RAILROAD COMMISSION OF TEXAS

STANDARD OPERATING GUIDELINES

Oil and Gas Division
Technical Permitting
Injection – Storage Permits Unit

Response Plan to Seismic Events in Texas

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Introduction

This Response Plan to Seismic Events in Texas ("Response Plan") describes the activities that the Railroad Commission of Texas ("RRC") Oil and Gas Division may implement on its own initiative following certain seismic events or sequences of events occurring in areas of oil and gas exploration and production activities in Texas. The Response Plan will ensure that RRC staff's actions are implemented in a consistent and transparent manner, and that the actions taken in response to seismic activity are authorized by 16 Texas Administrative Code § 3.9 and § 3.46. That is, the Response Plan will inform RRC staff, industry, the public, and other stakeholders of those actions RRC staff may take in response to seismic activity. These activities will be performed by RRC staff in the Underground Injection Control Unit ("UIC") in consultation with the RRC Seismologist.

Background

Effective November 17, 2014, the RRC revised its rules for saltwater disposal (SWD) wells to include consideration of seismic activity in the permitting process. In addition, the rule revisions stated that the RRC could modify, suspend or terminate an SWD well permit if the SWD well "*is likely to be or determined to be contributing to seismic activity*."[1] A permittee could request a hearing if staff acted to modify, suspend or terminate an SWD well permit. Since then, the RRC has considered seismicity in disposal well permitting and compliance matters, culminating in 2019 when the RRC implemented guidelines for permitting disposal wells in seismically active areas of the Permian Basin.[2] The Response Plan complements the permitting guidelines by providing a framework guiding RRC staff's actions in response to new or continued seismic activity.

Approach

Generally, the RRC staff's approach to responding to seismicity in areas of oil & gas exploration and production will include the following components:

- Monitor seismic activity in Texas
- Designate an area of investigation
- Gather additional information
- Analyze available and new information
- Take appropriate regulatory action

Two concepts central to the implementation of the Response Plan are the **Seismic Event of Significance ("SES")** and the **Seismic Investigation Region ("SIR")**. The occurrence of an **SES** and/or the establishment of an **SIR** would initiate the implementation of the Response Plan—and RRC staff actions that follow.

First, for the purposes of this Response Plan, an **SES** is defined as a seismic event of magnitude (*M*) greater than or equal to 3.5, as determined by the USGS and/or TexNet. A seismic event of this magnitude can typically be felt within 30 miles (approximately 48 km) of the event's hypocenter and is therefore personally observable. However, as a very general rule of thumb, damage generally does not occur until the magnitude exceeds 4 or 5 according to the USGS.[3] In addition, recent research indicates that mitigation efforts should be focused at up to

[1] *See* 16 Texas Administrative Code §3.9 (6)(A)(vi) and §3.46 (d)(1)(F).
[2] *See* Permitting Salt Water Disposal Wells in Seismically-Active Areas of the Permian Basin: Standard Operating Guidelines, 2019. https://rrc.texas.gov/oil-gas/publications-and-notices/manuals/injectiondisposal-well-manual/summary-of-standards-and-procedures/seismicity-review/ >
[3] https://www.usgs.gov/faqs/what-magnitude-does-damage-begin-occur-earthquake?qt-news_science_products=0#qt-news_science_products

two orders of magnitude lower than the desired protection level.[4] That is, generally, to reduce the hazard of a M 5 seismic event, pre-emptive response actions should occur when the prevailing event is between M 3 and M 4. The M 3.5 threshold for an **SES** is a value established by RRC staff for the purposes associated with regulating SWD wells in areas of seismic activity; it is not a threshold value that has been established by the action of the RRC though Final Order or Rule. RRC staff will use the observation of an **SES** as a trigger for deployment of the subsequent elements of the Response Plan.

Second, an **SIR** is the geographic area within which the elements of the Response Plan are implemented. To accomplish this purpose, RRC staff may designate an **SIR** to facilitate data gathering, organization and analysis in an area in which seismic activity is increasing and has, or may lead to, an **SES**. Thus, an **SIR** may be established following a single **SES** or following an increase in the number and/or magnitude of seismic events, suggesting an increasing seismicity hazard in the area**.**

Nothing in this Response Plan shall be construed to mean that an operator does not have the right to appeal RRC staff's actions via a hearing, as those rights are guaranteed in the RRC's rules. The elements of the Response Plan are further described in the following sections.

Monitor Seismic Activity

RRC staff monitor seismic activity in Texas using USGS and TexNet information through the normal course of business[5]. For SWD wells, the proximal occurrence of seismic activity may result in additional application and permitting requirements, and it may also lead to operational permit conditions being placed on existing facilities. In special cases, the RRC also provides incentives for operators in the SWD permitting process to place a seismic sensor and contribute to the public seismic network in exchange for an increase injection.

RRC staff monitor seismic activity in several ways.

USGS Direct Notifications

RRC staff subscribe to the USGS Earthquake Notification System ("ENS")[6], which sends automated notification emails for any earthquake located by the ANSS/NEIC (Advanced National Seismic System/National Earthquake Information Center). RRC staff respond by identifying whether there is oil or gas activity in the general area of the reported earthquake location. RRC data systems are updated daily with the latest TexNet earthquake catalog data.

