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Colorado Law & Induced Seismicity

Darlene A. Cypser

Abstract

Earthquakes can be induced by reservoir impoundment, fluid injection, mining, or oil and gas extraction. These induced quakes create a risk of personal injury or damage to property. The quakes induced at the Rocky Mountain Arsenal near Denver in the 1960's caused significant property damage. Currently, low level seismicity is being induced at several sites in Colorado, including the Rangely Oilfield, Paradox Valley, and Ridgway Reservoir areas. However, no Colorado statute specifically prohibits or regulates induced seismicity. If individuals are injured by seismicity induced in Colorado, they could claim compensation under trespass, negligence or nuisance theories of liability, but Colorado courts are unlikely to apply strict liability to the activities that can induce earthquakes.

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I. Introduction

Colorado holds a unique position in the history of induced seismology. The first in-depth studies of induced seismicity were conducted at the Rocky Mountain Arsenal northeast of Denver and at the Rangely oil field in northwestern Colorado. The Rocky Mountain Arsenal was not purposefully chosen as the site of an experiment in induced seismicity, but became one by default in the 1960's when a disposal well drilled by the Army began triggering quakes. Originally, Rangely was not intended as a research site either. However, tremors were detected in the vicinity of the oil field soon after injection for secondary recovery began. With cooperation from Chevron Oil Company, the operator of the Rangely oil field, U.S. Geological Survey geophysicists conducted injection experiments in the oil field and confirmed the relationship between fluid injection and seismicity noted at the Arsenal. These two cases still stand today as the mostly widely accepted cases of induced seismicity. Since the scientific study of induced seismicity was essentially born here in Colorado, it is appropriate that the study of the legal implications of induced seismicity begin here as well.

Human-induced seismicity usually occurs at low levels and rarely causes damage. However, some induced earthquakes, including those at the Rocky Mountain Arsenal, have caused serious property damage, and even loss of life. This potential for personal injury and property damage generates questions about liability.

In this paper, I will first briefly review what is currently known about induced seismicity, including what activities are believed to induce seismicity, examples of where seismicity has been induced, and what damages resulted. Then I will discuss in greater depth the history of induced seismicity in Colorado, the current status of Colorado induced seismicity and the potential for future seismicity in this state. With this as the scientific and factual background, I will analyze how Colorado law can be applied to induced seismicity.

II. Induced Seismicity

It is not accurate to say that no earthquakes were induced before the 1960's. Scientists had noted tremors associated with the filling of Lake Mead in Arizona as early as the 1930's.[1] A study in the 1970's concluded that an earthquake in Wappinger Falls, New York in 1952 was probably induced by the Trap Rock Quarry and that other earlier quakes may have been mistaken for blasting at the quarry.[2]

Historic induced seismicity is difficult to diagnose because fewer seismic networks were operating in the past. Techniques for discriminating natural from triggered seismicity were also less well developed. In fact, prior to the Rangely experiment some geoscientists were not willing to admit the possibly of any human activity triggering an earthquake.[3] Seismologists now recognize several different human activities which can stimulate seismicity including fluid injection and extraction, mining, quarrying, reservoir impoundment, and underground nuclear explosions.

A. Injection-Induced Seismicity

Fluid injection for waste disposal or secondary recovery of oil or gas can trigger earthquakes. Injecting fluids into deep wells increases the pore pressure in the rocks in the injection zone and areas communicating with the zone. This change in pore pressure can decrease the effective normal stress across pre-existing faults making them more likely to slip, as well as decrease the actual strength of the rock surfaces making them less resistant to slippage.

Nicholson and Wesson[4] list more than 30 documented cases of possible injection-induced quakes in the United States and Canada. Davis and Frohlich[5] studied 19 such cases in depth and found strong evidence to support 12 of them. Notable examples are the quakes associated with waste disposal in El Dorado, Arkansas[6] and Ashtabula County, Ohio,[7] the tremors associated with pressure maintenance projects in the Cogdell oil field near Snyder, Texas and other oil fields near Kermit, Texas,[8] and the seismicity induced in the Geysers geothermal field in northern California.[9] There is also strong evidence for microseismicity induced by solution salt mining near Dale, New York.[10]

B. Production-Induced Seismicity

Seismicity has also been associated with production of oil, gas and geothermal energy. Extracting fluids can cause faults which previously had been slipping aseismically to lock up for periods of time before slipping seismically. Fluid extraction can also lead to compaction and underground subsidence which can result in seismicity.

Grasso lists 24 oil fields worldwide associated with seismicity of magnitudes greater than 3 (i.e. earthquakes large enough to be felt). While one seismologist has suggested that the Coalinga (1983), Kettleman North Dome (1985) and Whittier Narrows (1987) earthquakes in California may have been induced by oil and gas extraction,[11] the proposed mechanism for inducing these quakes is not widely accepted by other seismologists. On the other hand, there is substantial evidence of seismicity induced by oil and gas extraction in some oil fields in Texas including the Imogene, Fashing and Falls City fields in south Texas.[12]

Some seismologists believe the three 7.0 magnitude Gazli, Uzbekistan (1976 & 1980) earthquakes were also induced by gas extraction. If this is true, these would be not only the most damaging production-induced quakes known, but the largest magnitude induced quakes of any kind.[13]

C. Reservoir-Induced Seismicity

Some of the most damaging quakes in the world have been induced by the impounding of reservoirs. Reservoirs increase stress by adding mass on top of the existing rock formations, and by increasing the pore pressure under and around the reservoir with results similar to those in fluid injection cases.

Gupta lists 25 cases of reservoir-induced seismicity which produced quakes of magnitude 4 or greater. Seven of those cases were magnitude 5.5 or greater.[14] Lake Mead in Arizona began inducing quakes when it was filled in 1935. The biggest quake near Lake Mead was magnitude 5 and occurred in 1939.[15] Some contend the 5.7 magnitude quake near the Oroville dam in California in 1975 was reservoir induced, though the case is far from clear.[16] However, for the most part the United States has been lucky. Most reservoir-induced earthquakes in this country have been of low magnitudes and/or located in isolated areas.

Reservoir-induced quakes over 6th magnitude have occurred in Greece, India, and China and on the Zambia/Zimbabwe border.[17] To date the most devastating of these was the December 1967 earthquake near the Koyna Reservoir in India. This 6.3 magnitude earthquake caused extensive damage to the town of Koyna Nagar and destroyed almost all the buildings in Denechiwada, Helwak and Nanel villages. Houses collapsed; bridges were destroyed; roads cracked. The dam itself suffered considerable damage. Over 1500 people were injured and over 200 were killed.[18]

C. Mining & Quarrying Induced Seismicity

Underground mining increases stress on surrounding rock and supporting columns when the supporting mass is removed. This can cause failure of the columns, walls, ceiling or floor, movement along pre-existing faults, or sometimes new faulting. Surface mining and quarrying remove mass from above, decreasing the stress bearing down on lower layers of rock. These lower layers of rock may then adjust to the change in stress by springing upward.

Many seismologists who study mining distinguish seismicity resulting from the collapse of underground cavities, such as occurred at the Solvay trona mine in Wyoming in February 1995[19], from quakes resulting from movement along a fault or due to uplifting and only refer to the latter as a “mining-induced earthquake.” However, sometimes tremors from both are included in the broader category of “mining-related” seismicity.

Seismicity of some form is probably associated with most mining though precise figures worldwide are hard to come by. Wong lists 32 cases of significant mine seismicity worldwide.[20] Redmayne believes that up to 25% of all earthquakes recorded by the British Geological Survey may be related to coal mining[21] and the Geological Survey of South Africa reports that “the bulk of the seismic events recorded by the regional network” are tremors resulting from deep mining operations in the gold fields of Transvaal and the Orange Free State.[22]

Strong correlations have been found between mining activity and seismicity. Seismicity slows when work stops for a holiday or a miners' strike and eventually stops when all work on the mine ends. The number of tremors also varies weekly and diurnally according to the rhythm of the work at the mine.[23]

The frequency and severity of mining-induced seismicity tends to increase with increases in the rate of extraction from the mine and depth of the mine.[24] Many who study seismicity related to mining believe that mining-induced seismicity and damaging rockbursts are increasing in number and severity as the easier to reach minerals are mined out worldwide and new technology allows for deeper mines and faster extraction.[25]

Mining companies have an incentive to study mining-induced seismicity since damage tends concentrate within the mine. Miners can be injured or killed, and access to productive areas of the mine can be lost. Research can determine what changes in mining practices may be able to control damaging events. Research has already determined that the geometry of the mine, and the sequence and rate of extraction, are important factors in mitigating damage.

