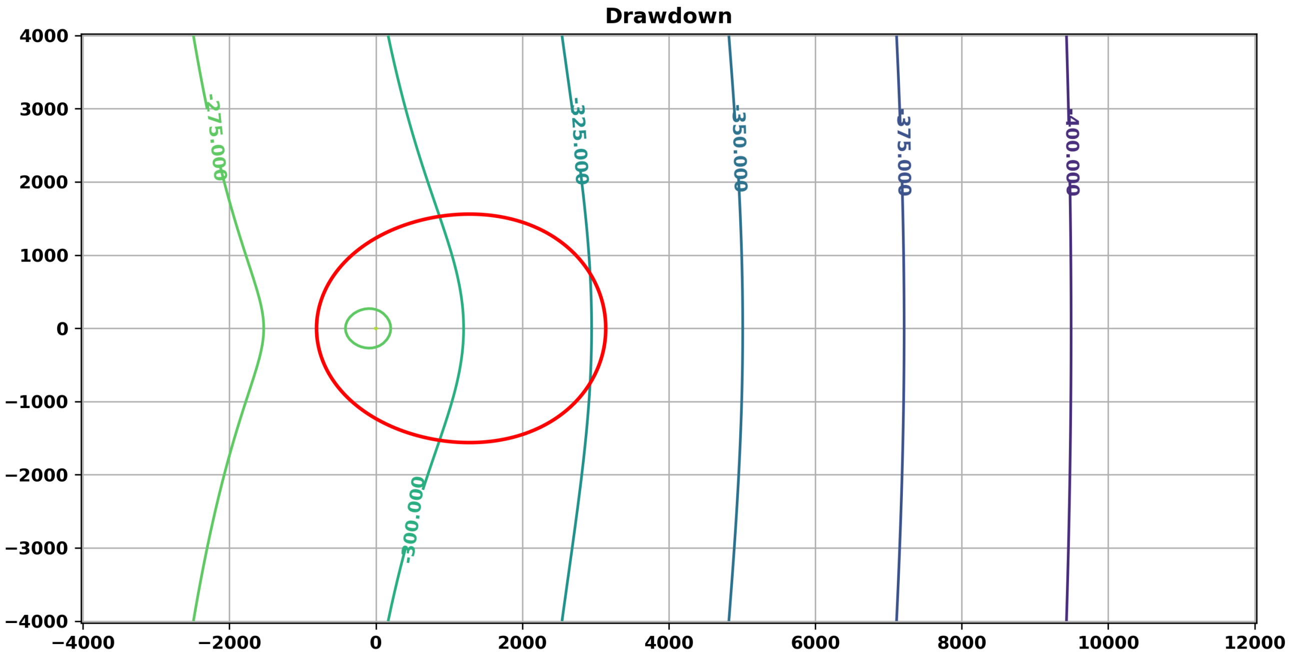
– Simple case

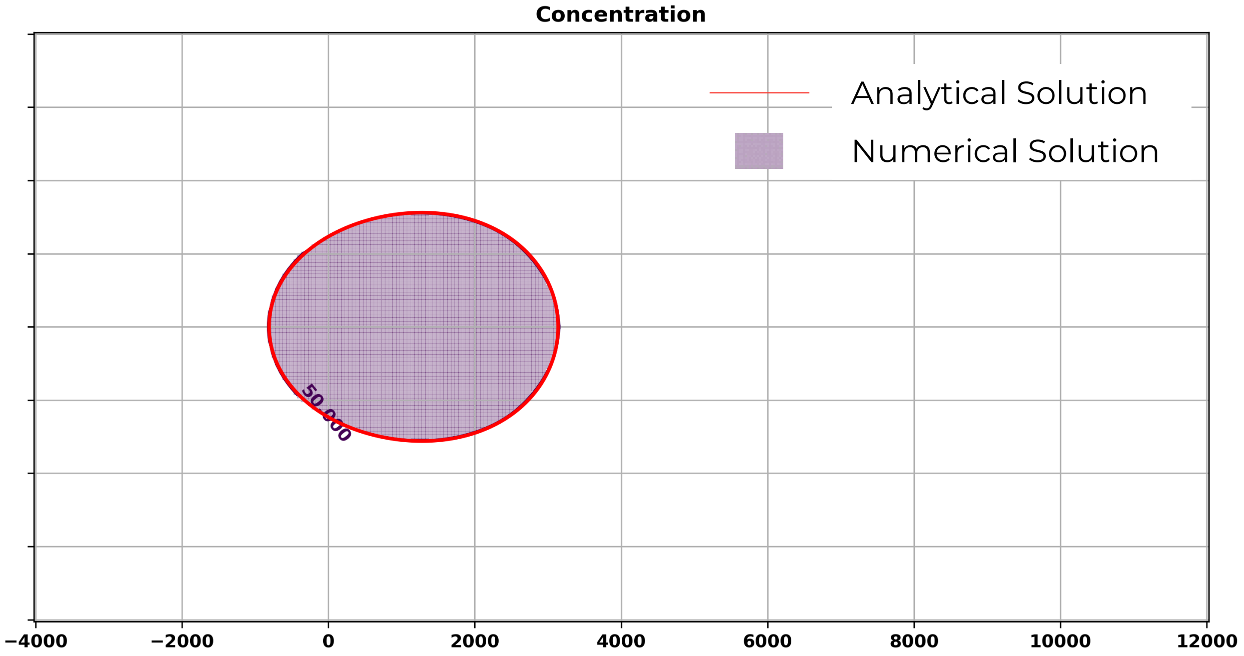
– Complex cases



# Analytical vs. Numerical

- One injection well
- Constant
  - *head gradient*
  - *injection*




wsp

# Summary: Advective migration

- Determines injectate migration
- Meets modeling objectives
- Data available
- Widely-used and accepted solutions
- Suitable analytical solutions include:
  - *EPA (1994) – considers radial flow only*
  - *Domenico-type solutions – considers regional flow only*
  - *Bear and Jacobs (1965) – considers radial and regional flow*

# Mapping Techniques – Processes

Simple → Complex

| Process | Modeling Technique | Data Availability | Meets Modeling Objective? |
| --- | --- | --- | --- |
| Injection flow hydraulics | Analytical solutions | Injection and aquifer data | No |
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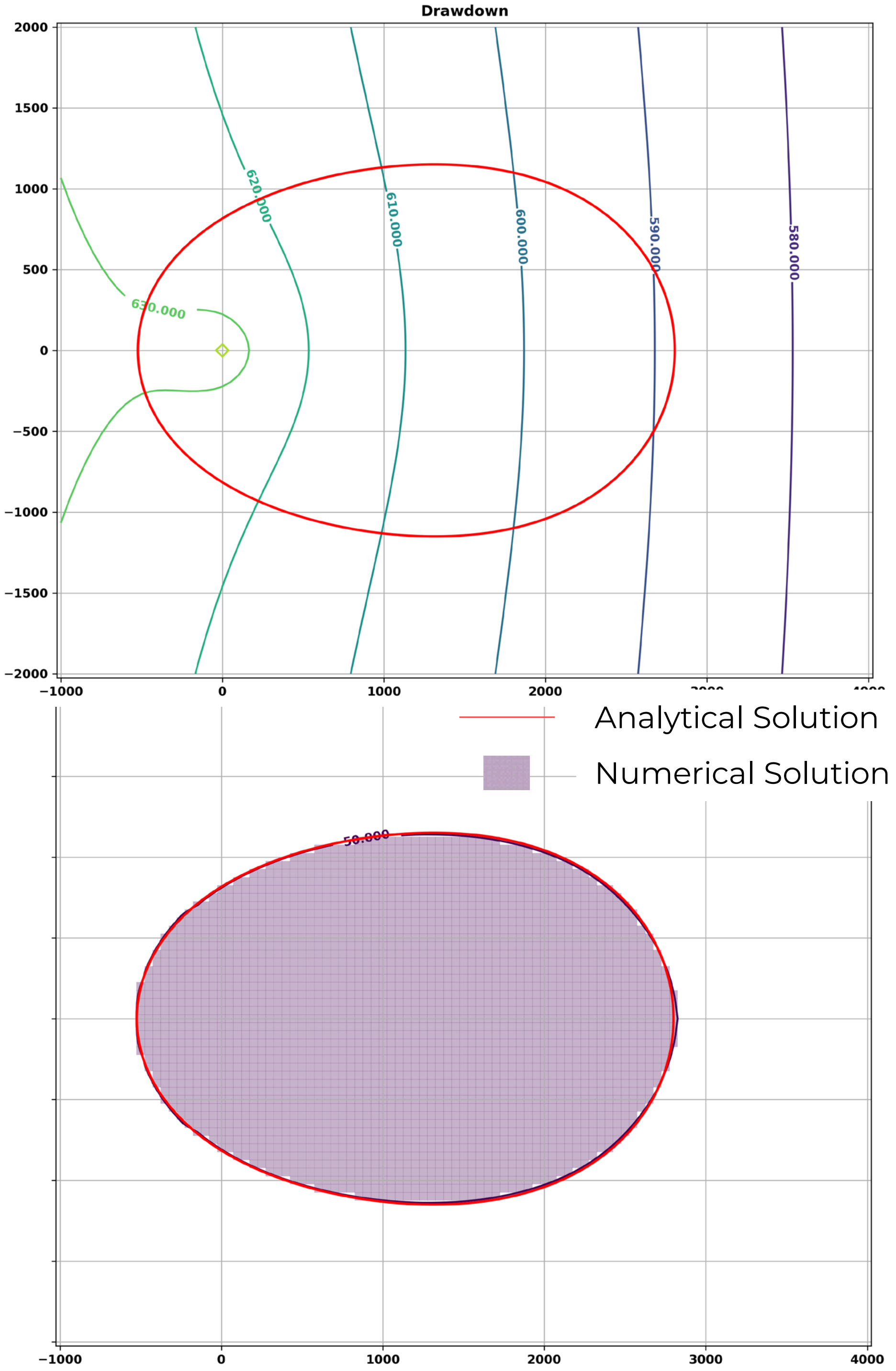
| Heterogeneity | Numerical solutions | Detailed well log data | Yes |
| Geochemistry | Numerical solutions | Site-specific and well specific data | Yes |