Disposal Well Applications

Pursuant to 16 Texas Administrative Code §3.9(3)(B) and §3.46(b)(1)(C), SWD well permit applications must include a review of USGS earthquake records for a circular area of 100 square miles around the proposed SWD

[4] e.g., Schultz, R., Beroza, G., Ellsworth, W., & Baker, J. (2020). Risk-Informed Recommendations for Managing Hydraulic Fracturing–Induced Seismicity via Traffic Light Protocols. *Bulletin of the Seismological Society of America*. https://doi.org/10.1785/0120200016.
[5] TexNet is now recognized by the USGS as the authoritative body for reporting seismicity in Texas.
[6] See https://earthquake.usgs.gov/ens/help

well location (a circular area with a radius of 9.08 kilometers, or 5.64 miles). Given new research[7,8], we may consider a larger radius around deep (> 10,000 ft) wells for permitting and for this response plan. Operators provide the results of a USGS online query with a map of the well location and nearby earthquakes (if any) to support the application. RRC staff's review of these applications indicates earthquake activity proximal to current oil and gas exploration and production activity.

Operator Notifications

Some oil and gas operating companies have developed and implemented seismic response plans that include a seismic event magnitude threshold that, if exceeded, prescribes notification to the RRC and may include details of their operational response to the earthquake(s). RRC staff review these notices and monitor this information accordingly.

Designate Seismic Investigation Region ("SIR")

An **SIR** is the geographic area within which the elements of the Response Plan are implemented, defining the spatial extent of the RRC's response actions. The purpose of designating an **SIR** is to facilitate the systematic and methodical information gathering and assessment that could be used to determine causal elements of earthquakes in the region before an **SES** occurs. The RRC Seismologist will designate an **SIR** for which consistent identification and data gathering approaches will be implemented.

SIR Location

The RRC Seismologist will be responsible for designating an **SIR**. An **SIR** may be designated for a region that has experienced a **SES**.

It should be noted that not all areas that experience a **SES** will be designated as an SIR. This may be due to evidence that an event is a natural occurrence, and/or regions that have experienced seismic events for many years are likely not to experience larger events (e.g., Snyder, TX). However, other factors may warrant staff attention and further investigation of a region by the RRC Seismologist but would not warrant an SIR designation unless a **SES** occurred. These factors include:

- A region that is experiencing multiple $M \geq 3.0$ earthquakes;
- Regions that are experiencing increases in instances or magnitude of $M \geq 2.0$ earthquakes (for example, 10 $M \geq 2.0$ earthquakes within a week).

SIR Size

The areal extent of an **SIR** will be centered on the reported **SES** hypocenter location, and it will extend for a radial distance of 9.08 km. The 9.08-kilometer radius is based on the 100-square mile area used for seismic event identification in disposal well applications[2].

The RRC Seismologist may adjust the location or areal extent of an **SIR** based on the occurrence or extent of earthquakes, faults and other geologic boundaries, and oil and gas operations in the area on a case-by-case basis as appropriate and justified. Examples of such adjustments may include:

- Multiple ≥ M 3.5 earthquakes with overlapping 100-square mile areas may be merged to create one SIR.

[7] Skoumal, R. J., Barbour, A. J., Brudzinski, M. R., Langenkamp, T., & Kaven, J. O. (2020). Induced Seismicity in the Delaware Basin, Texas. *Journal of Geophysical Research: Solid Earth*, *125*(1). https://doi.org/10.1029/2019JB018558
[8] Tung, S., Zhai, G., & Shirzaei, M. (2020). Potential link between 2020 Mentone, West Texas M5 earthquake and nearby wastewater injection: implications for aquifer mechanical properties. *Geophysical Research Letters*. https://doi.org/10.1029/2020GL090551

- A well-documented fault or other geologic boundary and the absence of earthquake activity on the far side of the structure may substantiate adjusting the **SIR** size.
- An increased risk from the far-field effects of fluid injection (i.e., near-basement injection, injection in to highly-transmissive karst zones, etc.) may warrant expansion of the **SIR** to include certain wells beyond the 9.08 km radius[7,8].
- Mathematical relocation of earthquake events (i.e., double-difference earthquake location algorithm, HypoDD) that delineates faults and fault zones may suggest that altering the location and size of the **SIR** is appropriate.

Notification of SIR Designation

When the RRC Seismologist designates an **SIR**, the Oil and Gas Division Director, the Executive Director, and the Commissioners' offices will be notified. Operators in an **SIR** will then be notified through a Request for Additional Data (RAD) letter (see below).

An **SIR** designation may be removed by the RRC Seismologist if seismicity decreases to the pre-existing level of seismicity or no events with M >2.5 for a least one year. RRC staff chose one year so that long term seismicity changes can be evaluated. Similarly, an **SIR** may be expanded based on continued or spreading seismic activity.

Gather Additional Data

An effective Response Plan must incorporate the potential for multiple causal factors. Although this regulatory program and the authority in 16 Texas Administrative Code §3.9 (6)(A)(vi) and §3.46 (d)(1)(F) applies to SWD well activity, the potential for seismicity to have been induced by other potential causes, including oil and gas industry activity, should also be considered[9]. For example, it may be difficult to distinguish seismicity induced by SWD well activity from seismicity induced by hydraulic fracture stimulation ("HFS"), but it is necessary to consider that possibility in order to ensure an appropriate and measured regulatory response.