While mining-induced earthquakes cause the greatest hazard to the mine and the miners, where mining takes place in populated areas large numbers of tremors may be felt beyond the mine and perceived as a nuisance.[26] The earthquakes with intensities up to V have been associated with the Trap Rock quarry in Wappinger Falls, New York, though no property damage has been reported.[27] In the 1940's Katherine and J. Freeman Dixon sued the New York Trap Rock Company which was operating the limestone quarry in Dutchess County.[28] The Dixons claimed that vibrations caused by blasting at the quarry had damaged their house and injured Katherine's health. The Referee ruled that vibrations from the quarry constituted a nuisance which entitled the Dixons to damages and the New York Court of Appeals later upheld this ruling.[29] Research by seismologists in the 1970's determined that earthquakes occurring in Dutchess County in 1974 and 1952 were probably triggered by the Trap Rock Quarry, and that other smaller quakes might have occurred earlier and been mistaken for dynamite blasts.[30] Thus, some of the “vibrations” that the Dixons complained of in their nuisance suit may have really been earthquakes induced by the quarry.

E. Seismicity Induced by Nuclear Explosions

Nuclear explosions at the Nevada test site and under Amchitka Island, Alaska have been followed by large numbers of small earthquakes beginning just after detonation and continuing for some weeks. Some tremors are located close to the shot chamber and are primarily due to the collapse of the underground cavity created by the nuclear explosion. Other small earthquakes have been observed up to 10 km (6 miles) away. These quakes may have been triggered by changes in stress caused by the opening of the cavity, changes in pore pressure caused by a pressure wave created by the explosion, or other stress changes generated by the explosion.[31]

In the late 1960's several large nuclear explosions at the Nevada Test site resulted in observable displacements on nearby faults and numerous earthquakes. People became concerned that such an explosion could trigger a large earthquake which would release as much seismic energy as the explosion itself or even more. This concern peaked prior to the detonation of a high yield nuclear device under Amchitka Island in Alaska called the "Cannikan" test. This test was located over a very active seismic zone in the Aleutian Islands. Environmental organizations attempted to enjoin the Cannikan test because they felt the Environmental Impact Statement did not adequately consider the possibility of the test inducing devastating quakes and tsunamis. The U.S. Supreme Court denied the injunction.[32] Seismic activity resulting from the Cannikan test was primarily associated with the cavity collapse and lasted approximately 36 hours. A few seismic events of tectonic origin which may have been triggered by the explosion occurred on nearby faults within the next few weeks. None of these quakes were over magnitude 3.[33]

Fault movements related to nuclear explosions are due to the release of pre-existing tectonic strain. While the Cannikan test was fired over a subduction zone where intense seismic activity is generated, there was evidence that the rocks in the upper few kilometers of Amchitka

Island did not carry any substantial tectonic stress and thus had little to release.

However, the Nevada Test Site exists in an entirely different stress environment allowing for greater fault movements and stress releases. But no earthquake has been triggered that released as much seismic energy as the explosion itself.[34]

In addition to nuclear explosions for weapons tests, the United States has detonated several nuclear devices in Nevada, New Mexico and Colorado as part of the Plowshare program in the 1960's and 1970's. The purpose of the Plowshare program was to test “peaceful” uses of nuclear explosions. The program and related seismicity will be discussed in more detail in the following section on the history of Colorado induced seismicity.

III. History of Induced Seismicity in Colorado

A. Confirmed Cases of Induced Seismicity

1. Injection-Induced Seismicity

a. Rocky Mountain Arsenal

The Rocky Mountain Arsenal covers 27 square miles of prairie due west of the Denver International Airport. The land was farmland prior to the establishment of the Arsenal. In 1942 the U.S. government condemned the land for military use and removed the farmers and their families. The Army Chemical Corps swiftly began constructing the Arsenal for the manufacture of chemical weapons.[35] As soon as the facilities were ready, the Arsenal began producing mustard gas, Lewisite and chlorine gas.[36] The Army produced GB nerve gas at the Arsenal from 1953-1957. Napalm bombs and other incendiary devices were also manufactured at the Arsenal throughout the Korean War.[37] The government also produced hydrazine rocket fuel at the Arsenal during the 1960's.

Beginning in the late 1940's portions of the Arsenal were leased to private industry for chemical manufacturing. In 1947, Colorado Fuel & Iron Corporation leased a portion of the Arsenal to manufacture chlorinated benzenes and DDT. Later Julius Hyman & Company took over that lease and produced pesticides at the Arsenal till the Shell Chemical Company purchased the company in 1952. Shell continued the manufacture of pesticides on the Arsenal till 1982.[38]

From 1942 through 1955 chemical wastes from these manufacturing processes were pumped to an evaporative basin near the center of the Arsenal called “Basin A”. During the summer of 1954 farmers northwest of the Arsenal complained of crop damage due to ground water contamination. Complaints increased after the GB nerve gas plant began production. In 1955, the Army constructed Basin F, a 96 acre asphalt-lined basin with a special waterproof membrane, to store the chemical wastes from the Arsenal. From 1955 through 1975 all of the Arsenal's chemical wastes were pumped to Basin F.[39]

However, construction of Basin F did not stop the contamination of ground water in and around the Rocky Mountain Arsenal.[40] In 1960 the Army began considering constructing a waste disposal well on the Arsenal. The plan was to construct a well over 2 miles deep which could inject the chemical wastes from Basin F between layers of rock far below the surface groundwater. Army officials thought the wastes would be trapped there and be unable to cause any further contamination. Construction of the well began in June 1961. The well was completed in early 1962 and the Army began pumping chemical wastes from Basin F into the deep well on March 8, 1963.[41]

At 4:10 pm April 24, 1962 a seismograph near Golden, Colorado recorded an earthquake from a location northeast of Denver. The quake was too small to be felt -- only magnitude 1.5 -- and would not have been noticed if it had been an isolated event. However, this quake was followed by over 1500 more earthquakes in the same general area between 1962 and 1967. These varied from quakes too small to be noticed by humans to some causing moderate damage up to 40 miles from the epicenter.[42]

Studies by graduate students at the Colorado School of Mines located the epicenters of the earthquakes and discovered that they were all within 5 miles of the Rocky Mountain Arsenal disposal well.[43] Later studies determined that the epicenters of the quakes were even closer to the well.

Minor damage caused by 3rd & 4th magnitude earthquakes caught the attention of the public and raised concerns. As the quakes continued, people began to fear that larger quakes would follow.

On November 23, 1965 consulting geologist David M. Evans publicized his opinion that the pumping activities at the Arsenal well were directly related to this seismic activity.[44] He produced charts comparing the frequency of the earthquakes and the monthly volume of fluid injected at the Arsenal. The number of earthquakes rose as the volume of wastes pumped into the well rose and fell as the volume fell.

This publicity prompted studies of the earthquakes and their association with the RMA disposal well by the U.S. Geological Survey and the Army Corps of Engineers. Colorado Governor John A. Love directed the Colorado School of Mines to study the earthquake series as well. As part of its investigation the U.S. Geological Survey established a dense seismic network on the Arsenal grounds. This network operated during January and February 1966. Data from this network showed that the epicenters of the earthquakes occurred within a narrow elliptical zone which included the disposal well.[45]

As evidence mounted of the relationship between the earthquakes and the disposal of chemical wastes into the Arsenal well, political pressure grew to end the pumping. The Army ceased injecting fluid into the Arsenal well on February 20, 1966.[46]

However, the earthquakes did not immediately cease. As the quakes continued, debates raged over whether an attempt should be made to remove the wastes injected into the well. Some scientists said that removal of the fluids would stop the quakes; some said it would make them worse; and others said that it would make no difference.[47] The “pumping out” question became a hot political issue between U.S. Representative Don Brotzman (Republican) and his Democratic challenger, former Congressman Roy H. McVicker.[48]

Before the decision was made three earthquakes larger than any of the previous quakes struck the area. In April, August and November 1967, 3 earthquakes over magnitude 5 and their aftershocks rocked the Denver area.