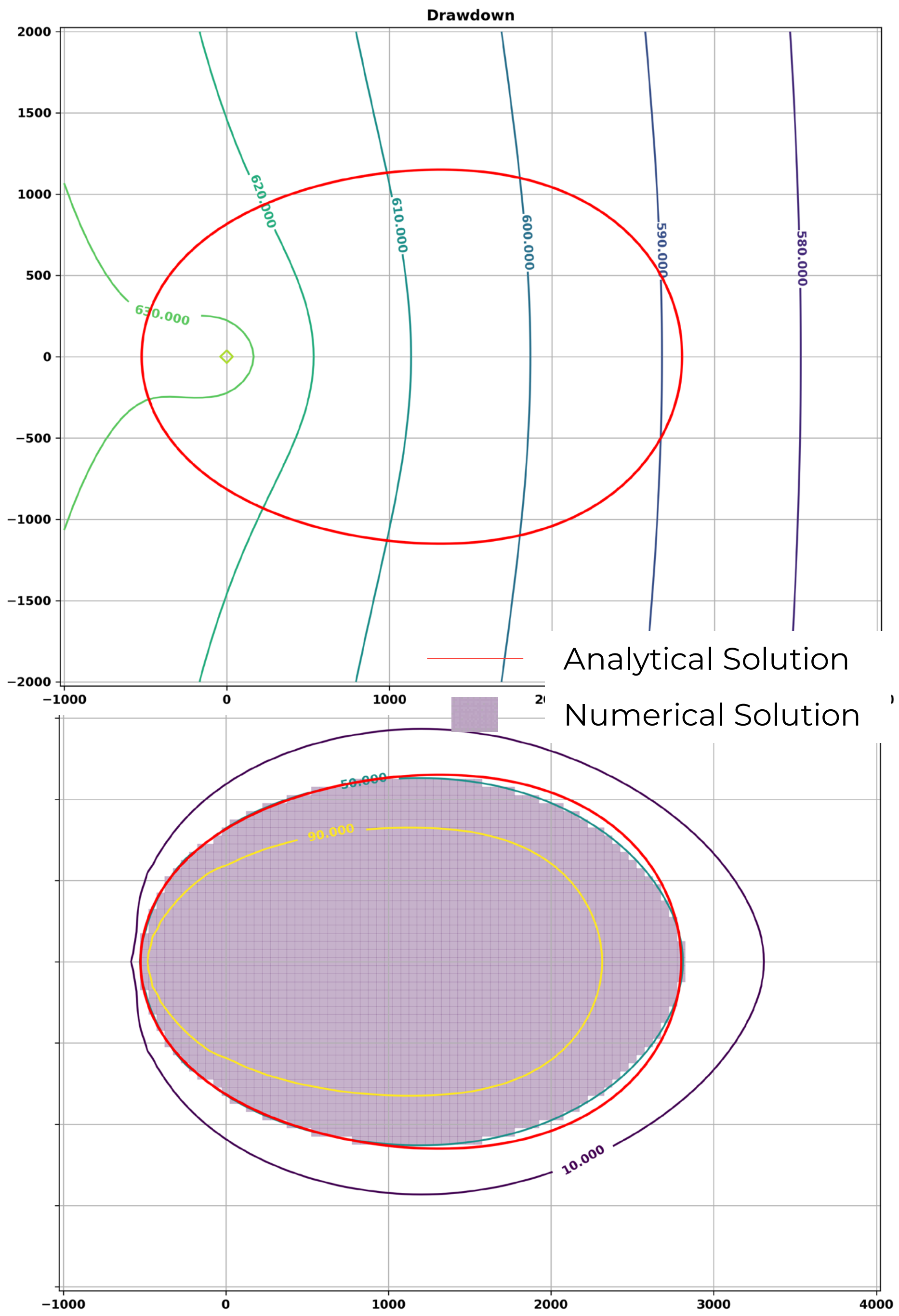
# Effect of Dispersion

— No dispersion



# Effect of Dispersion

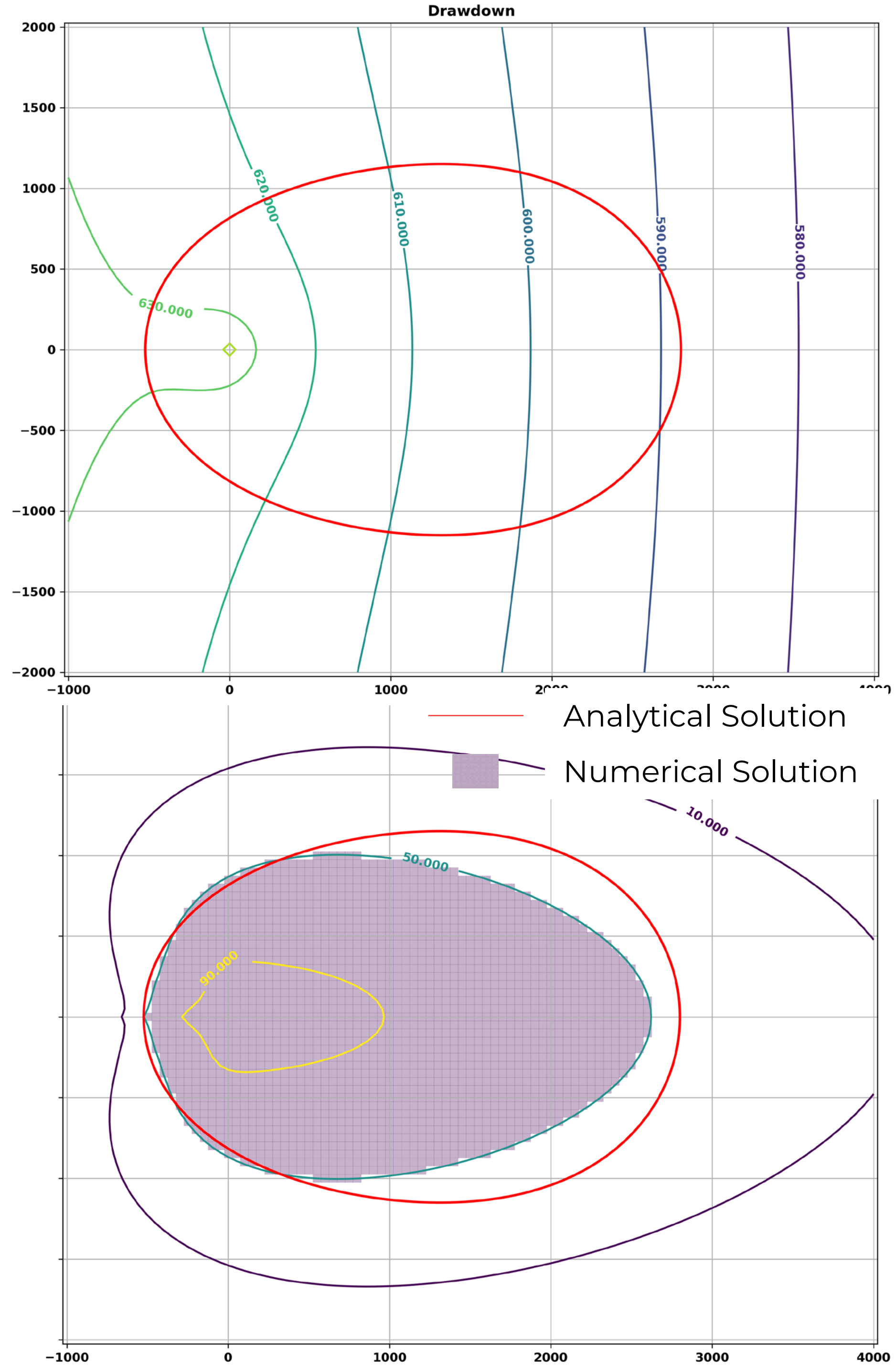
- Longitudinal dispersion = 40 feet
- Transverse dispersion = 1/10 LD



# Effect of Dispersion

— Longitudinal dispersion = 400 feet

— Transverse dispersion = 1/10 LD



# Summary: Dispersion

- 50% isocontour represents average injectate migration
- Analytical solutions match average injectate migration
- Analytical solutions that ignore dispersion but consider radial flow:
  - *EPA (1994)*
  - *Bear and Jacobs (1965)*
- Analytical solution that considers dispersion but ignores radial flow:
  - *Domenico-type solution*

# Mapping Techniques – Processes

Simple → Complex

| Process | Modeling Technique | Data Availability | Meets Modeling Objective? |
|---|---|---|---|
| Injection flow hydraulics | Analytical solutions | Injection and aquifer data | No |
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| Heterogeneity | Numerical solutions | Detailed well log data | Yes |
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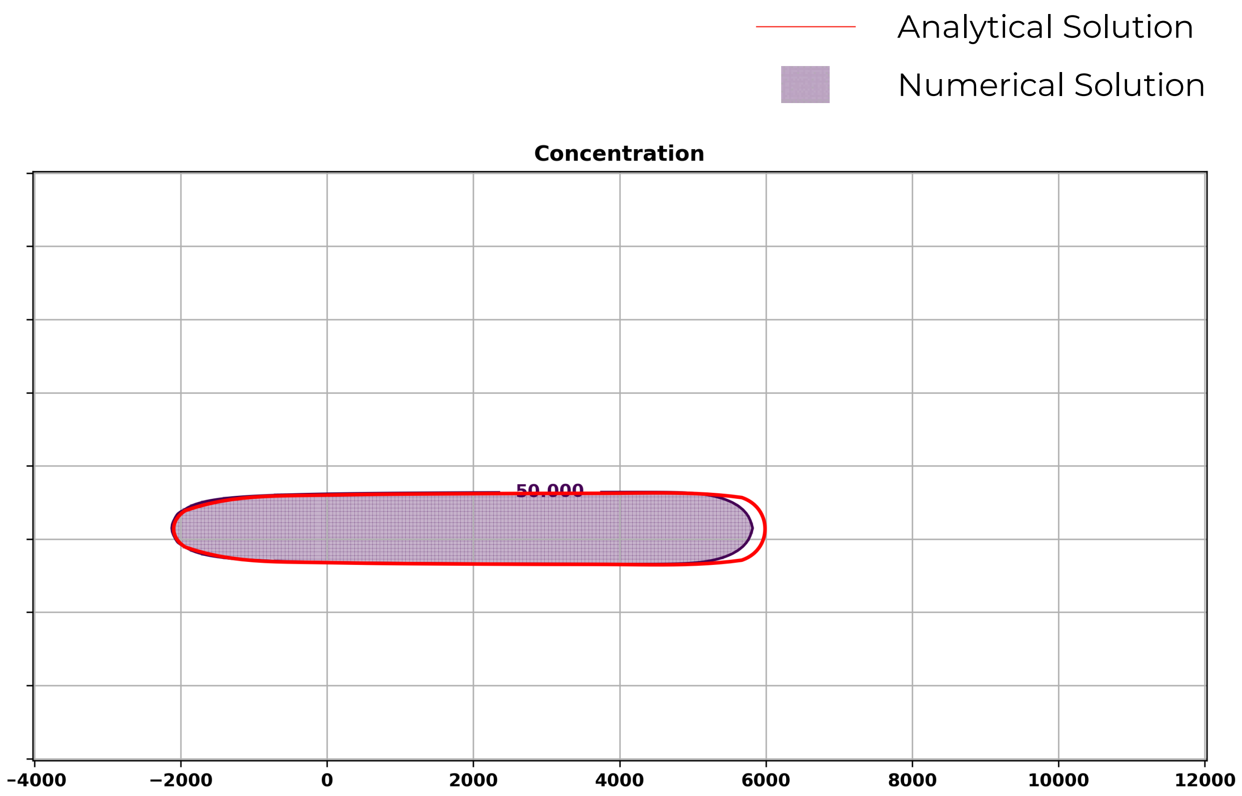
# Effect of Multiple Wells

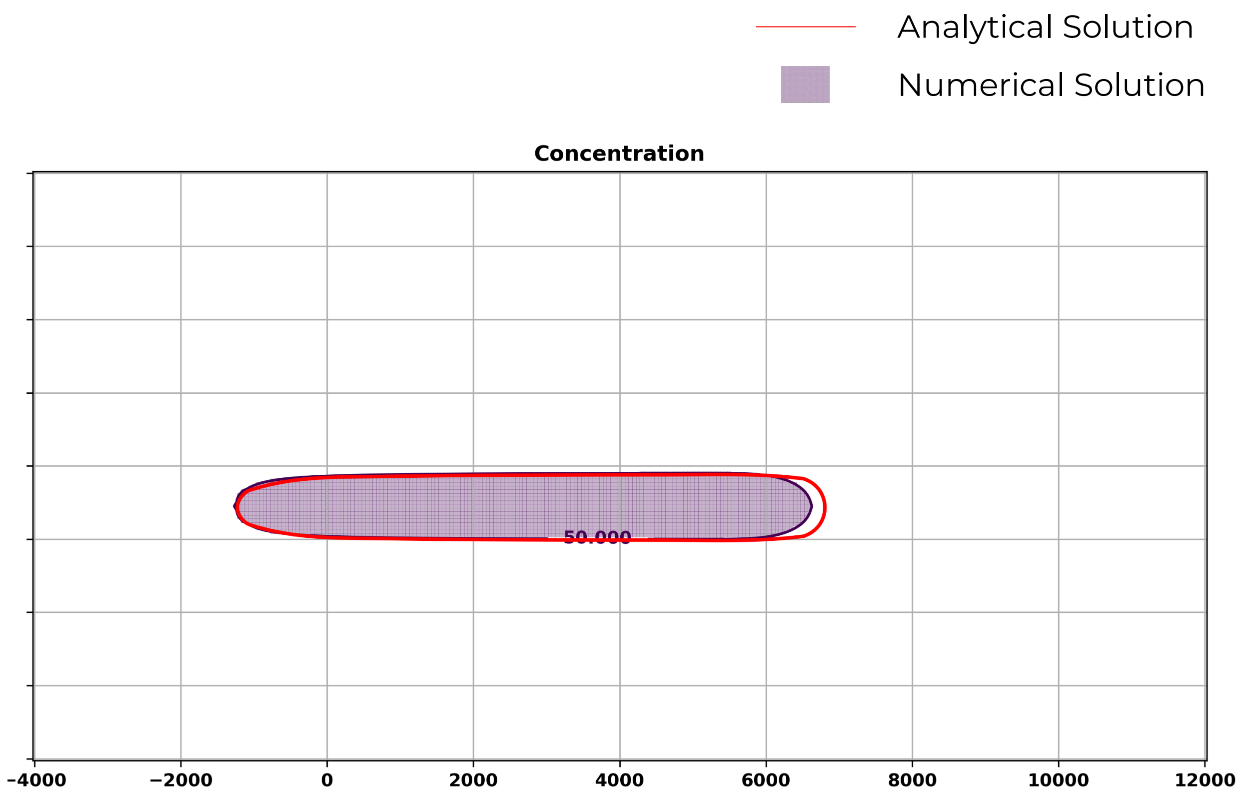
- Five wells
- Combined impact vs. individual impact