When a **SIR** is established, RRC staff will compile a project dataset consisting of information available in RRC records and gathering additional information from SWD well operators, oil and gas operators, and scientific literature. RRC staff intends to gather specific, relevant, and potentially causative information from oil and gas well operators in the **SIR**. Staff will standardize the approach for requesting information for SWD and other activities within the **SIR** to ensure all operators within the **SIR** are treated equally.

Request Additional Data ("RAD") From SWD Well Operators

RRC staff will identify all SWD wells (active SWD wells, shut-in SWD wells, and permitted but not drilled sites) in the **SIR**. For these SWD wells, RRC staff will issue a RAD letter to the operator requesting the following information:

- Provide daily injection volume and surface injection pressure (daily maximum and daily average) for six months prior to the establishment of the **SIR** or the onset of seismicity. RRC staff will provide a spreadsheet template for this information.
- Provide daily injection pressure and volume information on a recurring and timely basis (e.g., every month within two weeks of end of the month) while the **SIR** is active. RRC staff will provide a spreadsheet template for this information.

[9] Savvaidis, A., Lomax, A., & Breton, C. (2020). Induced Seismicity in the Delaware Basin, West Texas, is Caused by Hydraulic Fracturing and Wastewater Disposal. *Bulletin of the Seismological Society of America*. https://doi.org/10.1785/0120200087

- If available, seismic monitoring data from private seismometers that are available to the SWD well operator will be requested.
- Other information deemed necessary or important by the RRC Seismologist and the Oil and Gas Division Director.

The RAD letter will cite the RRC's jurisdiction in 16 Texas Administrative Code §3.9 (6)(A)(vi) and §3.46 (d)(1)(F) as the authority for the request pertaining to reporting daily injection volume and pressure data. In some cases, there may be permit conditions requiring this information be collected and maintained. Further, 16 Texas Administrative Code §3.1 (b) and (c) require operators to maintain accurate records of regulated activities for a period of three years and to make those records available to the RRC for inspection. SWD well operators will be asked to respond within 30 days. The RAD letter may indicate RRC options provided for in Statewide Rules 9 and 46 if no response is received.

Conduct Inspections

RRC staff will request the appropriate District Office conduct an inspection of the SWD wells in the **SIR**. In addition, the District Inspector will be asked to note evidence of recent well completion, stimulation, and flowback activities in the **SIR** that may suggest a temporal relationship to recent seismicity. RRC staff may request additional or regular inspections based on seismic activity, including the occurrence of individual **SES** or clusters of seismic events.

Request Well Completion and Stimulation Information

It is generally recognized by industry and academia that HFS treatments of oil and gas wells—especially horizontal wells—may induce seismic activity. It is important, therefore, to determine whether HFS activities are occurring in an **SIR** and to assess the potential for causal relationships with seismicity in the **SIR**. RRC Rules authorize RRC staff to act in response to seismicity associated with SWD wells, not HFS treatment activity. However, the assessment of multiple causal factors is necessary to effectively respond to seismicity associated with SWD activity, and therefore it is necessary to identify recent or ongoing HFS activity in the **SIR**. RRC Rules do not require operators to notify RRC about HFS activities. However, RRC staff can review several data sources to compile indicative information, including tabulation of the following:

- Identify active drilling permits in the **SIR**
- Review RRC records (mainframe) to identify wells with drilling permits that have been spud but have not filed completion reports
- Review recent completion reports filed
- Review the Ground Water Protection Council's FracFocus system. Operators in Texas are required by RRC Rule §3.29 to file certain HFS information on the FracFocus system as part of the well completion report
- Evidence of recent well completion, stimulation, and flowback activities in the **SIR** observed by District Inspectors
- Review the production records in the **SIR** to identify changes potentially associated with recent HFS activities.
- Other information deemed useful by the RRC Seismologist and the Oil and Gas Division Director

Based on this information, RRC staff will identify completion activities that may be temporally-correlated with the observed seismicity. RRC staff will identify those wells and operators and send a request for information regarding HFS activity. RRC staff recognizes such requests will be voluntary in nature, but RRC staff has had success in requesting such information and that such information has proven to be valuable to our regulation of SWD wells, in addition to the broader operator and scientific communities' understanding of induced seismicity.

For this data request, RRC staff will prepare a request letter identifying the specific data elements requested, and RRC staff will provide appropriate spreadsheet templates to gather, store and use this information. RRC staff will identify each potential location, which will include at a minimum a drilling permit number. The requested information, based on recent studies that illustrate the usefulness for causality determination[10,11,12] may include a stimulation report and/or the following information for each well and HFS treatment stage:

- Location of the HFS stage (x, y, z)
- Date and time HFS pumps on
- Date and time HFS pumps off
- Average surface injection pressure
- Maximum surface injection pressure
- Volume of liquid pumped
- Volume or weight of solids pumped
- Type of fracture fluid (gel, slickwater, etc.) and fluid density
- Date and time of observed pressure anomalies, if any, which may indicate loss of circulation events
- Other information deemed necessary or important by RRC Seismologist and the Oil and Gas Division Director

Compile Well Inventories and Fluid Volume Histories

RRC Staff will assemble other well information for producing and injection wells in the area including:

- Producing wells and fluid production histories
- Disposal well fluid injection histories
- Non-disposal injection well fluid injection histories

Identify Active Scientific Interest in the SIR

The RRC Seismologist maintains professional relationships with the industry and scientific communities studying seismicity in Texas. The RRC Seismologist will identify and compile current and historical research on faulting and seismicity in the **SIR**, to provide the RRC with current data and understanding of the seismicity knowledge in the **SIR**. For example, the RRC Seismologist and RRC staff typically rely on TexNet scientists at the University of Texas at Austin's Bureau of Economic Geology to rapidly determine whether an observed earthquake has a deep focus and therefore is not likely to be induced by oil and gas activities.