At noon on Monday, April 10, 1967, a magnitude 5.0 earthquake shook the Denver metropolitan area. There were no injuries. Damage reports consisted mostly of broken windows, cracked plaster and fallen objects. One hundred and eighteen window panes were broken in buildings on the Rocky Mountain Arsenal and an asphalt parking split in Derby. Ceiling beams at the Adams County Golf Course cracked. The walls of school buildings in Boulder were cracked by the shaking. A man in Commerce City reported that the quake broke pipes in his home and flooded his basement. Fifteen aftershocks were recorded within the first 5 hours after the quake.[49]

The August 8, 1967 quake struck at 7:25 a.m., throwing several people out of their beds and causing much more damage. The worst damage was concentrated in the Northglenn and Thornton areas to the northwest of the Arsenal. Windows were broken throughout the area and merchandise was thrown from the shelves. Rank Gornick of Northglenn Liquors estimated that he had $10,000 to $12,000 worth of merchandise broken. Fifteen grocery stores northeast of Denver also suffered breakage damage. The manager of Buddy & Lloyd's Supermarket in Commerce City estimated their loss from broken merchandise and windows at about $2,000. Twenty-five windows and three concrete pillars cracked at St. Stephens Lutheran Church in Northglenn. Many homeowners reported cracked walls, ceilings, floors and foundations in homes in the Northglenn and Western Hills areas. Water heaters shifted causing connections to leak. A woman in Lakewood saw a crack open in her concrete driveway during the tremor. Bricks were knocked loose from a chimney in downtown Denver and fell on a car below.[50] Damage from this quake was estimated to total $1 million (1967 dollars).[51]

In September 1967 after a visit to the Rocky Mountain Arsenal, Representative Don Brotzman asked the commander of the Army Material Command in Washington, DC to study the possibility of pumping the well. "The Army declined to seek a consensus from the scientific community on the advisability of lowering the level of the well and in fact steadfastly insisted there is no conclusive evidence there was any connection between the well and the earthquakes," Brotzman told the Denver Post. Concerned, Brotzman approached President Johnson's science advisor, Dr. Donald F. Hornig who consulted with experts at MIT on the issue.[52]

On the night of November 26, 1967 another earthquake over magnitude 5 struck northeast of Denver. Three 3rd & 4th magnitude aftershocks followed this quake within an hour.

The main quake was felt as far as Laramie, Wyoming. Scores of reports were received of minor wall, ceiling and floor damage. In Wheatridge an exhaust pipe broke loose from a dryer.[53]

Residents of the Denver area feared that larger quakes would follow if the waste fluids were not pumped out of the Arsenal well. The Army felt it was in a “damned if we do & damned if we don't” situation. If they did pump and a larger earthquake occurred the quake would be blamed on the pumping. If they did not pump and a larger earthquake occurred it would blamed on their failure to pump out the fluids.[54] A decision was finally made to do some test pumping with extensive seismic monitoring to establish both the feasibility and safety of pumping out the well.[55]

Pump tests were carried out by the Army Corps of Engineers between September 3, 1968 and October 26, 1968. The U.S. Geological Survey established a seismic network of 21 seismometers at 17 locations. Fourteen locations were on the Arsenal. Three additional locations were northwest of the Arsenal across the South Platte River. The system was devised to detect earthquakes in the vicinity of the Arsenal of -1.0 Richter magnitude or larger. The Army agreed to halt a pump test if informed by the Geological Survey that certain seismic criteria had been exceeded. After each of two major pumping periods the frequency of small earthquakes increased. The Army delayed one test scheduled to begin on September 20, 1968 until October 17 because seismic activity from the first test had not settled down and the U.S.Geological Survey feared the criteria would be exceeded.[56]

These tests demonstrated that it would be possible to pump an average of 40 gallons per minute from the Arsenal well. At that rate it would require approximately 8 years to remove all the waste that had been pumped down the well. Pressure drops during pumping and increases in seismic activity created complications. The tests also determined that pumping at the rate of 35-40 gallons per minute would cause the toxic chemical wastes to flash to steam (which could further contaminate the area around the Arsenal) unless the wastes were kept cold and under pressure until released back into Basin F. These requirements would greatly increase the expense of removing the wastes.[57] The remainder of the waste fluid was not pumped from the well.

Since 1967 the earthquakes have been declining.[58] The total cost of property damage for the entire earthquake series through 1982 was approximately $8 million (1990 dollars).[59]

Most seismologists who have studied this earthquake series believe the high-pressure injection of fluids into a fault or fracture zone triggered the quakes.[60] Larger quakes occurring over a year after the Army had stopped injecting wastes into the well were caused by the continued migration of fluid pressures along the fault or fracture zone away from the Arsenal well.[61]

b. Rangely Oil Field

Scientists with the U.S. Geological Survey and the Army Corps of Engineers were forced to take a conservative approach to the study of the Rocky Mountain Arsenal quakes due to the proximity to Denver and other cities. However, they began looking for a site where they could test their theories about the relationship between high pressure fluid injection into deep wells and earthquakes. In 1967 W. W. Rubey advised U.S. Geological Survey that the Rangely oil field in northwestern Colorado might meet their needs.[62]

The Rangely Oil Field in Rio Blanco County, Colorado is one of the most prolific oil fields in the Rocky Mountain region. The Rangely Oil Field produced over 815 million bbls (barrels) through the end of 1995, over eight times the cumulative production of the next most productive field in Colorado. In 1995 alone the Rangely field produced nearly 9 million barrels.[63] The oil reservoir at Rangely is an anticlinal entrapment about 12 miles long and 5 miles wide. A normal fault cuts through the long axis of the reservoir about one third of the distance from the southeast end of the field.[64] The oil field surrounds the town of Rangely.

The California Oil Company (now a division of the Chevron Oil Company) discovered the Rangely oil reservoir in 1932 but did not develop the field until 1943. After development began formation fluid pressure decreased rapidly till 1957. In 1957 the field was unitized under the management of the California Oil Company. Waterflooding was started in December 1957 to maximize oil recovery. By 1961 the bottomhole pressure at the northwest end of the field had recovered and slightly exceeded the initial pore pressure of 2500 psi (pounds per square inch). By 1963, the bottom hole pressure in that part of the field had increased to about 3,000 psi. Ninety-eight of the 482 wells in the field were converted to water injection by January 1964. Seventy-five of the injection wells were located on the periphery of the reservoir, 16 in a 5-spot pattern on the east flank and 7 in the gas cap. As production from peripheral wells became uneconomical they were converted to injecting water. The number of injection wells thus increased steadily, reaching 158 by July 1967. By this time bottom hole pressures were as high as 4200 psi.[65]

The Uinta Basin Seismological Observatory near Vernal, Utah was the closest seismographic station to the Rangely oil field from 1962 to 1970. This station began operating in December 1962. It immediately began recording a large number of small quakes in the vicinity of Rangely.[66] There are no prior instrumental records of seismicity in the area and only one secondhand, unverified record of a pre-injection earthquake. Therefore, seismologists are unable to establish any correlation between the initiation of waterflooding and the onset of seismic activity.[67]

In November 1967 the U.S. Geological Survey installed four temporary portable seismographs around the field in an effort to locate the active earthquake areas. These recorded for 8 days and revealed a pattern of seismic activity that correlated with the areas in the field where fluid pressure was high.[68] This study also showed that the earthquakes clustered in two places within the Rangely field. The clusters of epicenters lay in the northwest end of the field and along the south central margin of the field. In both places the pore pressure due to water injection exceeded the original field pressure.[69]

A 14 station network of seismometers was installed at the Rangely oil field in the fall of 1969. Between October 1969 and November 1970 approximately 1000 earthquakes were located with the data collected. Nearly all the quakes were in the south-central part of the field. These epicenters corresponded to places in the field where the pore pressure exceeded the original pore pressure of 2500 psi. These quakes ranged in magnitude from -0.5 to 3.5 and none caused significant damage. The quake epicenters lay along the southwestern extension of a fault previously mapped by Chevron, but only along that part of the fault where pore pressures were greater than about 2900 psi. Earthquakes located originated at depths within or below the injection zone.[70]

In November 1970 the U.S. Geological Survey began an experiment at the Rangely oil field. Four injection wells straddling the fault zone were backflowed to reduce the pore pressure in the hypocentral region. The wells were backflowed and pumped out for about 6 months. Within a short time after backflowing began earthquakes within 3000 feet of the wells decreased markedly in frequency and ultimately almost ceased.[71] Calculations based on the measured stresses indicated that a pore pressure of at least 3700 psi was required for shear failure. Earthquakes occurred near the bottom of wells where pressure was around 4000 psi. Seismicity ceased after pressure in those areas dropped 500 psi.[72] The portion of the field without natural faults did not produce earthquakes even when the fluid pressures were quite high.[73]

The largest earthquakes recorded at Rangely occurred on March 20, 1995 (mag. 4.8), April 21, 1970 (mag. 4.6), July 6, 1966 (mag. 4.5) and each caused minor damage to the town of Rangely.[74] Waterflooding continues and larger quakes could occur in the future.

c. Paradox Valley

The induced earthquake series at the Rocky Mountain Arsenal and the Rangely oil field are fairly well known in the seismological community, but a lesser known case of injection-induced seismicity is currently being observed by the U.S. Bureau of Reclamation in southwestern Colorado.