# Effect of Multiple Wells

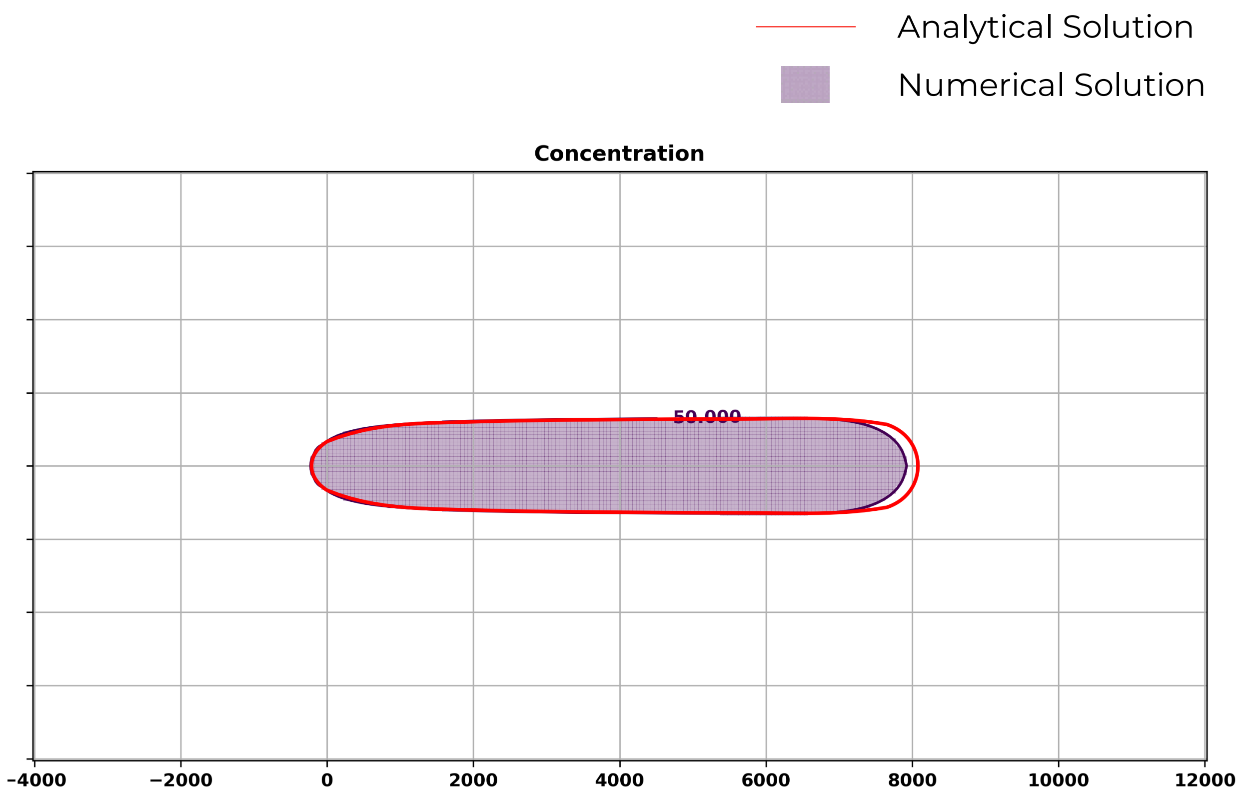
- Five wells

- Combined impact vs. individual impact



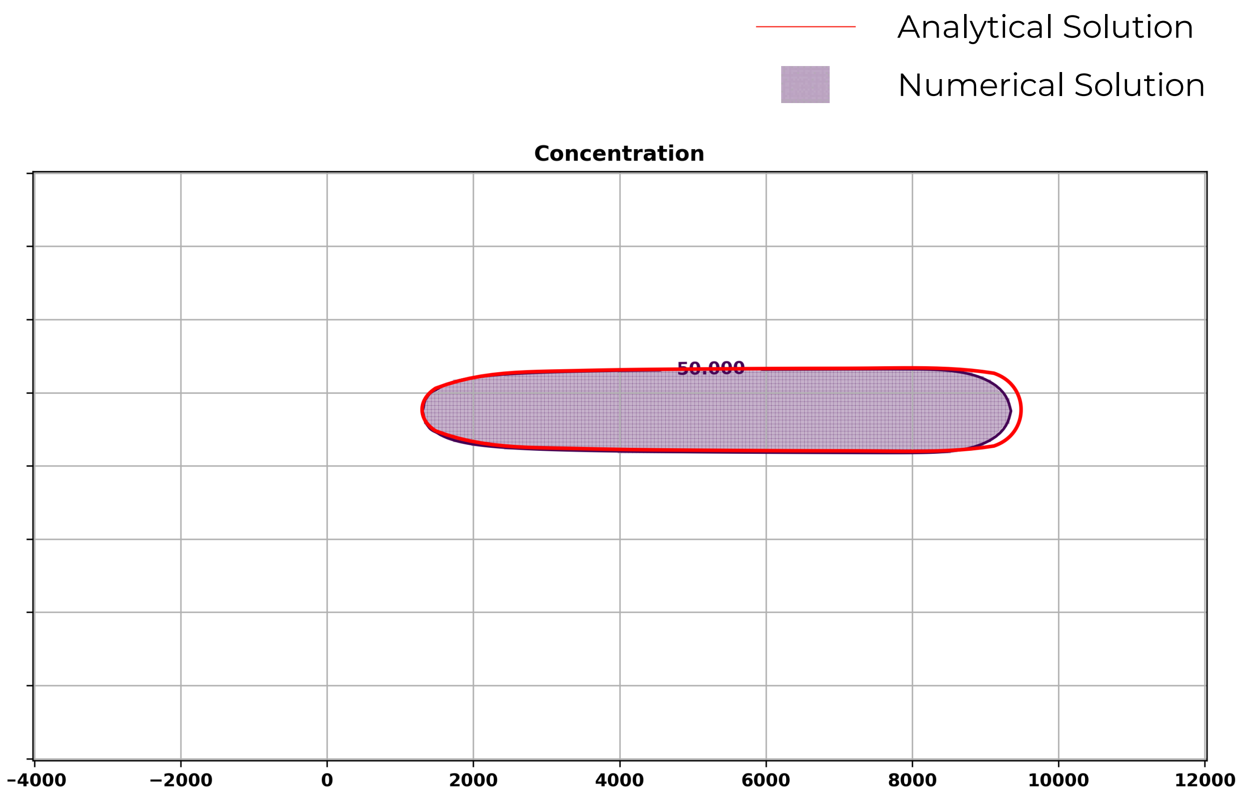
# Effect of Multiple Wells

- Five wells
- Combined impact vs. individual impact



# Effect of Multiple Wells

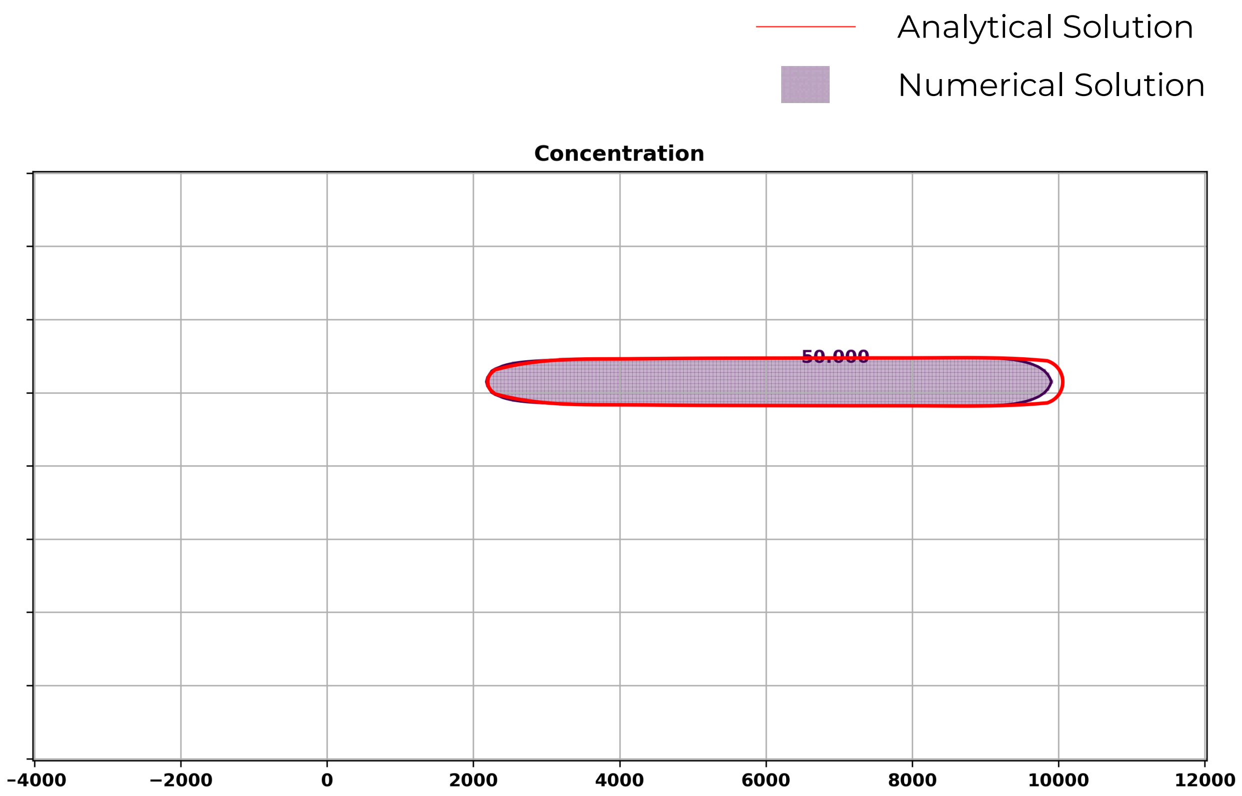
- Five wells
- Combined impact vs. individual impact