Data Analysis

The purpose of the data analysis component is to determine (1) whether the seismic activity in the **SIR** is correlated with activities subject to the jurisdiction of the RRC, and (2) to support regulatory actions, if any, that the RRC staff may take in response to the seismic activity. The data analysis will endeavor to classify the seismic activity in the **SIR** into one or more of five categories. Once categorized, Commission staff can determine the appropriate response action, if any. The five categories are:

1. Deep seismicity with focal depths of more than 15 km (9.3 miles) that can be reasonably assumed to not be related to oil and gas activities and not subject to the RRC's jurisdiction;
2. Seismicity correlated with HFS activities and therefore broadly under the RRC's jurisdiction

[10]Schultz, R., Skoumal, R. J., Brudzinski, M. R., Eaton, D., Baptie, B., & Ellsworth, W. (2020). Hydraulic fracturing-induced seismicity. Reviews of Geophysics, 58(3), e2019RG000695.
[11]Schultz, R., Atkinson, G., Eaton, D. W., Gu, Y. J., & Kao, H. (2018). Hydraulic fracturing volume is associated with induced earthquake productivity in the Duvernay play. Science, 359(6373), 304-308.
[12]Ries, R., Brudzinski, M. R., Skoumal, R. J., & Currie, B. S. (2020). Factors influencing the probability of hydraulic fracturing-induced seismicity in Oklahoma. Bulletin of the Seismological Society of America, 110(5), 2272-2282.

3. Seismicity correlated with SWD activities and subject to the RRC's jurisdiction in Statewide Rules 9 and 46
4. Seismicity correlated with other oil and gas activities (production, non-SWD injection, etc.) and therefore broadly under the RRC's jurisdiction although not codified in specific rules
5. Other seismicity, including natural seismicity, mining or blasting, or indeterminate earthquakes

The RRC staff seismic event classification is not absolute nor definitive. The categorization, especially for SWD-correlated Category 3 events, must be sufficient to meet the standards in Statewide Rules 9 and 46, which state that the RRC may take subsequent action on an SWD permit, including modification, suspension or termination, for just cause after notice and opportunity for hearing, if injection is likely to be or determined to be contributing to seismic activity.[13] The purpose of this Response Plan is to identify seismic events that meet this criteria and then to take appropriate action, if warranted.

Seismic event categorization is dependent upon the availability of sufficient information—of sufficient type and quality—which may not be readily available when the **SIR** is designated. For example, once an **SIR** is designated, RRC staff will begin to compile information and to make specific data requests from SWD well and other operators, who will be asked to respond within 30 days; in the case of HFS data, the response will be voluntary. Categorization will be based on the best information available at the time and is subject to change as new information becomes available. In addition to the time associated with obtaining the requested data, assembling and managing large amounts of data will take time as well. However, in general, RRC staff believes that categorization may be performed within the following relative temporal hierarchy (Table 1).

Table 1: RRC Seismicity Categorization

Assessment Category	Analytical Dependencies	Optimal Timing for Categorization (Dependent)
1. Deep	Coordination with TexNet and other researchers. For example, the October 20, 2018, M 4.7 earthquake northeast of Amarillo occurred > 15 km in depth[14].	24 hours
2. HFS Correlated	Highly dependent on voluntary reporting to allow spatial/temporal correlation of HFS activities and seismic events. With adequate data, many HFS-related earthquakes can be rapidly and reliably categorized.	48 hours to two weeks
3. SWD Correlated	Highly dependent on available information including (1) RAD response and required reporting, and (2) categorization of HFS-related events, to determine whether "injection is likely to be or determined to be contributing to seismic activity."	Two weeks to months
4. Other Oil & Gas Correlated	Analysis of production, injection activity, and geological characteristics. Consensus of the research community (Bureau of Economic Geology, etc.). For example, enhanced oil recovery related	Variable, but typically months

[13] *See* 16 Texas Administrative Code §3.9 (6)(A)(vi) and §3.46 (d)(1)(F).
[14] TexNet Catalog; Personal Communication, Robert Herrmann, Saint Louis University, St. Louis, CO

	earthquakes in Snyder and production related earthquakes in Fashing since the 1970s[15].	
5. Other or Indeterminate	Consensus of the research community and/or correlation with other types of anthropogenic events. For example, the February 18, 2008 refinery explosion in Big Spring appears in USGS records as a M 2.1 earthquake.	Variable, but typically months

As a practical matter in the short term, categorization will focus on distinguishing between events that are HFS related (Category 2) and those that are SWD related (Category 3). With appropriate data, RRC staff is capable of broadly identifying Category 2 and 3 earthquakes in a sufficiently reliable manner to take regulatory actions within RRC staff's authority under this Response Plan and Commission Rules. In some ambiguous cases, it may take the research community months to determine the categorization, which was the case for the March 26 Mentone (M 5.0) earthquake[16,17]. HFS activities tend to have a narrow spatial focus and are limited in time to a few hours or days, and thus the fluid pressure disturbance does not have an opportunity to extend far away from the well. .SWD activities are broadly focused on the permitted injection interval and are not limited in time (after authorization) but are limited by authorized pressure and injection rate.