The Paradox Valley in southwestern Colorado is an elongated salt anticline near the border with Utah. The Dolores River crosses the valley by piercing the valley walls perpendicular to the long axis of the valley. The Dolores River picks up a large amount of brine in the valley which later flows into the Colorado River. As part of the Colorado River Basin Salinity Control Project the U.S. Bureau of Reclamation is extracting brine at shallow depths in the Paradox Valley and reinjecting the brine at high pressure beneath the salt deposits of the valley.[75]

Since this portion of the Colorado Plateau was characterized by low level seismicity, and other factors indicated a potential for induced seismicity, the Bureau of Reclamation installed a seismic network in the Paradox Valley in 1983 to determine the background level of natural seismicity.[76] The Paradox Valley Seismic Network consisted of 14 seismometer stations. The closest was located 2 km (1.2 miles) from the well and the most distant was 30 km (18 miles) away. Another station was added within 1 km (.6 miles) in the fall of 1995. In the seven years of monitoring prior to the start of injection, only one to two earthquakes per year were recorded in the valley. No seismic events at all were within 5 km (3 miles) of the well during this period.[77]

Two trial periods of injection occurred in late 1991. Both were accompanied by a small number of earthquakes located very near the injection well. The earthquakes began within 24-48 hours after injection was initiated and ceased shortly after injection stopped. The hypocenters of the earthquakes were located near the base of the well.[78]

There were seven periods of fluid injection at various wellhead pressures and injection rates in the Paradox Valley between July 1991 and September 1995. Seismicity accompanied six of the seven periods of injection. More than 600 quakes have been recorded in the vicinity of the well. Analysis of the data collected from the injection tests suggests that during injection pressures at the well bottom are sufficient to cause slipping on pre-existing faults, as well as cause new faulting in some intact rock. The injection-induced seismic events are clearly associated with pre-existing fractures, including some identified from previous oil exploration in the area. None of these faults is expressed on the surface. There is a general correlation between injection rate, wellhead pressure and number of quakes observed. The higher the pressure and injection rate the more quakes observed and the larger magnitude. The largest magnitude quake through 1995 was 2.6, which occurred halfway through the seventh injection period. Larger events are possible.[79]

2. Reservoir-Induced Seismicity

a. Ridgway

Only 48 miles (80 km) to the southeast of the Paradox Valley is the Ridgway Reservoir. The region near Ridgway has been the site of some of the largest instrumentally recorded earthquakes in Colorado (M 5.5 in 1960 and M 4.6 1994).[80] Several historic quakes are believed to have occurred in the region.[81]

A temporary five station seismic network was operated in the area for 3 months in 1979 around the site of the proposed Ridgway Reservoir as part of the seismotectonic investigation of the dam site. This temporary network located 22 microearthquakes within or near the seismic array varying from -0.3 to 2.7 in magnitude. Thirty-four other tremors were recorded but were too small to locate the source. All of the quakes detected by this temporary network were thought to be associated with the Ridgway Fault or the connected branch faults. One branch fault, named the Cow Creek Fault, passes under the damsite and was discovered during excavation for the dam foundation. The Cow Creek Fault is an eastward dipping normal fault and the bulk of the Ridgway Reservoir sits on the down-throw side of the Cow Creek Fault.[82]

Based on the seismic history of the region and the results of the temporary seismic network, the seismotectonic study concluded that the Ridgway Fault and the branch faults were active or potentially active. And even though the proposed Ridgway reservoir was not considered a prime candidate for reservoir-induced seismicity based on dam height or planned volume, the proximity of active faults to the dam site raised the possibility. For this reason a six (later seven) station seismic network was installed in the area prior to constructing the Ridgway Dam. This network monitored seismicity in the area from 1983-1987 to establish a baseline of naturally occurring seismicity. This baseline study showed a fairly low level of seismicity with a few events occurring in the vicinity of the Ridgway fault and associated branch faults. No quakes larger than magnitude 2.0 were observed during this period.[83]

Filling for storage began in October 1986. The frequency of quakes increased at that time and has continued to be higher than during the baseline period.[84] Seismicity also increased during test fillings in January 1986 and late September/early October 1986. Since the filling of the Ridgway Reservoir, seismicity within 5 km of the reservoir has increased by a factor of seven. The largest event beneath the reservoir to date was magnitude 2.3. A large number of small events also appear associated with north-trending branch faults including the Cow Creek fault. The hypocenters of these earthquakes tend to be 7-9 kilometers deep. In addition to the large number of earthquakes occurring beneath the reservoir, there is a persistent cluster of seismicity east of the reservoir beneath the Cimarron Ridge. These events are consistent with the location of the 1960 magnitude 5.5 earthquake. The largest tremor in this area since 1985 was magnitude 2.8. The hypocenters of these quakes seem to form a plane 6 -9 km below surface and dipping eastward. No surface faults have been mapped in that area.[85]

The rapid increase in microseismicity near the reservoir coinciding with initial filling suggests that increased stress due to the added mass of the water of the reservoir is an important factor.[86] This additional stress on the down throw side of the Cow Creek fault is probably causing the seismicity in the vicinity of that fault. Whether increases in pore pressure are also contributing to seismicity in the branch faults or beneath the Cimarron Ridge has not yet been determined. But a "clear association has been established between reservoir impoundment and increased seismicity near the dam site."[87]

A 4.6 magnitude earthquake occurred on September 13, 1994 on the western edge of the Ridgway seismic network and was followed by several hundred aftershocks. The hypocenters of these quakes tended to be deeper than those associated with the reservoir filling, between 9-12 km (5-7 miles) below the surface. Due to the distance from the reservoir (over 12 miles) this swarm of quakes is not thought to be reservoir-induced.[88]

The Ridgway Dam Seismic Network is a prime example of the precautions which are appropriate at the site of a proposed reservoir where reservoir-induced seismicity is possible. Not only can the data collected from the network and reservoir be used to further understand the mechanisms of induced seismicity, but this seismic monitoring would provide some warning of changes in patterns of seismicity related to changes in the reservoir. Such monitoring might have prevented disasters resulting from reservoir-induced earthquakes in China and India. In recognition of the importance of maintaining the network the Dam Safety Office of the Bureau of Reclamation has argued strenuously for the continued funding of seismic monitoring in the vicinity of Ridgway Reservoir, including arguing that the cost of monitoring the risk of seismicity created by the reservoir should be a cost of doing business: “The reservoir is impacting the environment and the environmental changes have the potential to effect the health and well-being of the public as well as the risk the dam poses to the public. Monitoring the magnitude of the impact is a project cost and should be reimbursable. The environmental change and the need to monitor would not be required if the facility were not in existence.” [89] However, this proposal was vetoed by the Acting Regional Director of the Upper Colorado Region of the Bureau of Reclamation because the monitoring was “not necessary to monitor the structural integrity ... or for the operation and maintenance of the dam and reservoir.” [90]

4. Mining-Induced Seismicity

> "Mining has been extensively carried on in the Rocky Mountain region since 1859. Of the seismic events recorded in Colorado, possibly 10% may be large mine blasts or rockfalls associated with blasting."[91]

Seismologists in Colorado often must identify and remove recordings of mine and quarry blasting from their seismic records in order to study the earthquakes recorded. But mining and quarrying have such a long history in Colorado that mining-induced seismicity would be expected to be found in this state in addition to the contamination of the seismic record by blasting and rockfalls. However, very little study has been done of these types of induced seismicity within Colorado. One notable exception is the Somerset coal mine in Delta and Gunnison counties.