# Effect of Multiple Wells

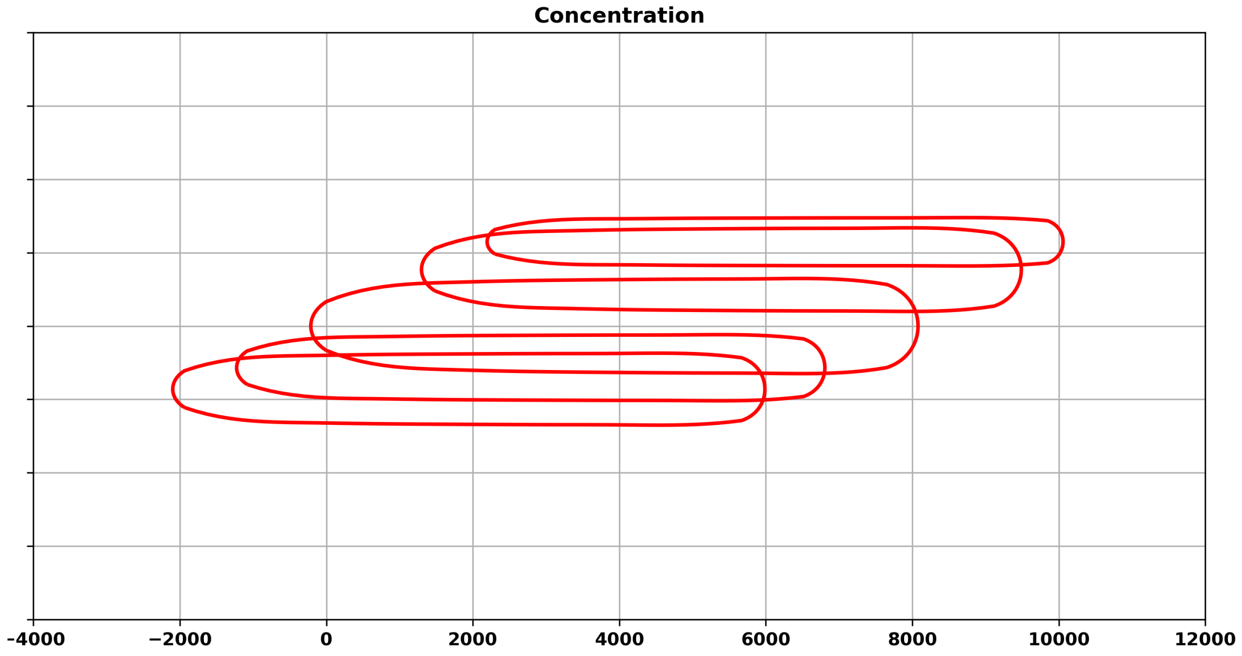
- Five wells

- Combined impact vs. individual impact



# Effect of Multiple Wells

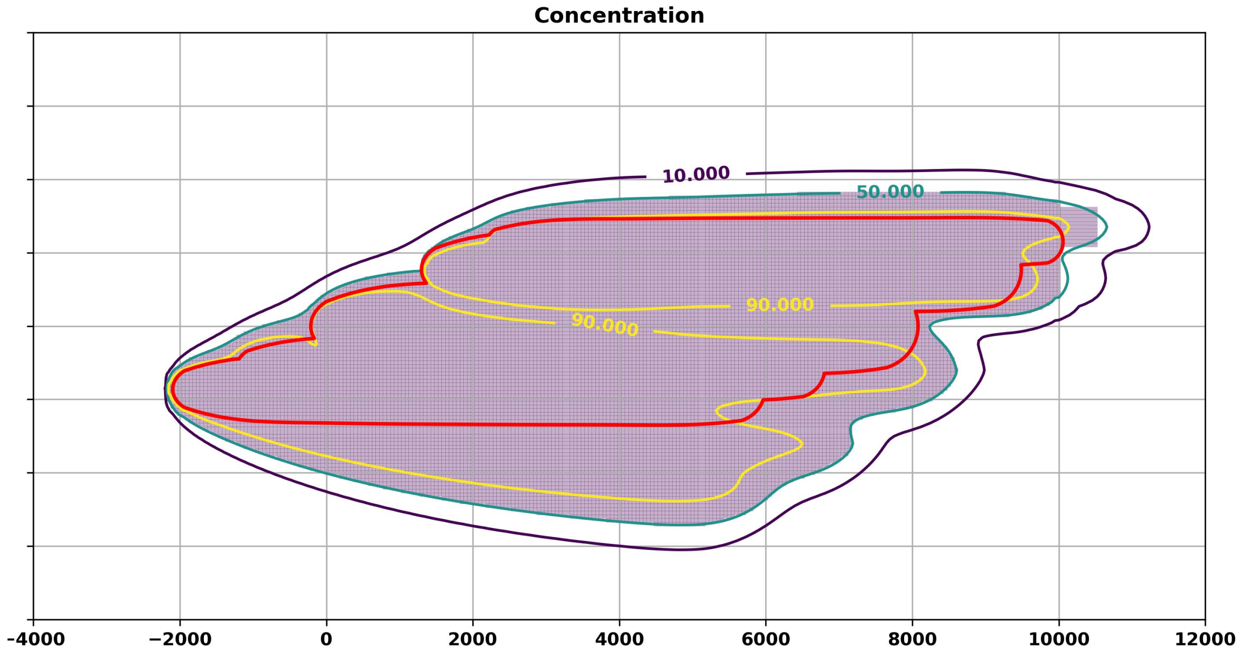
- Analytical solutions for individual wells



# Effect of Multiple Wells

- Analytical solutions for individual wells (ensemble)

- Numerical solution



# Summary: Multiple wells

- Analytical solutions estimate single well injectate migration
- Multiple wells in close vicinity may influence each other
- Analytical solutions may underestimate injectate migration from multiple wells in close vicinity
- Numerical solutions capable of estimating migration with multiple wells in close vicinity, albeit at a high cost
- Suitable numerical solution includes:
  - *MODFLOW 6*

# Mapping Techniques – Processes

Simple → Complex

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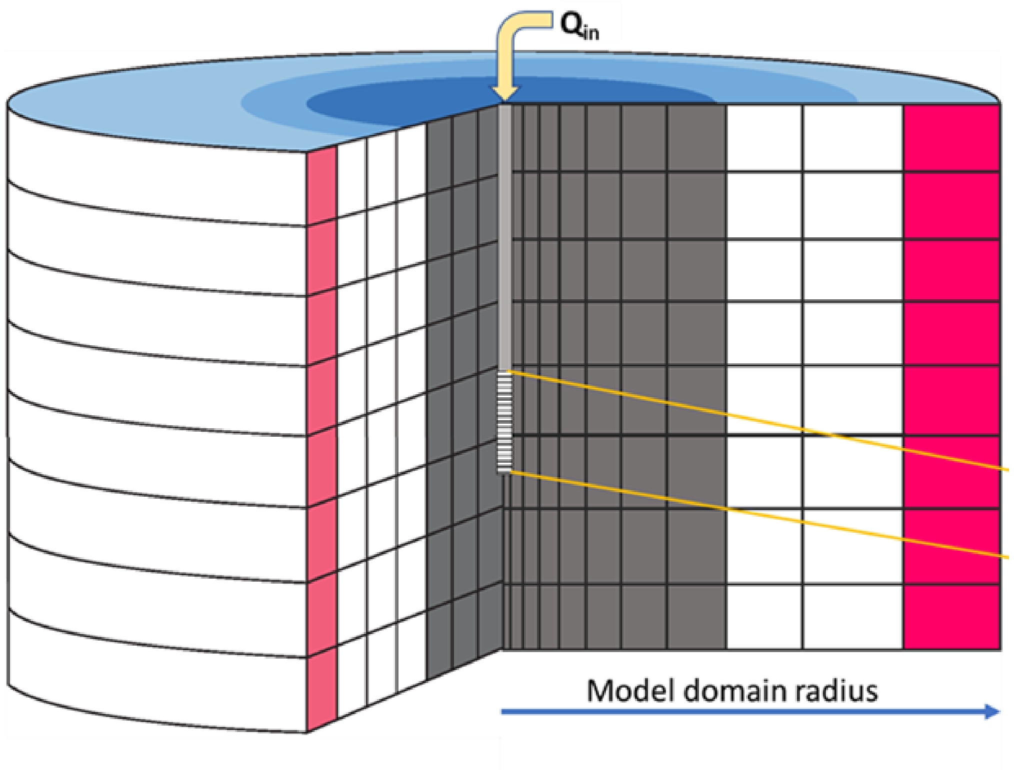
| Heterogeneity | Numerical solutions | Detailed well log data | Yes |
| Geochemistry | Numerical solutions | Site-specific and well specific data | Yes |

# Effect of Density

- Axisymmetric model
- Injection
  - *Fully penetrating well*
  - *Partially penetrating well*
- Density effects evaluated
- Isotropic conditions assumed



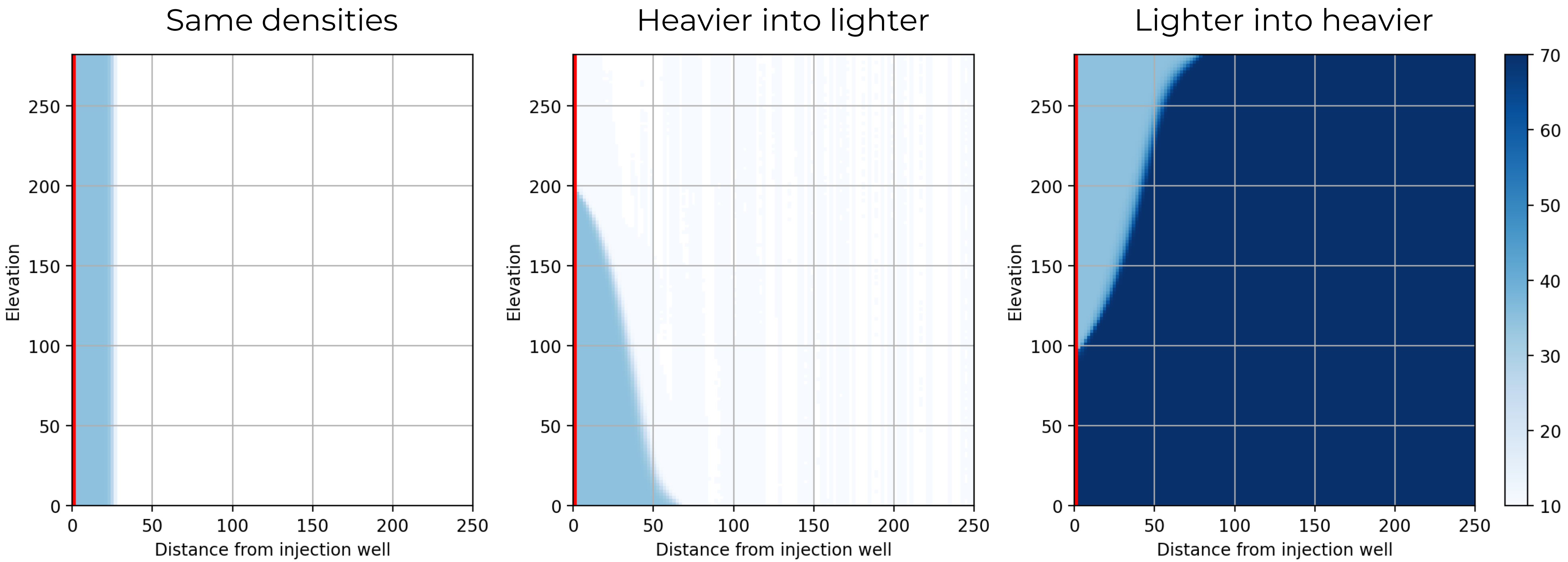
# Effect of Density Simulations

- Injected water at seawater density (TDS = 35 g/l); receiving water at TDS = 10 g/L
  - *Heavier into lighter*

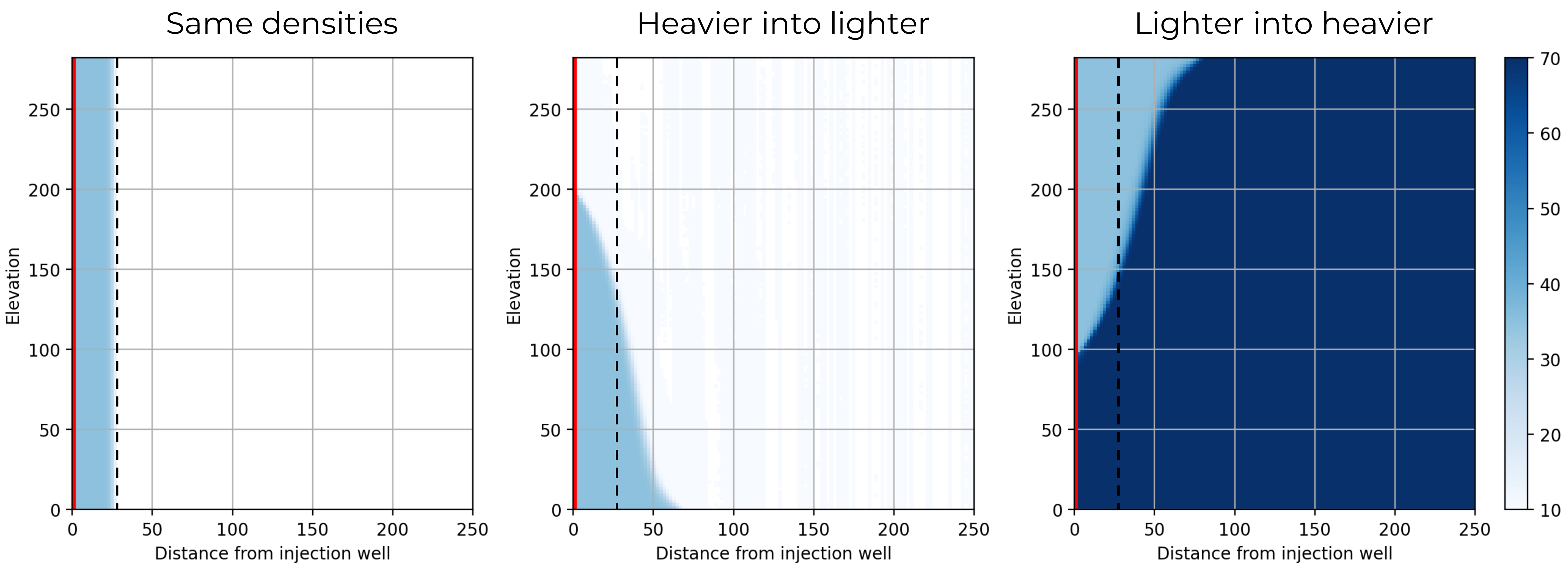
- Injected water at seawater density (TDS = 35 g/l); receiving water at TDS = 35 g/L
  - *Same densities*