Deep (Category 1) events occur infrequently in Texas and can be categorized relatively quickly based on standard earthquake location procedures with adequate azimuthal coverage and with a nearby station (less than a focal depth away from the hypocenter). Other procedures, which may take more time, include seismometer signal characteristics review by seismologists at TexNet and the research community, plus other modeling approaches (i.e., moment tensor inversions). Category 4 (other oil and gas related activity) and Category 5 (other activity or indeterminate) earthquakes are unique. There are several well-known Category 4 earthquake events in Texas, which have been studied over years with varying degrees of scientific consensus[18,19]. Category 5 events typically can be associated with explosions or other non-oil and gas related anthropogenic activity.

Seismic Response Area (SRA) and Actions

RRC may undertake response actions to reduce the probability or prevent the occurrence of an **SES**. For events with $M \geq 3.5$, the RRC Seismologist, with the concurrence of the Oil and Gas Division Director, may designate a need for a seismic response (termed "response") in a defined region (a sub region of the **SIR**), termed a Seismic Response Area (**SRA**), for which consistent identification and seismic response approaches will be implemented. We chose the M 3.5 threshold due to several factors: 1) it can be felt within a short distance from the epicenter, raising public awareness/concerns, 2) it allows us to address if the earthquake could be a foreshock for larger

[15] Pennington, W. D., Davis, S. D., Carlson, S. M., DuPree, J., & Ewing, T. E. (1986). The evolution of seismic barriers and asperities caused by the depressuring of fault planes in oil and gas fields of south Texas. Bulletin of the Seismological Society of America, 76(4), 939-948.
[16] Savvaidis, A., Lomax, A., & Breton, C. (2020). Induced Seismicity in the Delaware Basin, West Texas, is Caused by Hydraulic Fracturing and Wastewater Disposal. *Bulletin of the Seismological Society of America*. https://doi.org/10.1785/0120200087
[17] Skoumal, R. J., Kaven, J. O., Barbour, A. J., Wicks, C., Brudzinski, M. R., Cochran, E. S., & Rubinstein, J. L. The Induced Mw 5.0 March 2020 West Texas Seismic Sequence. Journal of Geophysical Research: Solid Earth, e2020JB020693
[18] e.g., van der Elst, N. J., Savage, H. M., Keranen, K. M., & Abers, G. A. (2013). Enhanced Remote Earthquake Triggering at Fluid-Injection Sites in the Midwestern United States. *Science*, *341*(6142), 164–167. https://doi.org/10.1126/science.1238948
[19] Frohlich, C., DeShon, H., Stump, B., Hayward, C., Hornbach, M., & Walter, J. I. (2016). A historical review of induced earthquakes in Texas. Seismological Research Letters, 87(4), 1022-1038.

earthquake, and 3) it is consistent with the RRC Standard Operating Guidelines (SOG) for Permitting Salt Water Disposal Wells in Seismically-Active Areas of the Permian Basin, which outlines a minimum trigger for initiation of Earthquake Response Plan and notification to RRC-UIC. The purpose of the response actions is to determine causal elements of a **SES** and to forestall another future **SES** if it is related or likely related to SWD wells. The Oil and Gas Division Director, the Executive Director and the Commissioners' offices will be notified of an **SRA** when a response is being executed. Similar to the RAD request during our information gathering, staff may request similar or new information for activities during a response, such as:

- Monthly SWD well information for the year prior to the most recent **SES** in the **SRA**
    - Monthly updates thereafter
- Review of current and pending drilling permits
- On-going submission of data related to past HFS operations
- Regular district office inspections of wells in the seismic response region
- Other information or actions deemed necessary by the RRC Seismologist and the Oil and Gas Director

RRC staff's approach will be to designate an **SRA**, and at the same time, propose a curtailment plan tailored for the region based on the data analysis. The curtailment plan will list voluntary limits on existing permit conditions. Staff will approach all operators in the **SRA** to share all relevant information and request seismic response plans from each operator. The operators may choose to work together to respond to any curtailment plan proposed by the RRC, providing additional data and analysis that would clarify the role of SWD injection. Operators will have 90 days to offer alternative solutions to the curtailment plans. Staff and the RRC Seismologist will promote and guide operators to submit voluntary seismic response plans with specific items, including one or more of the following for SWD and HFS operations:

SWD

- Reduce Maximum Daily Injection Volume (MDIV)
    - For example, reduce MDIV to less than the volume when the **SES** occurred, or reduce MDIV to 10,000 barrels/day
- Reduce Maximum Surface Injection Pressure (MSIP)
    - For example, reduce MSIP to less than the pressure when the **SES** occurred, or reduce MSIP to 0.25 psig/ft
- Reduce variability of injection volume and injection pressure

HFS

- Pause HFS for 24 hours or skip HFS stages if within 9.08 km of a **SES**
- Avoid zipper HFS
- Avoid HFS with high viscosity fluids

The plans will be reviewed by staff and the RRC Seismologist and any modifications will be suggested for voluntary action. If an operator (or operators) declines to take voluntary action, RRC staff may pursue permit modification, suspension or termination in accordance with Statewide Rules 9 and 46.