Somerset Coal Mine

Coal has been mined near Somerset since 1901.[92] Coal bumps, heaving rocks and cave-ins are serious hazards in the Somerset coal mine. In July 1969 a seismometer was installed at the Somerset mine to study such mining hazards. In the first month the seismometer recorded 1,000 small tremors in and around the mine.[93]

In the fall of 1969 a temporary seismic network was installed for about two weeks on the surface near the Somerset coal mines to further study seismic activity associated with mining hazards. This seismic network operated from August 30 through September 16 with continuous recording from September 3rd through 16th. During this time 38 tremors were recorded by the temporary network and the permanent seismometer at the mine recorded 517 tremors.[94] Hypocenters for 13 of the 38 tremors recorded by the net could be located and were found to be within 1 mile of the active areas of the Somerset mine. Six of these hypocenters formed a line parallel to several faults east and west of the mine. This line of seismicity was thought to result from the release and unequal distribution of stress caused by the nearby mining. Most of the other seismicity originated near areas in the mine where pillars were being removed. Only two events were over magnitude 2.[95]

In general, this brief study indicated that seismicity in the Somerset coal mining district is similar in occurrence pattern, depth of focus, and origin, to seismicity associated with coal mining in the central Utah coal mining district which has been extensively studied.

Additional studies of seismicity and patterns of coal extraction were done in the Somerset coal mine in 1973 and 1974. Peaks in seismic activity coincided with periods of unstable roof conditions, bumps and squeezes. Some of this seismicity seemed to be due to stresses caused by prior mining practices in a lower bed.[96]

Seismicity near Somerset is likely to continue as long as extraction from the coal mine continues.

5. Nuclear Explosion Induced Seismicity

The Plowshare Project was proposed to find “peaceful” uses for nuclear explosions. Twenty-seven nuclear tests were conducted as part of the project between December 1961 to May 1973. Three tests called Gasbuggy, Rulison, and Rio Blanco were designed to demonstrate the potential for using nuclear explosions to stimulate natural gas recovery from low permeability sandstone reservoirs. The experiments were successful in increasing gas recovery from the reservoirs. However, in some cases the gas was far too radioactive to use, and public opinion “fallout” resulted in a discontinuation of the project in 1973.[97]

Two of these experiments (Rio Blanco and Rulison) took place in Colorado and one (Gasbuggy) was just south of the Colorado border. Each of these explosions caused a considerable amount of ground motion and was felt over a large area. Microseismicity increased near the blast site after each test but diminished rapidly within a few days.[98]

Project Gasbuggy consisted of a single 29-kiloton nuclear explosive detonated at a depth of 1,292 meters about 88 km east of Farmington, New Mexico. The explosive was detonated on December 10, 1967.[99]

The Rulison Project was a cooperative project of the Atomic Energy Commission, the Department of Interior, and the Austral Oil Company and involved detonating a single 43 kiloton nuclear explosion in the Rulison gas field in Garfield County on September 10, 1969.[100] Some property damage resulted from the shock of the explosion. Damage claims were filed and promptly settled.[101] A seismic network operating near the Somerset mine approximately 41 miles from the test site recorded an increase in the maximum number of large tremors per day immediately after the explosion though there was no increase in the absolute number of quakes.[102]

Rio Blanco was the third of these experiments and was co-sponsored by CER Geonuclear Corporation, Equity Oil Company of Salt Lake City, Utah, Lawrence Livermore National Laboratory (known as Lawrence Radiation Laboratory at the time), and the State of Colorado. For Rio Blanco three nuclear explosives were detonated at depths of 1752 m (5782 ft.), 1869 m (6168 ft.), and 2007 m (6623 ft.) in the Piceane Basin in Rio Blanco County northwestern Colorado. The three explosions were detonated nearly simultaneously at approximately 10 am on May 17, 1973. The total yield from the three explosions was approximately 90 kilotons. [103]

Seismic Engineering/Geological Survey installed and operated seismographs for three major seismic studies of Project Rio Blanco: the ground motion study, the structural response study and the aftershock study. The ground motion program consisted of an array of 35 documentation stations to give comparisons between predicted and actual ground motions. The purpose was to compare low rise structural damage and to help establish insurance rates for subsequent Plowshare nuclear events.[104] No fault displacements were found after the test.[105]

One seismic monitoring station began operating 1.5 years before Rio Blanco was detonated to provide background seismicity information. This station continued in operation till December 17, 1973 (7 months after detonation). This station recorded only one earthquake (<1.0 mag.) within 40 km (24 miles) of the detonation site in the year and a half before detonation. Seismicity recorded after detonated was confined to within 500 meters (1650 feet) of the cavity.[106] The seismic events varied in magnitude from -0.3 to 2.4 with the majority less than 1.0. Ten were greater than or equal to 1.5 and the largest (2.4) occurred within 82 minutes of detonation.[107] The vast majority (90+ events) of the seismic events occurred within 12 hours of the detonation.[108] After that period events were relatively few in number. Of the 120 seismic events recorded only one shock was recorded more than 8 days after detonation and none more than 4 months after detonation.[109] The explosion did not seem to have any long term effect on the natural seismicity of the area.[110] Rockfalls were not observed beyond approximately 20 miles from the detonation site, and claims for seismic damage from the explosion were fewer and less significant than anticipated.[111]

In general, the bulk of the seismicity resulting from these three Plowshare tests seems to have come from the explosions themselves and the subsequent collapse of the test cavity, rather than from induced fault movements.

B. Unconfirmed Cases

In addition to the above confirmed cases of induced seismicity in Colorado, there have been numerous rumors of cases of induced seismicity in Colorado. This list includes both cases which seem to have been disproved by scientific studies, and cases which have not been sufficiently studied to either prove or disprove.

1. Mining-Induced Seismicity

Henderson Mine

During 1979 and 1980 the area near the Henderson mine west of Empire, Colorado, was the site of a large number of seismic events. There were nearly 100 events per day with magnitudes up to 2.5. The swarm of quakes subsided after the block-caved mine broke through the surface.[112] No studies of this swarm of quakes have been published.

2. Reservoir-Induced Seismicity

Prior to the filling of the Ridgway Reservoir there were no documented cases of reservoir-induced seismicity in Colorado. Isolated earthquakes anywhere near an artificial lake sometimes results in rumors of possible reservoir-induced seismicity. However, with the exception of Ridgway, the cases of reservoir-induced seismicity which have been studied in Colorado have not been confirmed.

Among the reservoirs that have been associated with seismic activity are: Harvey Gap (north of Silt, Colorado), Cabin Creek (south of Georgetown), and Blue Mesa (west of Gunnison).[113] Brief investigations of seismicity have also been carried out at other reservoirs.

a. Cabin Creek Reservoirs

In 1967 David M. Evans reported that Ruth Simon of the Colorado School of Mines Seismological Observatory had noticed occasional tremors originating near Georgetown, Colorado. Public Service had recently completed two reservoirs in this area. In April 1967 there was a sudden increase in the number of tremors. Twelve tremors, ranging in magnitude from 1.0 to 1.5 were recorded that month rather than the usual one or two. This burst of activity seemed to coincide with the filling of the upper reservoir and Evans suggested this might be a case for further research.[114]

In 1972 David Snow wrote that the area near the Cabin Creek Reservoirs had continued to be seismically active for the following six years, showing daily peaks of seismic activity lagging several hours behind the daily reservoir peaks resulting from the operation of the pumped storage facility.[115]

However, in 1975 Hadley investigated the possibility of reservoir-induced seismicity at the Cabin Creek Reservoirs and found no evidence of it. After reviewing the seismic history of the area, Hadley concluded that most of the recorded seismic activity was blasts related to construction activities. The pattern of the tremors was related to the daily work patterns. [116]

b. Blue Mesa Reservoir

Blue Mesa Reservoir on the Gunnison River is another reservoir listed by Simon as one where seismic activity had been observed. Simon also lists several historic quakes felt in the Mount Gunnison/Blue Mesa area prior to the building of the reservoir.[117] Warner suggested that the 3.4 magnitude Cimarron earthquake on August 14, 1983 may have been induced by the Blue Mesa Reservoir.[118] However, studies of this earthquake have not attributed it to the reservoir.[119] No microseismicity studies of the Blue Mesa Reservoir have been published.

c. Harvey Gap Reservoir

Ruth Simon listed one quake over magnitude 2 at Harvey Gap Reservoir in Garfield County, Colorado.[120] However, no other evidence exists of any potential for reservoir-induced seismicity and no detailed study has been made of it.

d. Bear Creek Reservoir

A Corps of Engineers' report written prior to the completion of the Bear Creek Reservoir states: "The installation at Bear Creek, Colorado, may be of interest, since the reservoir will inundate a known active fault, as evidenced from epicenter locations determined from small earthquakes."[121] However, microearthquake monitoring conducted over eight months in 1973 by the Colorado School of Mines for the Corps of Engineers did not record any definite earthquakes. Six seismic events recorded might be local quakes.[122]

e. Strontia Springs Reservoir

A temporary seismic network was operated at the Strontia Springs dam site from August 6 to September 11, 1977. Sixty-seven events were recorded within 45 km (27 miles). All were thought to be blasts.