- Injected water at seawater density (TDS = 35 g/l); receiving water at TDS = 70 g/L
  - *Lighter into heavier*

# Fully Penetrating Well

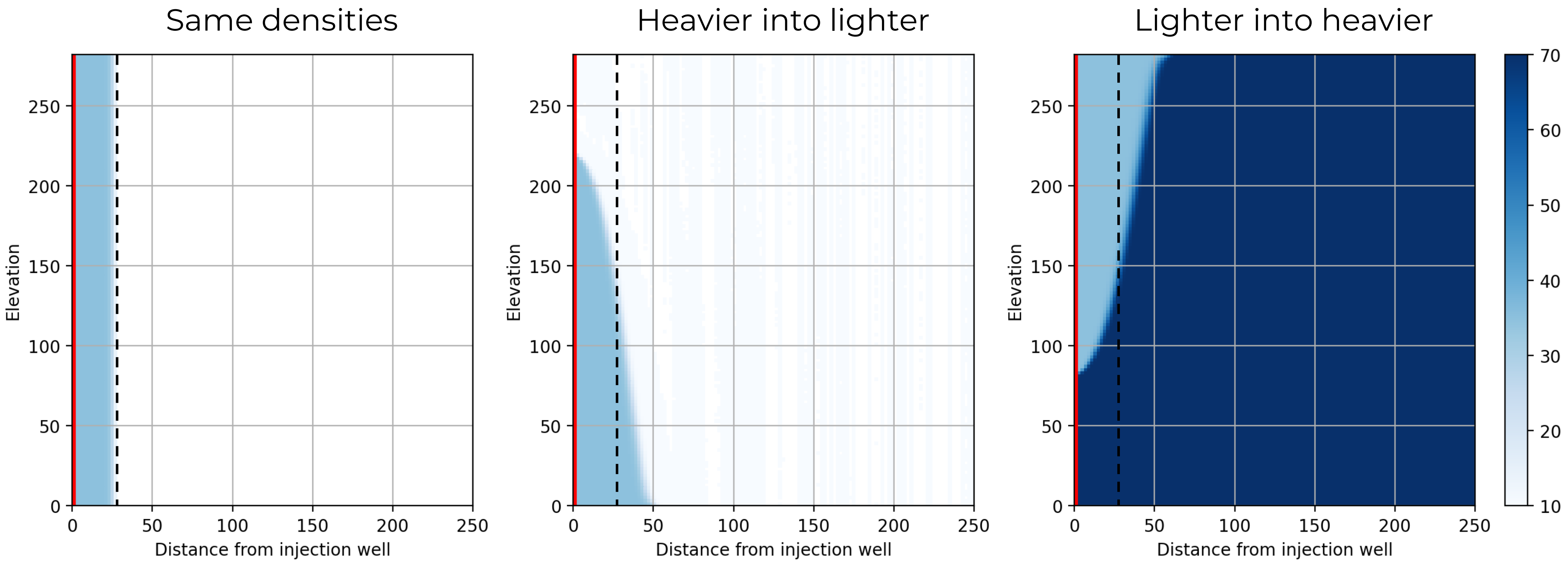


# Fully Penetrating Well



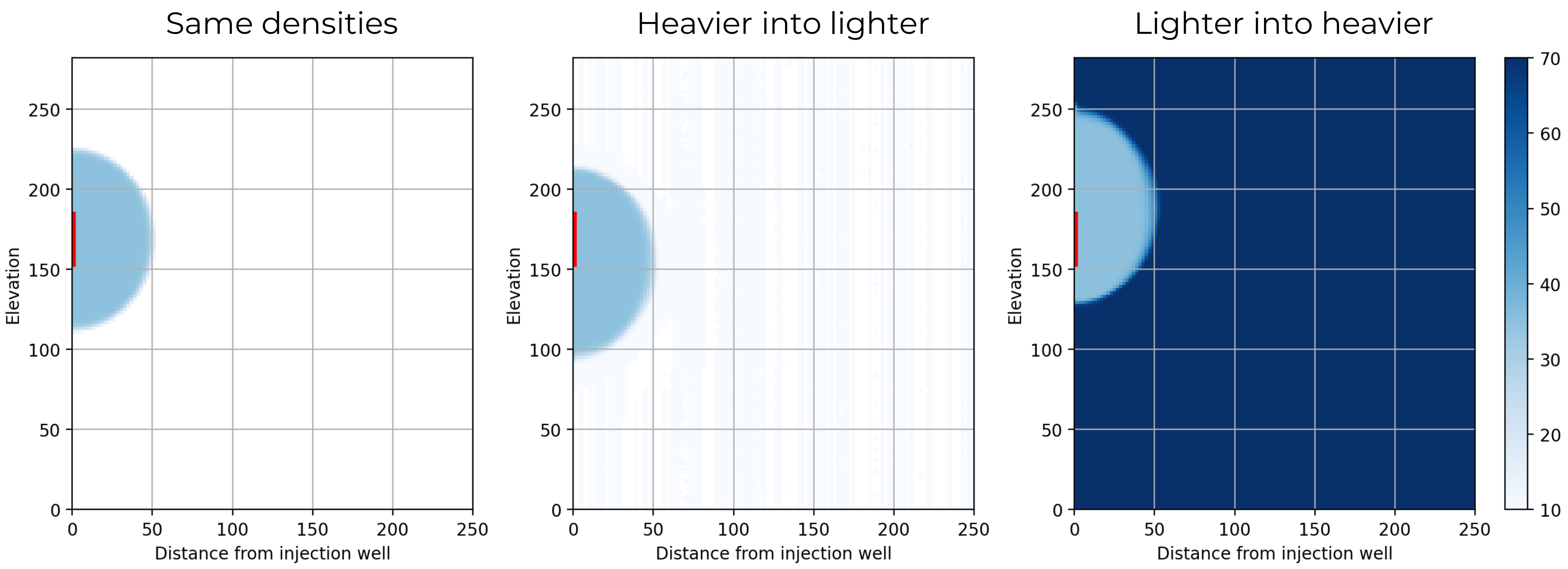

- - - - - Proposed Analytical Solution (Bear and Jacobs, 1965)

# Fully Penetrating Well – With Anisotropy of 10

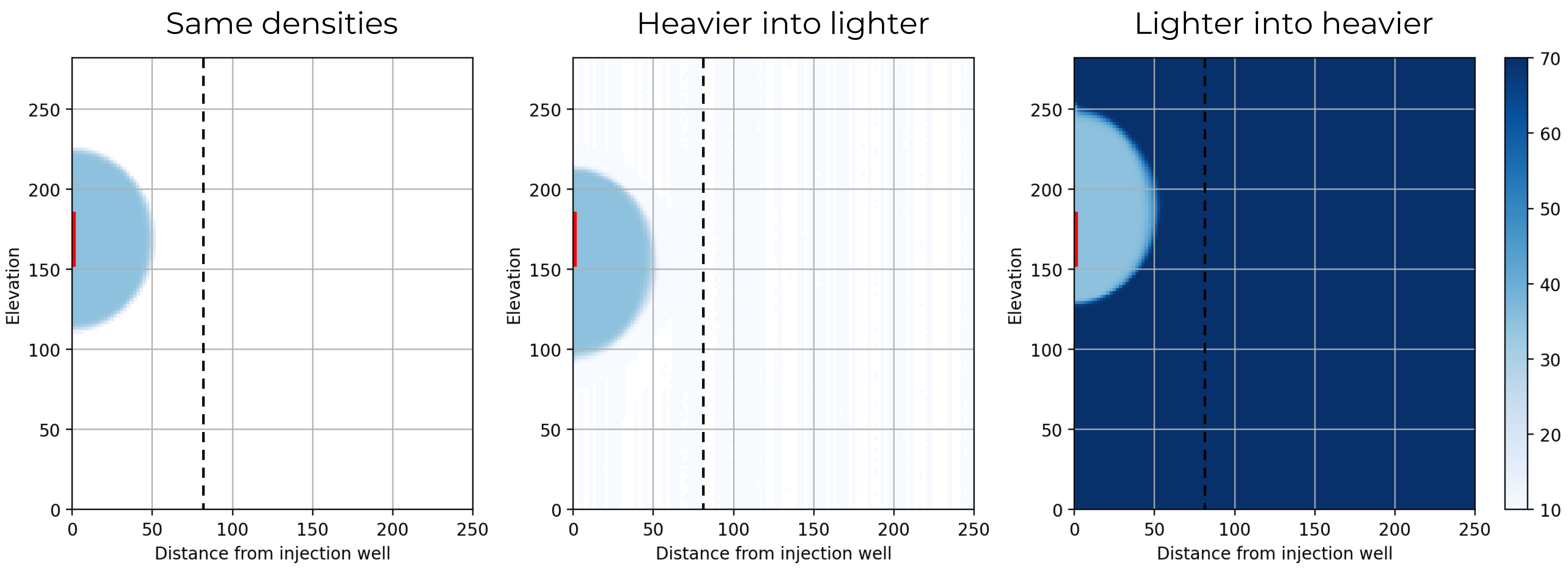



---- Proposed Analytical Solution (Bear and Jacobs, 1965)