Non-Voluntary Actions

If the Oil and Gas Division Director and RRC Seismologist determine that an action is necessary after an operator demonstrates that they are not willing to take action voluntarily, staff will pursue the action according to the RRC's rules[20]:

[20] See 16 Texas Administrative Code §3.9(6)(A) and §3.46(d),

> *A permit for saltwater or other oil and gas waste disposal well may be modified, suspended, or terminated by the RRC for just cause after notice and opportunity for hearing, if … injection is likely to be or determined to be contributing to seismic activity…*

Actions taken under this authority, if any, will be subject to the rights afforded to the SWD well operator by statute and RRC rules, which include the opportunity to request a hearing on the merits of the proposed RRC staff action.

Resources

RRC staff maintains, and will continue to develop, resources to facilitate staff's response to seismicity. Below is a list of resources that staff has identified as necessary to implement the Response Plan.

- Tools for investigation of seismicity:
  - UT Bureau of Economic Geology's – TexNet Seismic Monitoring Program
  - GIS, including:
    - ArcGIS
    - Seismic AOI tool
    - GWPC's Seismic Application
  - Reservoir modeling software, including:
    - Petra
  - Fault hazard analysis software, including:
    - Fault Slip Potential from Stanford Center for Induced and Triggered Seismicity
- Templates for staff correspondence to make consistent requests of operators subject to this plan:
  - Notification of **SIR** and RAD, as well as a request for a seismic response plan
- Templates for operators to use when responding to RAD:
  - Recommended Monthly H-10 data table
  - Recommended HFS data table
- Drilling permits:
  - Drilling Permit Conditions for reporting of HFS
  - Drilling Permit Alert Areas to communicate to drilling permit staff and operators where to report HFS

Regular Review

Staff and the RRC Seismologist will evaluate each designated **SIR** on a quarterly basis, with the intent to investigate any changes that have occurred in each region. This is intended to: (1) ensure periodic review of **SIRs** to note increases or decreases in seismicity rate and magnitude and to assess removing or adjusting designations, and (2) keep decision-makers updated of the status of established **SIRs**. An **SIR** designation is temporary; therefore, it is incumbent that RRC Seismologist and staff periodically review each designated region.

In addition, the RRC Seismologist and the Oil & Gas Division Director may make recommendations to the RRC regarding the need for other response actions that are outside of RRC staff's delegated authority in Statewide Rules 9 and 46.

It should be noted that several regions in Texas have experienced a M ≥ 3.5 or larger event since the inception of the TexNet network (since Jan. 2017), as shown in Figure 1, including events in east Texas, the Dallas/Ft. Worth region, and south Texas (Eagle Ford). These regions were once regions of interest for the RRC and would have been designated as SIRs using this response plan. Actions taken either by the RRC and/or industry partners may have changed the seismicity rates and maximum observed magnitudes in these areas, and thus, these regions would no longer be classified as SIRs (Figure 2). Seismicity near Synder, TX has been attributed to