From January 1, 1978 through July 12, 1978, MicroGeophysical Corporation operated a temporary seismic network of 5 seismometers near the Strontia Springs dam site to provide baseline seismicity information. This study located 32 microquakes (only 4 larger than magnitude 1.0) within 25 km (15 miles) of the dam site. After the baseline monitoring ended there were two significant local earthquakes within 30 km (18 miles) of the proposed reservoir site.

A review of the seismicity study by William Spence of the U.S. Geological Survey was critical of the short length of the baseline study. According to Spence the level of background seismicity indicated a high level of sheer stress in the area which could be a sign of a potential for induced seismicity. He recommended that additional stress and seismicity studies be made.[123]

Excavation for the dam also revealed signs of faulting and sheering under the dam itself. This raised the possibility of induced seismicity under the dam. [124]

MicroGeophysical Corporation established another seismic network around the Strontia Springs Reservoir site in early September 1982, just after the dam was completed. Monitoring continued through March 15, 1983. Filling of the reservoir began October 18, 1982. The first stage of filling ended October 24 when the reservoir reached 5925 feet in depth. This depth was held till November 6th when the second stage of filling began. Filling continued till a depth of 5995 feet was reached on November 24th. During this six month period of monitoring 91 seismic events were recorded within 20 km (12 miles). Sixty-five of those events were believed to be blasting, leaving 26 natural events. This rate was .2 quakes per day higher than the previous six months of monitoring but still consisted of less than .5 quakes per day. There seemed little correlation between filling rates or water level and the seismicity. MicroGeophysical Corporation concluded that there was no evidence of induced seismicity.[125]

f. Chatfield Reservoir

A seismic network of 5 monitoring stations was installed near Chatfield Reservoir southeast of Denver and operated for 8 months in 1973. Thirty events were recorded but all were believed to be blasts or other surface phenomena. Only 6 events might have been local earthquakes.[126]

3. Seismicity Induced by Underground Gas Storage

Leyden Mine/Gas Storage Facility

In January 1972 the U.S. Geological Survey did a preliminary seismic study of the gas storage reservoir in the Leyden coal mine near Leyden, Colorado. Public Service uses the old coal mine to store about 2.1 billion cubic feet of natural gas. The company withdraws gas from the mine during peak demand periods and injects it into the mine during periods of low demand. The purpose of the study was to look for small tremors caused by the cyclic loading and unloading of the pillars of the mine as the gas was withdrawn and injected.

For the study eight seismometers were installed over and around the mine. All eight seismometers operated for 7 days and at least three of them operated for a total of 14 days.

Two types of seismicity were recorded during this short study. The most abundant type (type I) was only recorded by the seismometers above or very near the mined area. The investigators postulated that these tremors might be "resonant vibrations" caused by the gas moving within the mine.[127]

The second type, type II, registered on all the seismometers but seemed to be located a couple of miles to the southeast of the mine. These tremors might be associated with the Golden fault or mines in that area.

The short time span of the study makes it impossible to correlate the recorded seismicity with gas injections or withdrawals. A much longer study would be necessary to determine if there was any relationship between seismicity in or near the mine and the storage of gas in the mine.[128]

IV. Induced Seismicity in Colorado Today and Tomorrow

Today the Rocky Mountain Arsenal fault seems quiet again, but seismicity is still being actively induced at Rangely, Ridgway and Paradox. New cases of induced seismicity may arise (or be discovered) and the known sites could produce larger, more damaging quakes.

New reservoirs are being proposed. Oil and gas exploration is increasing in some parts of the state. New mines are being opened and old ones reopened. While there are currently few waste disposal wells in Colorado, others might be proposed in the future. All of these activities have the potential for inducing earthquakes.

Reservoirs are usually large government projects requiring rigorous environmental assessments and public disclosures. However, private projects like oil wells and waste disposal wells have more limited licensing and siting requirements and their potential for inducing seismicity is rarely assessed in advance.

And more people are moving to Colorado. This means not only increasing pressure for more water, power, and minerals, and the generation of more waste, but also that more people will be living closer to these activities than before. Where there are more people there is greater potential for property damage and personal injuries if earthquakes are induced.

It is this potential for future induced seismicity, and the possibility of property damage and personal injuries which raise the possibility of liability.

V. Liability for Induced Seismicity in Colorado

A. Sovereign Immunity

The victims of the Rocky Mountain Arsenal quakes had very little recourse in 1967. At that time the Arsenal was operated by the Army and the country was in the midst of the Vietnam War. I have not found any case that was filed against the Army specifically to collect damages for the earthquakes nor any record of the Army paying any compensation. A class action suit, McQueary v. Laird,[129] was filed in the U.S. District Court for Colorado on June 4, 1969 seeking to enjoin the storage of chemical weapons at the Arsenal. The pleadings mentioned the recent earthquakes as a possible means of escape of the chemicals stored at the Arsenal, but the damages caused by the earthquakes were not mentioned nor was the source of the quakes. McQueary v. Laird was dismissed on the grounds of sovereign immunity and lack of jurisdiction.[130] On appeal the Tenth Circuit affirmed the dismissal.[131] While the Federal Torts Claim Act (FTCA) was not at issue in this case because the plaintiffs were seeking a declaratory judgment and an injunction, not damages, statements in the opinion of the Court of Appeals make it clear that the court felt these activities were discretionary.[132] It is likely that any attempt to file an action under FTCA for damages caused by the induced earthquakes would have also been dismissed under the "discretionary function" exception of the FTCA.[133]

Insurance was not helpful since most people did not carry earthquake insurance.[134] The Property Claims Services database shows no earthquake damage claims having been paid in the state of Colorado between 1960 and 1969.[135]

The only recourse of the frightened and injured public was politics. People wrote and called their Senators and Representatives. Challengers lambasted incumbents for not dealing with the quakes. Reports by the Army Corp of Engineers and the U.S. Geological Survey ended up on President Lyndon Johnson's desk. Political pressure stopped the injection but did nothing to compensate people for property damage. Sovereign immunity shielded the inducers of the Rocky Mountain Arsenal quakes.