# Partially Penetrating Well

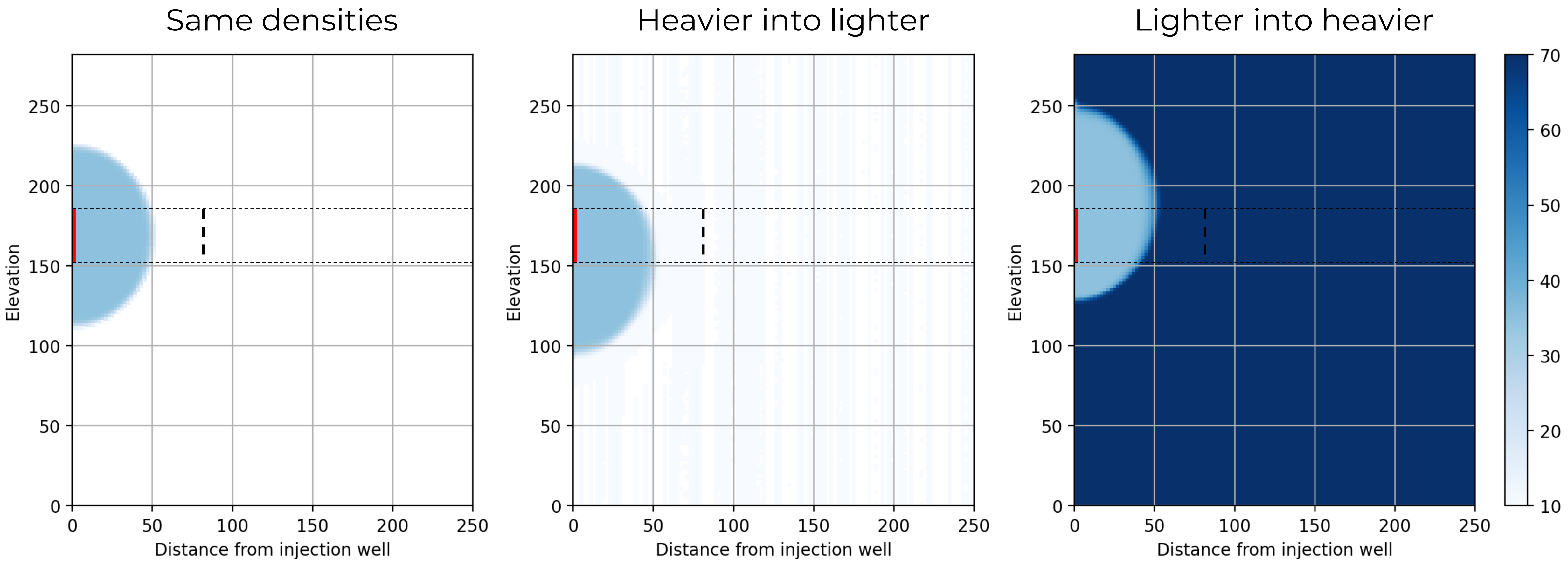


# Partially Penetrating Well



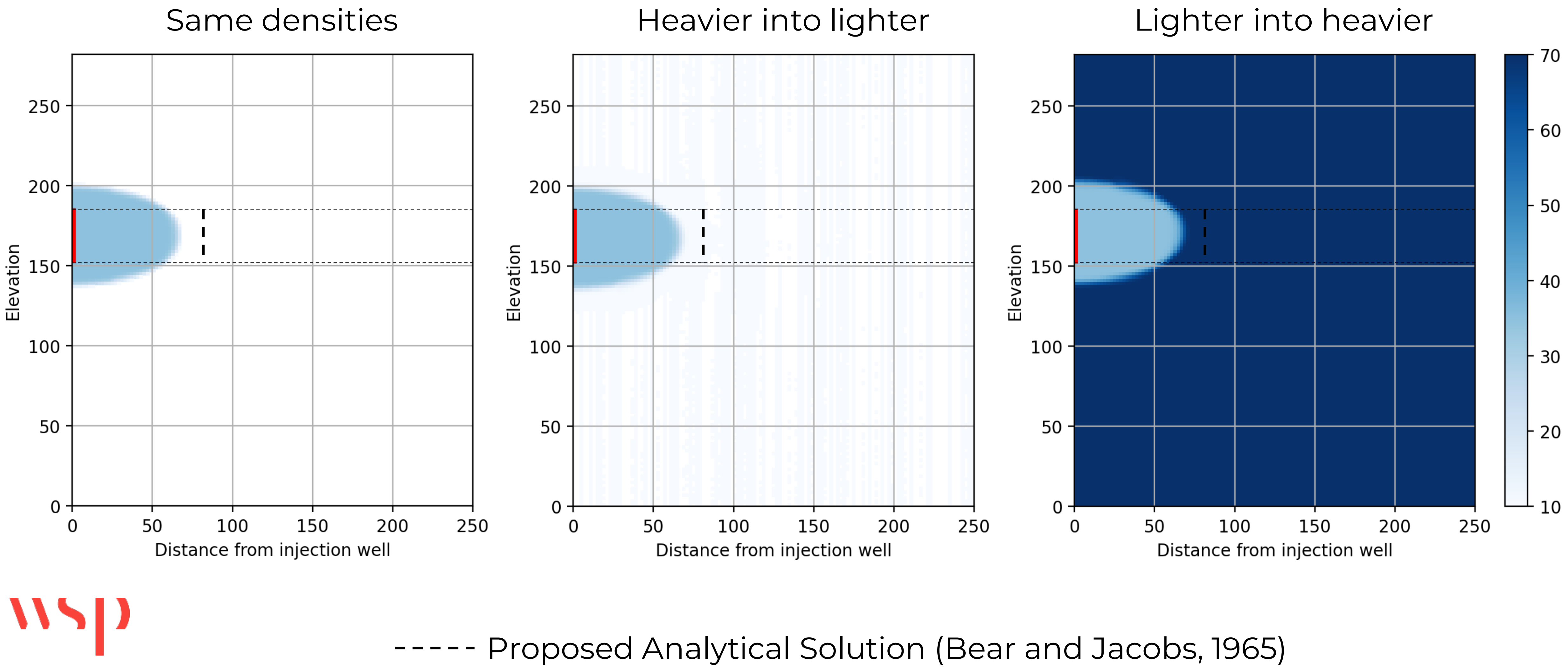

----- Proposed Analytical Solution (Bear and Jacobs, 1965)

# Partially Penetrating Well




----- Proposed Analytical Solution (Bear and Jacobs, 1965)

# Partially Penetrating Well – With Anisotropy of 10



# Summary: Density-effects

- Density may vertically stratify injectate
- Anisotropy
  - *Limit vertical spread of injectate*
  - *needs site-specific information*
- Migration underestimated in fully penetrating wells
- *Migration overestimated in partially penetrating wells*
- *2/3 wells of analyzed wells partially penetrating*
- Modeling variable-density complex
  - *Not suitable for regional-scale studies*
- Suitable numerical solutions include:
  - *SEAWAT; USG-Transport; MODFLOW 6, FEFLOW, SUTRA, HST3D*

# Mapping Techniques – Processes

Simple → Complex

| Process | Modeling Technique | Data Availability | Meets Modeling Objective? |
|---|---|---|---|
| Injection flow hydraulics | Analytical solutions | Injection and aquifer data | No |
| Flow gradient | Analytical solutions | Regional flow gradients assumed | Yes |
| Advection | Analytical solutions | Basic data is available | Yes |
| Dispersion | Analytical solutions | Values need to be assumed | Yes |
| Multiple wells | Numerical solutions | Injection well locations | Yes |
| Density | Numerical solutions | Injectate and receiving water data | Yes |
| Heterogeneity | Numerical solutions | Detailed well log data | Yes |
| Geochemistry | Numerical solutions | Site-specific and well specific data | Yes |

*Not discussed in detail*

# Summary: Heterogeneity & Geochemistry

- Modeling issues:
  - *Highly complex, requires intensive resources*
  - *Needs more data than is available*
  - *Not suitable at regional-scale studies*
- Suitable numerical solutions include:
  - *PHT3D, PHREEQC, USG-Transport*

# Mapping Techniques – Decision Tree

| Process | Modeling objective by technique | | | |
|---|---|---|---|---|
| | EPA 1994 | Bear & Jacobs | Domenico-type | MODFLOW 6 |
| Injection flow hydraulics | N/A | N/A | N/A | N/A |
| Advection-radial flow | Yes | Yes | No | Yes |
| Advection-ambient flow | No | Yes | Yes | Yes |
| Dispersion | No | No | Yes | Yes |
| Multiple wells | No | No | No | Yes |
| Density | No | No | No | Yes |
| Heterogenity | No | No | No | Yes |
| Geochemistry | No | No | No | Yes |

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# Mapping Techniques – Decision Tree

| Process | Marginal Utility | | | |
|---|---|---|---|---|
| | EPA 1994 | Bear & Jacobs | Domenico-type | MODFLOW 6 |
| Injection flow hydraulics | N/A | N/A | N/A | N/A |
| Advection-radial flow | High | High | Low | Low |
| Advection-ambient flow | N/A | High | High | Low |
| Dispersion | N/A | N/A | High | Low |
| Multiple wells | N/A | N/A | N/A | Low |
| Density | N/A | N/A | N/A | Low |
| Heterogenity | N/A | N/A | N/A | Low |
| Geochemistry | N/A | N/A | Low | Low |

# Mapping Techniques – Decision Tree

| Process | Pertinence | | |
|---|---|---|---|
| | EPA 1994 | Bear & Jacobs | Domenico-type |
| Injection flow hydraulics | N/A | N/A | N/A |
| Advection-radial flow | Yes | Yes | No |
| Advection-ambient flow | No | Yes | Yes |
| Dispersion | No | No | No |
| Multiple wells | No | No | No |
| Density | No | No | No |
| Heterogenity | No | No | No |
| Geochemistry | No | No | No |

# Bear and Jacobs: Acceptable in TX

## Texas Aquifer Storage & Recovery (ASR) Applet

Main | More info | How to use

> **Aquifer Storage and Recovery** [30 TAC §331.2(8)]: *"The injection of water into a geologic formation, group of formations, or part of a formation that is capable of underground storage of water for later retrieval and beneficial use."*

The movement of injected waters into a confined aquifer is controlled both by the natural flow patterns in an aquifer and by the flow patterns generated during injection and pumping of water from wells. Understanding the movement of injected waters is essential for predicting the efficiency of later retrieval (i.e., recovery efficiency).

The TxASR App determines recoverability for a single ASR well under steady flow conditions. TxASR is based on the analytical solution of the *Complex Potential Function* for combined flow in the *(x, y)* plane derived by Bear and Jacobs (1965).

$$f(z) = \phi + i\psi = -q_0 z - \frac{Q_i}{2\pi B} ln(z); \quad z = x + iy$$

$$Where:$$

$$\phi = K\varphi = velocity\ potential$$

$$\varphi = piezometric\ head$$

$$\psi = stream\ function$$

# Recommendation

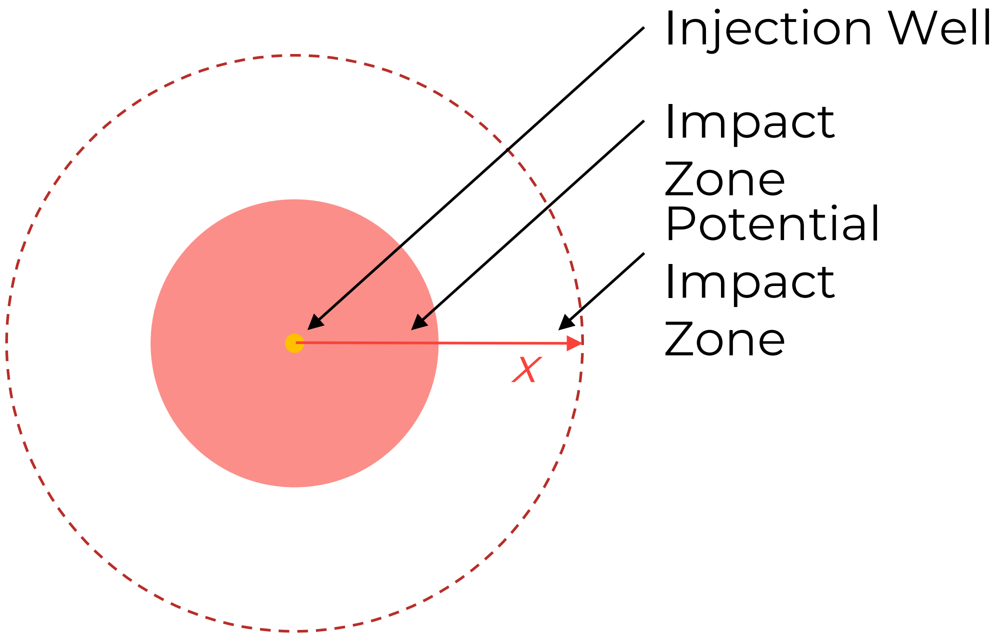
- Recommended modeling techniques
  - *Tier 1 analysis – EPA (1994) – assumes radial flow*
  - *Tier 2 analysis – Bear and Jacobs (1965) – considers radial and regional flow*

- Tier 3 analysis considered but not recommended
  - *Requires intensive resources (staff training, effort, and computational time)*
  - *For very selective areas with high Class II well density*