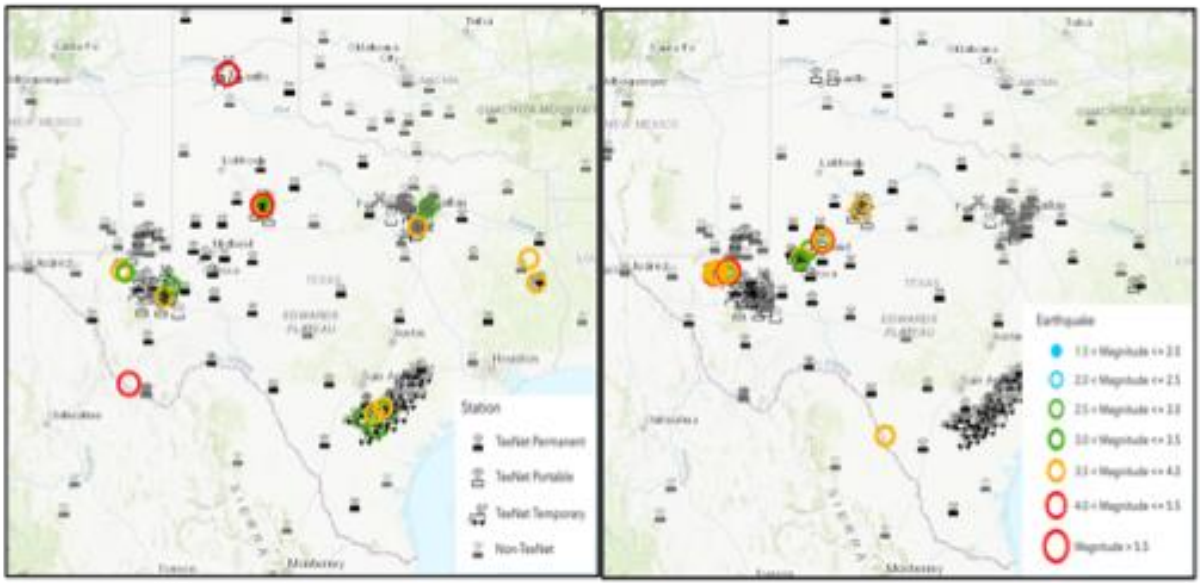

Figure 1: Maps of Texas showing M ≥ 3.5 earthquakes between (left) Jan. 2017 to Dec. 2019 and (right) Jan. 2020 to March 26, 2021. Rectangles represent seismic station while circles represent earthquakes (see legends). Note that M ≥ 3.5 events in east Texas, the Dallas/Ft. Worth region, and south Texas (Eagle Ford) are no longer are occurring and thus would not be considered an SIR. The seismicity since the beginning of 2020 illustrates regions that could be classified as SIRs, which includes Culberson/Reeves Co., Gardendale, Stanton, and El Indio, TX.

Enhanced Oil Recovery (EOR) activity and has been ongoing for over 30 years, and thus would not be classified as an SIR. Following an analysis of earthquake location and depth, two events (near Amarillo and Presidio) were classified by the RRC Seismologist and staff as natural events and required no action. However, since Jan. 2020, Culberson/Reeves Co., Gardendale, Stanton, and El Indio have experienced recent M3.5 earthquakes (Figure 1) and would thus be designated as SIRs (Figures 2 and 3).

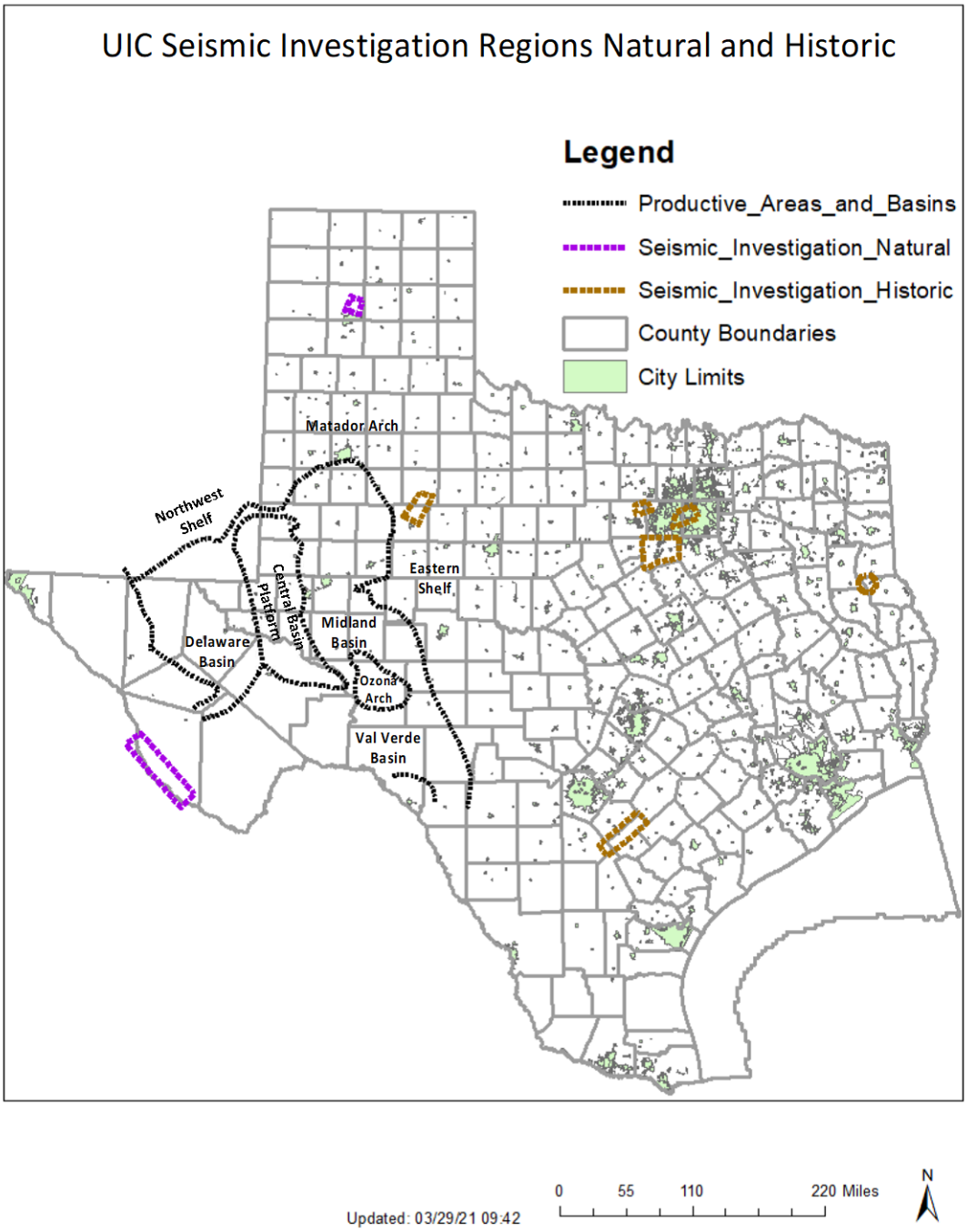

Figure 2: Map of Texas showing tectonic regions (e.g., Permian and Midland Basins) and past and current SIRs (left) From Jan. 2017-Jan. 2020, areas in Texas that would have been classified as SIRs from Jan. 2017-Dec. 2019 (see Figure 1) using the criteria of having M ≥ 3.5 earthquakes occur. Two regions were determined to be natural seismicity (Presidio and Amarillo) while the other regions have had significant reduction of seismicity and are no longer considered SIRs One region (Snyder) has exhibited seismicity for many years from EOR activity and is thus would not be classified as an SIR. (right) Since Jan. 2020, map showing regions that would be classified as SIRs.