1. Colorado Governmental Immunity Act

Most of the inducing activity in Colorado has been done by federal agencies (e.g. the

Army at the Arsenal and the Bureau of Reclamation at Paradox and Ridgway.) If, however, a reservoir or a waste disposal well owned and operated by the State of Colorado or one of its subdivisions, such as the Denver Water Department, were to induce seismicity it would be necessary to determine if the State of Colorado had waived sovereign immunity for the project under the Colorado Governmental Immunity Act.[136] Under this Act "sovereign immunity is waived by a public entity in an action for injuries resulting from: (f) The operation and maintenance of any public water facility, gas facility, sanitation facility, electrical facility, power facility, or swimming facility by such public entity."[137]

A reservoir may easily be considered a "public water facility" and a waste disposal well could be considered a "sanitation facility" under the Act. If so, this would allow individuals injured by seismicity induced by the project to bring a negligence claim against the "public entity."[138] However, the Act does not waive immunity for trespass or strict liability claims. [139]

2. Federal Torts Claim Act

For federal projects, the most likely approach to seeking compensation would be to file a claim under the Federal Torts Claim Act (FTCA). The FTCA waives the sovereign immunity of the United States government for personal injury or damaged property caused by the negligent act of government employees acting within the scope of their employment. [140] However, the FTCA prohibits a claim against the U.S. "based upon the exercise or performance or the failure to exercise or perform a discretionary function or duty". [141] Two factors must be examined to determine if the "discretionary function" exception applies 1) whether the challenged act involves an element of judgment or choice and 2) whether the discretion involved is of the kind the exception was designed to shield.[142] The exception only applies to acts involving judgment or choice. If a federal statute, regulation or policy specifically prescribes a course of action, the action is not discretionary. The exception is not intended to shield every kind of choice but only government actions and decisions based on considerations of public policy.[143]

Application of the discretionary function exception requires an examination of the nature of the challenged conduct.[144] Where specific behavior is required of federal employees by federal statute the discretionary function exception does not apply. However, the FTCA still requires that the law of the state where the event occurred recognize comparable private liability before there will be federal government liability.[145]

For example, the Secretary of the Interior is “authorized to construct, operate or maintain” the salinity control unit in the Paradox Valley, including the injection wells, by 43 U.S.C. §1592 but that statute provides no specifics as to how the facility is to be constructed or operated. The details, such as the precise location of wells, the depth of wells, the volumes injected, and the injection pressures, are left to the discretion of the Secretary. As discussed later, a claim can be made under Colorado tort law for damage caused by negligently inducing earthquakes. But if the claim was that the Bureau of Reclamation (a division of the U.S. Department of Interior) had negligently operated the facility at excessive injection pressures or negligently located the well, the Bureau could claim that the conduct was a “discretionary function” and that the Bureau was shielded from any potential liability by sovereign immunity. Would these siting and operation decisions be “decisions based on considerations of public policy”? The Bureau is required by 43 U.S.C. §1591 to implement the salinity control policy adopted at the Conference in the Matter of Pollution of the Interstate Waters of the Colorado River and Its Tributaries. Geology and hydrology may dictate to some extent the most efficient manner of implementing that policy, but safety and environmental protection would also have to be considered in siting and operating the wells. A court could easily find that water policy, environmental protection and public safety were matters of public policy and that the Bureau was immune from liability for the results of decisions based on these considerations.

Sovereign immunity may sometimes be extended to contractors on government projects but does not apply to private projects.

B. Colorado Statutes & Regulations

The industries known to induce seismicity, namely: mining, quarrying, oil & gas extraction, geothermal energy extraction, reservoir impoundment, and deep well waste disposal, are regulated by state, local and federal authorities to varying degrees. No Colorado state statutes or regulations explicitly prohibit inducing seismicity or seek to control it. However, some statutes and regulations could possibly be used for that purpose.

For example, while the statutes and regulations related to reservoirs are primarily aimed at avoiding flood damage,[146] the regulations do require that the geotechnical report submitted to the state engineer include information on the geology of the area, and Class I dams and some Class II dams must submit information on faults and seismicity of the area. [147] While the requirement is somewhat vague and does not explicitly require trenching or seismic monitoring during the site investigation, it could be interpreted in that manner. Since there is often a relationship between the amount of water in a reservoir and the seismicity activity associated with it, the state engineer's power to determine the amount of water that is “safe to impound in the reservoir”[148] could be used to regulate seismicity by regulating the water level.

While the regulations on geothermal leases in Colorado do not require seismic monitoring, the regulations do authorize the state engineer to order the installation of "meters, gauges or other measuring devices" [149] and authorize the state engineer to "require corrections in a manner or method" of any condition in a geothermal lease threatening "the public health and safety, and the environment."[150] These regulations could be used to limit the potential for damaging induced earthquakes.

The Colorado Oil and Gas Commission regulates all aspects of oil and gas exploration and production including injection for secondary recovery, and disposal of salt water and oil field wastes.[151] The Commission is also empowered to enforce the provisions of the federal Underground Injection Control Program for Class II injection wells[152], which contains some siting and monitoring requirements which may be applicable to induced seismicity. Operators of underground disposal activities must seek authorization from the Director.[153] The application must contain anticipated injection pressures, but the Director sets maximum injection pressure in the authorization.[154] The Director's power to set maximum injection pressures could be used to limit seismicity. C.R.S. §34-60-106(11) also requires the Commission to promulgate rules and regulations to "protect the health, safety, and welfare of the general public in the drilling, completion and operation of oil and gas wells and production facilities." This would authorize the Commission to create regulations intended to mitigate induced seismicity.

Violations of the rules and regulations of the Oil and Gas Commission constitute negligence per se if the injured party is within the class of persons intended to benefit from the regulations.[155] State statute establishes a private right to sue for injury resulting from failure to comply with statutes and regulations related to the oil and gas industry.[156]

The Colorado Surface Coal Mining Reclamation Act also contains some provisions which could be used to enforce siting and operating requirements to limit potential induced seismicity. For example, C.R.S. 34-33-126 allows a person who may be affected, and appropriate government agencies, to petition the Mined Land Reclamation Board to designate an area as unsuitable for all or certain types of surface coal mining operations if the board determines such operations could substantially endanger life and property, and C.R.S. 34-33-121, related to surface effects of underground coal mining, requires an operator to adopt measures to maximize mine stability and protect off-site areas from damage which may result from underground coal mining.

Ideally, induced seismicity should be considered in site selection and monitoring of these industries, and control or mitigation should be required if seismicity occurs. Appropriate agencies should be empowered to enforce these provisions, and compensation should be available to those injured.

Currently, however, a person who suffers property damage from induced seismicity in Colorado must depend primarily on the law of common law torts for compensation and abatement of future injuries.

C. Colorado Common Law Torts

If quakes similar to the Arsenal quakes were triggered by a private individual or a corporation in Colorado today, the inducer could be liable under several tort theories. I will consider the applicability of trespass, negligence, private nuisance and strict liability.

1. Trespass

In Colorado, trespass is the physical invasion of property without the owner's permission. Trespass requires only the intent to do the act constituting, or inevitably causing, the intrusion.

No negligence, or intent to cause harm, is necessary. Colorado does not differentiate between "direct" and "indirect" injuries in trespass.[157] A person who sets in motion a force which, in the usual course of events, will damage another's property commits trespass when that force enters that property, and thus that person becomes liable for any resulting damages.[158]

In Cobai v. Young, the Colorado Court of Appeals applied this rule to an "improvement" constructed by the landowner which "propagates a damaging force."[159] In this case the "improvement" was a house with a roof constructed in a way that caused snow to slide off and strike the side of the neighbor's house in a forceful manner. Each time the snow slid off the defendant's house it struck the plaintiff's house with a thunderous noise and jarred the house. This jarring had caused some non-structural damage. The court believed the continuing assault was likely to cause structural damage in the future. The Court of Appeals agreed with the trial court's assessment that the defendants controlled "an instrumentality which sets in motion a force which in the usual course of events [would] damage" the plaintiff's property. The trial court had ruled this was a continuing trespass, awarded plaintiffs nominal damages of $1 and granted an injunction. The Court of Appeals affirmed.[160]

The Court of Appeals also upheld the granting of an injunction in Docheff v. City of Broomfield, where a new development was discharging water over the plaintiff's land in a concentrated flow which was causing damage. The court held that the discharge of water is enjoinable as a continuing trespass if the water is sent down in a manner or quantity greater than the natural flow.[161]

In Burt v. Beautiful Savior Lutheran Church, the Court of Appeals upheld the award of damages for trespass caused by leakage of water onto the plaintiffs' property from a drainpipe constructed by the defendant.[162] The court also rejected the defendant's argument that some of the defendants should not recover because they had moved to their house after the trespass had begun.[163]

Vibrations or concussions can also be a trespass in Colorado whether applied directly to the plaintiff's property or as a “force set in motion” which eventually reaches the plaintiff's property. In Pueblo v. Mace [164] the Colorado Supreme Court held that vibrations of a viaduct built flush against the plaintiff's building constituted a continuing trespass. In numerous cases in other jurisdictions concussions caused by blasting were determined to be trespasses.[165] Vibrations from heavy equipment have also been deemed trespasses in other jurisdictions.[166] Seismicity caused by fault movements triggered by human enterprises is just another type of vibration set in motion by human intervention and the same rules should apply.