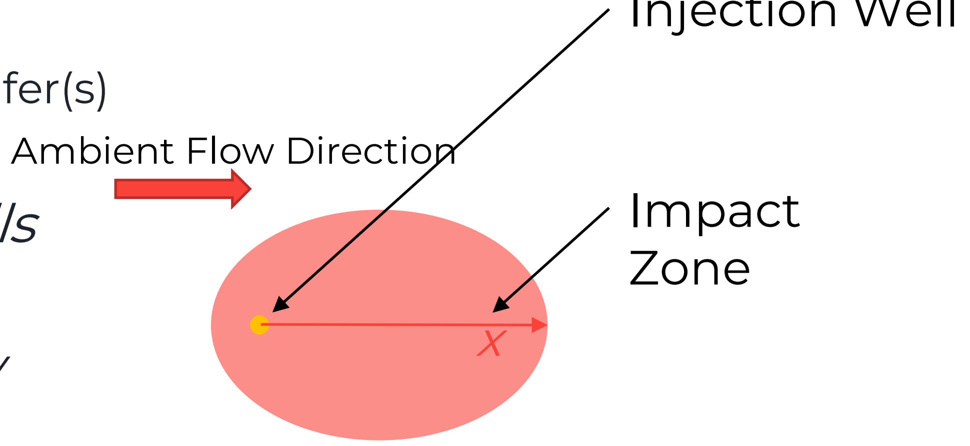
# Tiered Analysis

- Tier 1 Analysis: Phase II
  - *Potential impact zone considering (i)*
  - *but ignoring direction*
- Tier 2 Analysis
  - *Bear and Jacobs (1965)*
  - *Case Study*
    - Smaller set of injection wells for selected aquifer(s)
  - *Consider fully/partially penetrating wells*
  - *Consider gradient and direction of flow*

**Tier 1 Analysis**




**Tier 2 Analysis**

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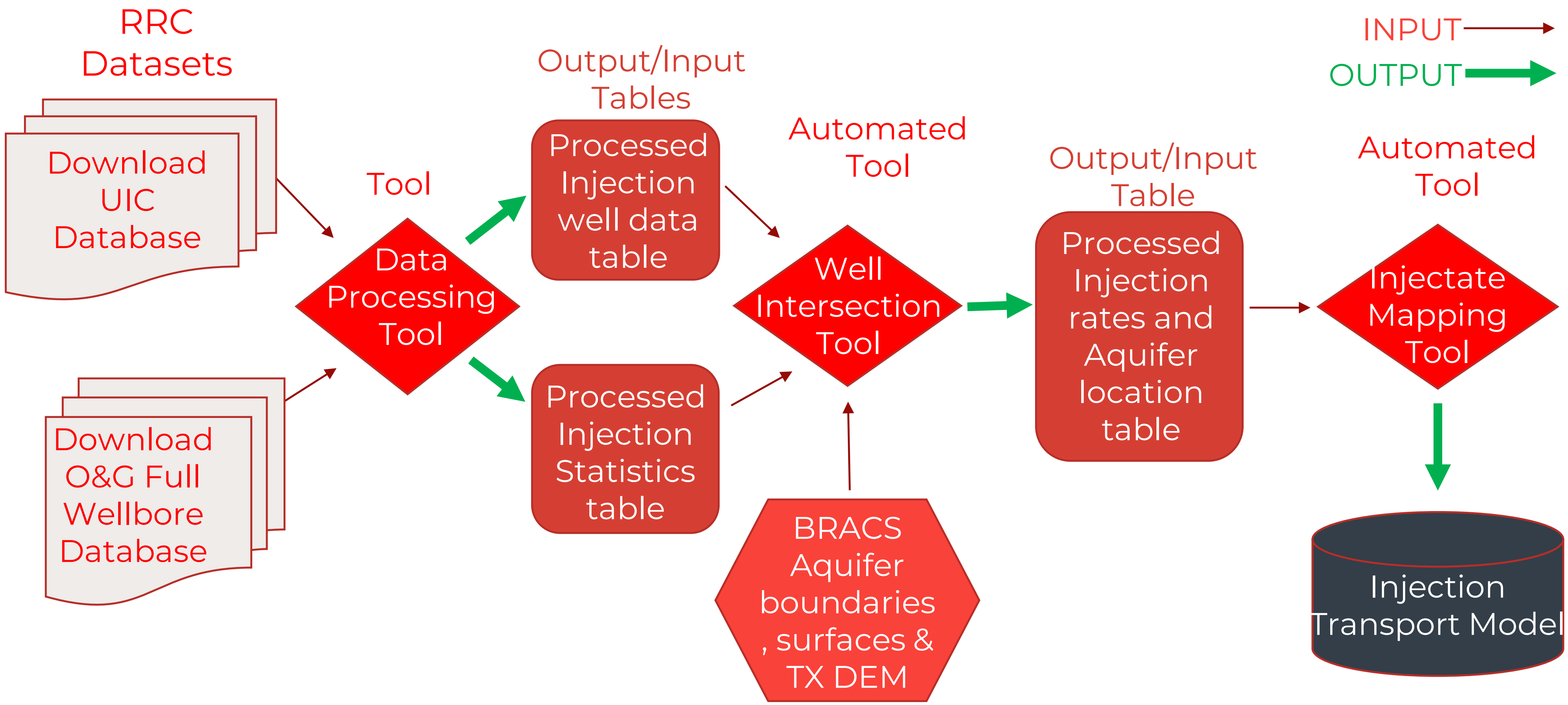
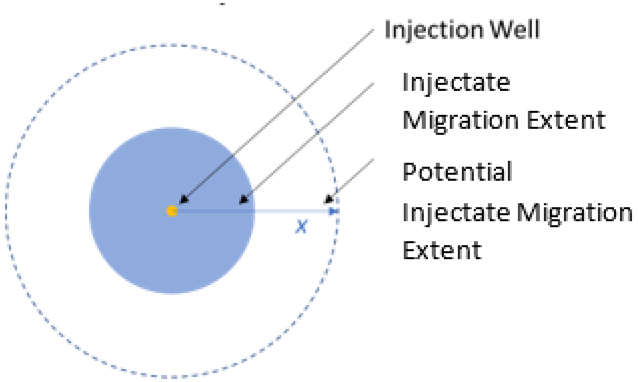
# Workflow


RRC Datasets
Download UIC Database
Download O&G Full Wellbore Database
Tool
Data Processing Tool
Output/Input Tables
Processed Injection well data table
Processed Injection Statistics table
Automated Tool
Well Intersection Tool
BRACS Aquifer boundaries , surfaces & TX DEM
Output/Input Table
Processed Injection rates and Aquifer location table
Automated Tool
Injectate Mapping Tool
Injection Transport Model
INPUT
OUTPUT

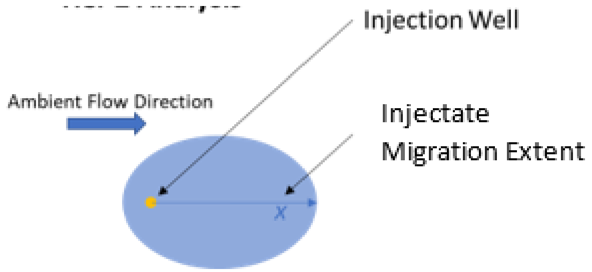
# Injectate Mapping Techniques

— *EPA 1994 - assumes no ambient hydraulic gradient*




Tier 1
Screening level
evaluation

— *Bear and Jacobs 1965 - includes ambient hydraulic gradient*




Tier 2
Used when
refining model

# Automated Tool: Injectate Mapping Tool

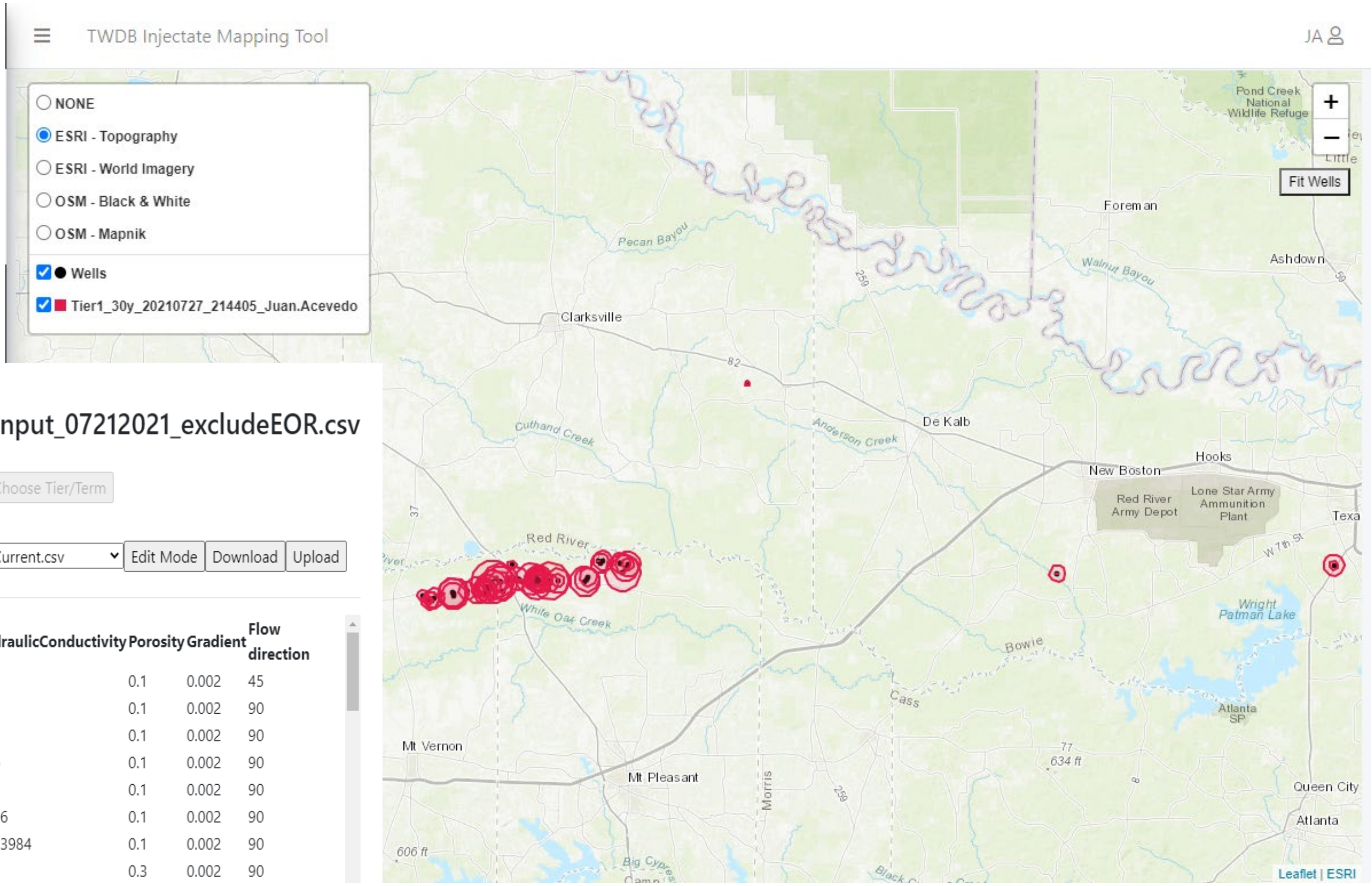
- Applies the EPA 1994 and Bear and Jacobs 1965 analytical solutions to the injection well dataset

- **Tool Input**:
  - *Table output from Well Intersection Tool (AquiferName_InjectateMappingInput_Date.csv)*

- **Tool Output**:
  - *Shapefile of injectate transport model (AquiferName_TierNumber_TimePeriod_Date_Username.shp)*
    - Shapefile contains table with aquifer parameters used for modeling process as well as injection transport distances for accurate record keeping

- **Tool abilities**:
  - *BRACS staff can edit aquifer parameters as necessary*
  - *BRACS staff can decide to apply Tier 1 (EPA 1994) or Tier 2 (Bear and Jacobs 1965) analysis on dataset for 30- to 50-year periods*