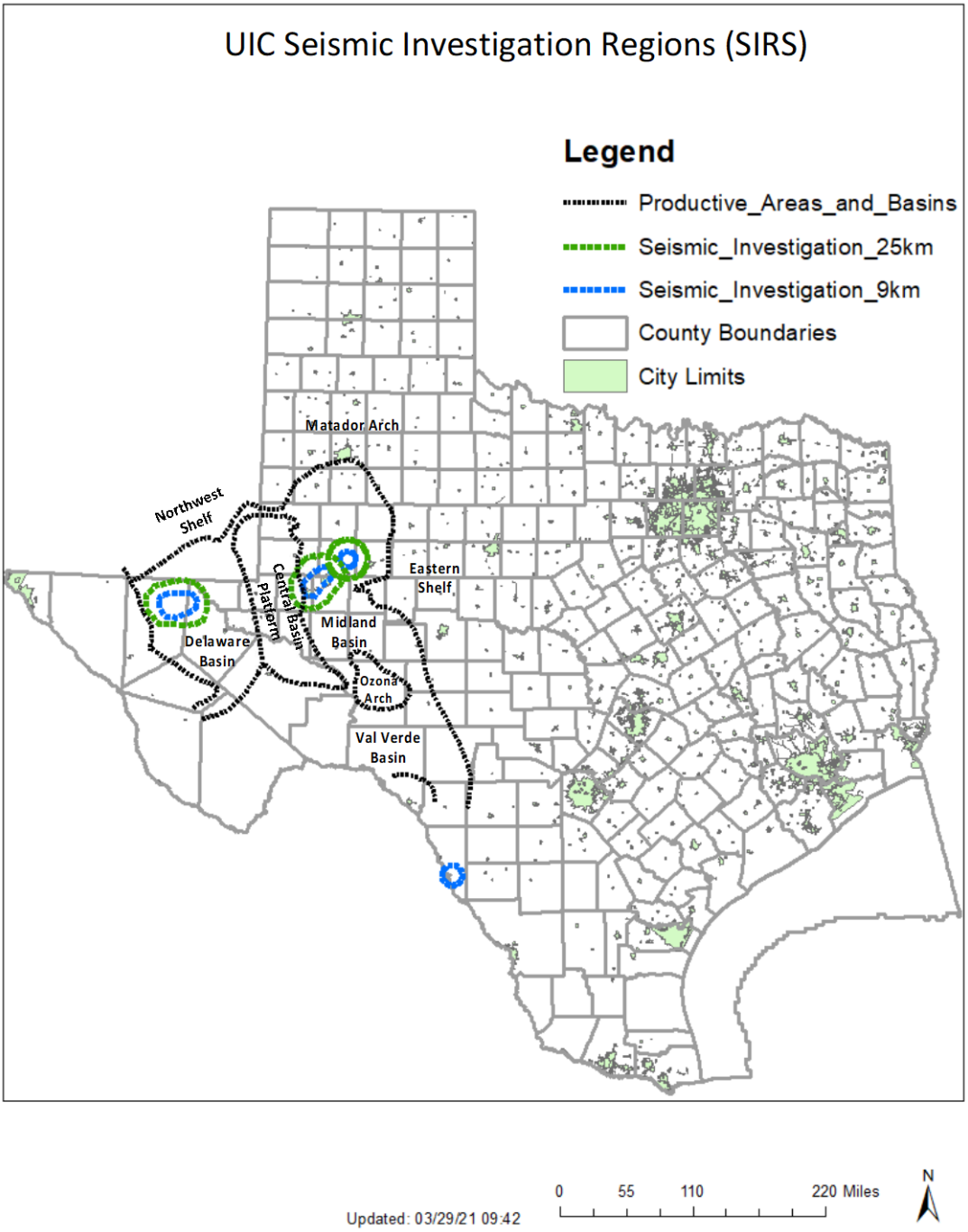

Figure 3: Mas showing tectonic regions (e.g., Permian and Midland Basins) and past and current SIRs (left) From Jan. 2017-Jan. 2020, areas in Texas that would have been classified as SIRs (see Figure 1) using the criteria of having M ≥ 3.5 earthquakes occur. Two regions were determined to be natural seismicity (Presidio and Amarillo) while the other regions have had significant reduction of seismicity and are no longer considered SIRs One region (Snyder) has exhibited seismicity for many years from EOR activity and is thus would not be classified as an SIR. (right) Since Jan. 2020, map showing regions that would currently be classified as SIRs based on activity since Jan. 2020.