# Automated Injectate Mapping Tool




Run Options

NorthernTrinity_InjectateMappingInput_07212021_excludeEOR.csv

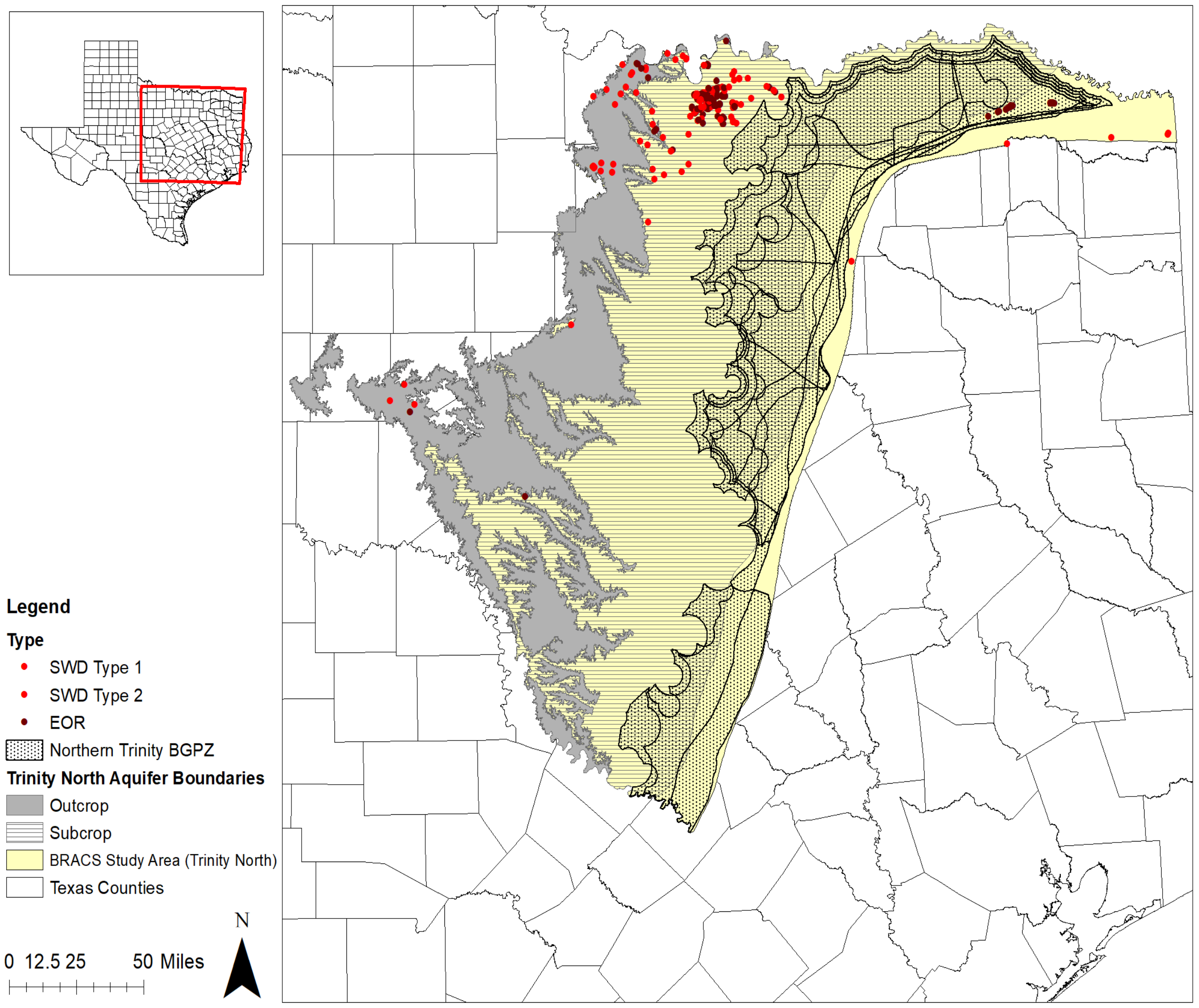
| Analysis | Time Horizon | |
|---|---|---|
| Tier 1 | 30 years | Please Choose Tier/Term |
| Tier 2 | 50 years | |

Default Aquifer Parameters AquiferCurrent.csv Edit Mode Download Upload

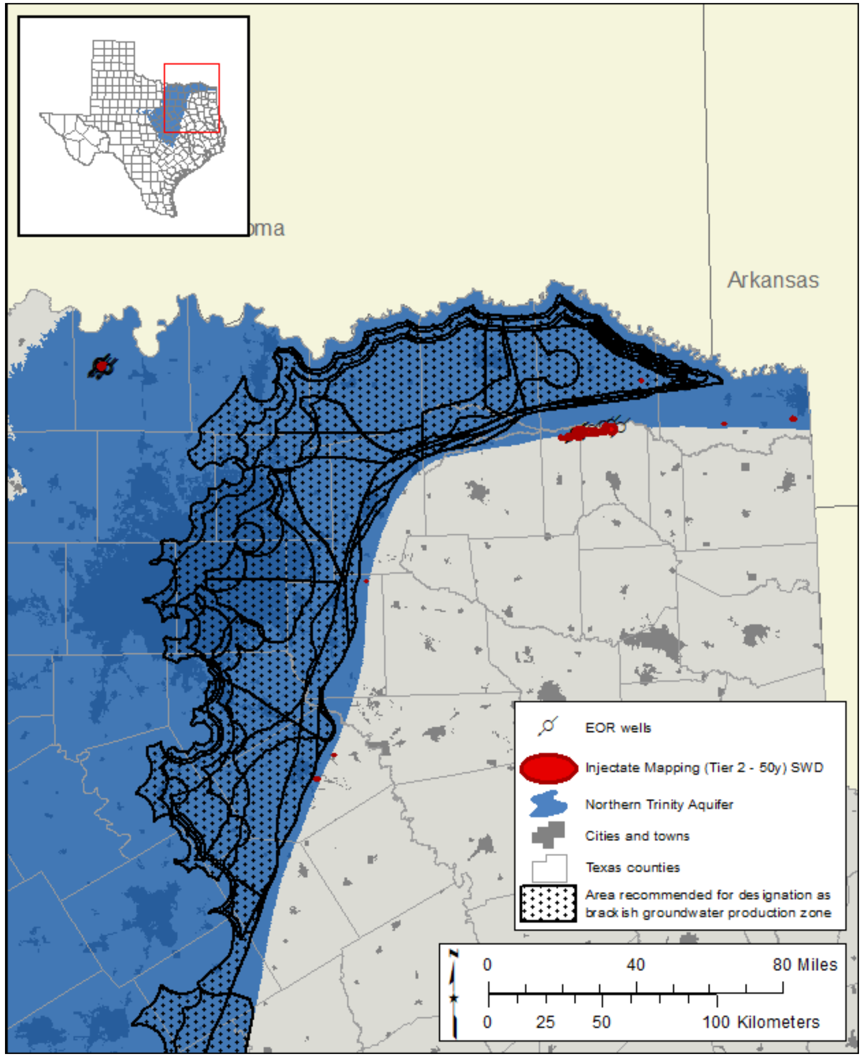
| Aquifer | HydraulicConductivity | Porosity | Gradient | Flow direction |
|---|---|---|---|---|
| Nacatoch | 5.95 | 0.1 | 0.002 | 45 |
| Trinity (northern section) | 1.97 | 0.1 | 0.002 | 90 |
| Blossom | 3.65 | 0.1 | 0.002 | 90 |
| Carrizo (southern section) | 0.46 | 0.1 | 0.002 | 90 |
| Wilcox (southern section) | 2.33 | 0.1 | 0.002 | 90 |
| Gulf Coast (north of the LRGV) | 29.96 | 0.1 | 0.002 | 90 |
| Rustler | 0.813984 | 0.1 | 0.002 | 90 |
| Gulf Coast (LRGV) | 18 | 0.3 | 0.002 | 90 |

# WSP Testing – Northern Trinity Aquifer

- Case study
- 260 Class II injection wells
  - 123 SWD wells
  - 137 EOR wells

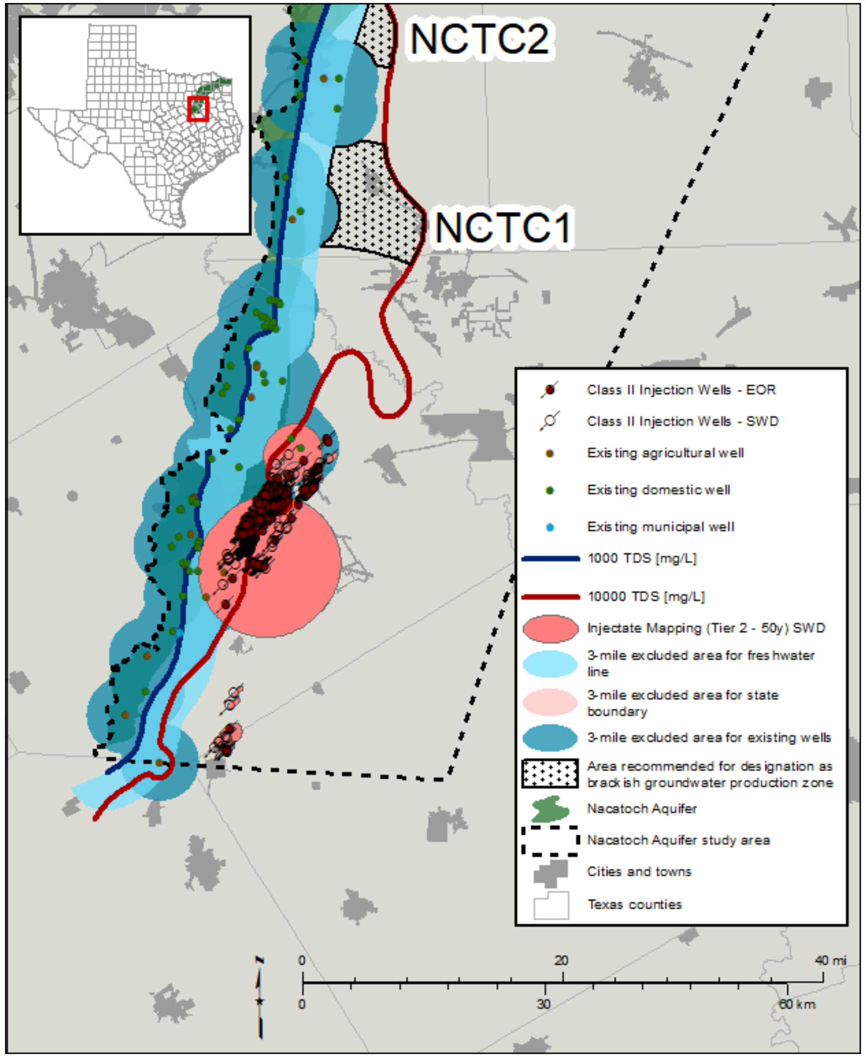


# BRACS Testing – Northern Trinity Aquifer




- BRACS staff replicated WSP
- 81 Class II Injection wells
  - *59 SWD*
  - *22 EOR*
- Largest injection radius
  - *1.5 miles*

# BRACS Testing – Nacatoch Aquifer




- Additional testing of workflow procedures on Nacatoch Aquifer
- Original designation (2019)
  - *525 Class II wells*
    - 84 SWD
    - 441 EOR
- Updated Methods (2021)
  - *435 Class II wells*
    - 60 SWD
    - 375 EOR
  - *Largest injection radius*
    - 6 miles



wsp

# Workgroup Feedback

- Five workgroup meetings

- Don’t apply inject mapping tool to EOR wells
  - Suggested to map top and bottom of production areas to avoid enhanced oil recovery wells – future project

- Contact Schlumberger EOR Mapping team to discuss modeling methods
  - *Met with them and they agreed on methods for mapping subsurface injectate transport*

- Contact EPA about a specific modeling method and obtain information
  - *Compared Zone of Endangering Influence calculations with our analytical solutions – analytical solutions provided more conservative estimate on injection transport*

# Key limitations

- Generic tool based on simplifying assumptions.
- Site-specific details missing
  - *local well injection effects, boundary flows, presence of faults and fractures, formation stratigraphic details, heterogeneity*
- Density effects ignored
  - *possible sinking or rising of plume into lower or upper formation ignored*
- Cannot simulate migration into adjacent aquifer formations
- Vertical separation of injected water head within the aquifer cannot be simulated
  - *anisotropy can potentially play an important role in real-world scenarios if continuous clay units are present*

# Key limitations

- Aquifer data availability
- Injection well data availability
  - *incomplete or erroneous data*
- Effects of multiple wells
  - *influence of one injection well on another*
  - *use numerical models, if necessary*
- Injectate mapping tool provides visualization of subsurface transport of injectate
  - not actual buffer distances