The force released or set in motion by the inducing activity is usually the result of natural tectonic strain accumulated in the earth. But the precipitation which deposited the snow on Young's roof and the gravity of the earth which accelerated it off the roof and slammed it into Cobai's house, are also natural phenomenon. By creating the structure which released or redirected the natural forces so that they entered another's property, Young committed a trespass. The same is true of the rainwater and its damaging forces in Burt and Docheff, and the same would be true of an enterprise inducing the vibrations of an earthquake to travel through the ground into another's property and cause damage. Thus, a Colorado court could properly conclude (in an appropriate case) that induced seismicity was a trespass and that the inducer was liable for any injuries. If the court found a continuing trespass, and a likelihood of future injury, the court could also enjoin the inducing activity.[167]

2. Negligence

For plaintiffs to recover for damages under a negligence theory in Colorado, they must show that the defendants breached a duty of care owed to the plaintiffs and that the breach resulted in the plaintiffs' damages.[168] Where damage is foreseeable there is a legal duty to avoid it.[169] A landowner owes a duty of care to prevent injury to people and property outside his land caused by artificial conditions placed on his land either by himself or a lessee or contractor.[170] The existence and scope of that duty is a question of law.[171]

In Moore v. Standard Paint & Glass Co, the Colorado Supreme Court ruled that a landowner had "an affirmative duty not to permit its land to remain in an altered state if such altered state created a condition the natural and foreseeable result of which would result in injury to the adjoining property."[172]

Was it foreseeable that the injection well at the Rocky Mountain Arsenal would cause earthquakes in the 1960's? No. Very little was known about induced seismicity in the 1950's and 1960's. However, in the 30+ years since the Arsenal quakes began much has been learned about induced earthquakes, and much more is known about when and where they can be expected. While it is still not possible to precisely predict when and where they will occur, "foreseeability" does not require clairvoyance. If you drive through a heavily populated area at high speed, a crash that injures someone is a foreseeable consequence, even though it may be impossible to predict where or when it will occur, and you may be lucky enough not to hit anyone.

Now that it is known that certain activities such as injecting fluids into deep wells or impounding water in reservoirs can cause earthquakes, entities engaged in these activities are under a duty to investigate the magnitude of the risk involved with their project and ways to control that risk. Failure to investigate is a form of negligence itself.[173] If the information is obtainable with a reasonable amount of investigation, a court could decide that the inducer "should have known" of the risk[174] and taken steps to mitigate it. "Willful ignorance of a fact is equivalent to actual knowledge of the fact."[175]

In Calvaresi v. National Development Company, Inc.,[176] a developer purchased agricultural land over an abandoned coal mine. At the time of the purchase there was visible evidence of the mine's existence. The developer removed all signs of mining, had the land rezoned and a subdivision platted and then sold lots to potential homeowners. Purchasers later sued the developer when it was determined that the mine posed a substantial subsidence risk and the county revoked building permits in the subdivision. The jury determined that the developer knew about the mine and was negligent in failing to investigate the possibility of subsidence and in failing to disclose the existence of the mine to purchasers.

In Public Service Co. v. Williams,[177] a young man was crushed by a landslide caused by the saturation of a hillside by water leaking from a pipeline. The jury found that the owner of the pipeline, Public Service Co., had negligently maintained the pipeline and created the landslide danger of which it "knew or in the exercise of reasonable care and investigation should have ascertained."

The standard of care required to avoid negligence is that of a "reasonably prudent person under the circumstances." Thus, for example, a well operator whose well triggers an earthquake would be negligent if she "failed to do an act which a reasonably prudent operator would do, or did an act which a reasonably prudent operator would not do, when faced with a foreseeable risk of damaging tremors."

The care required is commensurate with the all circumstances, including the special knowledge and skill of the parties. A person or organization having special expertise is supposed to use that expertise to avoid injury.[178] People are presumed to have special knowledge and skill in the field that they make their business,[179] and while compliance with industry standards and government regulations is relevant to establishing due care, it is not conclusive.[180] The fact that industry standards or custom do not require certain precautions is not sufficient to avoid liability if the organization knows or should know of a risk that a reasonable prudent person would avoid.[181] Negligence can even be found when all applicable laws and regulations are satisfied if prudence dictates further measures.

Thus a company engaged in an industry that can induce earthquakes, such as reservoir impoundment, quarrying, and oil and gas extraction, has a legal obligation to be familiar with the risks inherent in their trade, including induced seismicity. Ignorance of such risks, whether intentional or simply negligent will not protect them from liability. Such a company is also obligated to take reasonable steps to mitigate the risk of induced seismicity to avoid injury to other people or property. Such steps include proper site investigations and seismic monitoring. Even though Colorado and federal laws and regulations may not currently require that the potential for induced seismicity be considered in site planning or monitoring, these steps maybe considered due care by a Colorado court considering an induced seismicity negligence claim.

The greater the risk of injury, the greater the care required by Colorado law.[182] Colorado courts have ruled that certain activities such as the transmission of electricity and propane gas are inherently dangerous businesses with a high degree of risk requiring “the highest degree of care which skill and foresight can attain.”[183] This higher degree of care is required only when “1) the activity is inherently dangerous; 2) the defendant possesses expertise in dealing with the activity; and 3) the general public would not be able to recognize or guard against the danger."[184] Certainly the general public is unable to recognize the danger of induced seismicity or guard against it. For the most part the general public is unaware there is such a thing as induced seismicity and even if they were, guarding against the possibility would be difficult and expensive, and in some cases impossible. Companies entering the inducing business fields should have the expertise necessary to deal with the risk of induced seismicity because it is one inherent in their field. To be "inherently dangerous an activity need not be extremely or even highly dangerous, but must present a foreseeable and significant risk of harm to others if not carefully carried out."[185] But it must be a situation "where all minds concur that the defendant is engaged in an activity that possess a high risk of injury to others..."[186] The damages which have occurred in other induced earthquake situations testify to the significance and foreseeability of the risk of injury. However, whether a court would determine that "all minds concur" that activities which induce earthquakes are inherently dangerous is questionable.

Regardless of how the courts label the degree of care that earthquake-inducing activities warrant, the surrounding circumstances must be considered when determining the precautions required. Those surrounding circumstances include the local population density, the probability of inducing seismicity, and the potential for damage.

a) Res Ipsa Loquitur

The doctrine of res ipsa loquitur is a rule of evidence creating a rebuttable presumption that the defendant's negligence caused the injury. Before the rule will be applied the plaintiff must present evidence that 1) the injury is one which ordinarily does not occur without negligence; 2) responsible causes other than the defendant's negligence have been sufficiently eliminated; and 3) the negligence is within the scope of the defendant's duty to the plaintiff.[187] Courts usually also require that the mechanism or instrument causing the injury be under the exclusive control of the defendant.[188] In general, the circumstances must indicate that the defendant has superior knowledge or opportunity to explain the event.[189]

Could the doctrine of res ipsa loquitur be applied to an induced earthquake situation? The activities which can trigger earthquakes such as geothermal wells, waste disposal wells, oil and gas wells and reservoirs and mines, are usually under the exclusive control of the operator and/or owner. Access to information on injection rates and pressures, and extraction rates are usually limited to the owners and operators of the project. But to claim that the operators have true control over the tectonic processes themselves would be going too far.

As discussed previously, landowners and lessees do have a duty to prevent injury to those outside their land by the activities on their land. Whether other responsible causes can be eliminated will depend upon the circumstances. But can we say that an induced earthquake is the kind of event which does not ordinarily occur in the absence of negligence? Certainly microseismicity can be triggered without any negligence. Is the occurrence of a <u>damaging</u> induced earthquake sufficient to imply there was negligence? At the current state of the science, I think the answer must be “no”. Thus we must conclude it would not be appropriate to apply res ipsa loquitur to induced seismicity at this time.[190]

b) Professional Liability

> "Cases involving ... professional malpractice are species of the phylum denominated `negligence' cases."[191]

A professional, such as a seismologist called upon to do an induced seismicity risk assessment, has a duty to perform with the care that a reasonable and prudent seismologist with like education and experience would use under similar circumstances. While no government regulations or written industry standards dictate minimum requirements for such assessments, scientific literature provides some basic guidelines.[192]

But to whom does the seismologist owe this duty of care? A seismologist who undertakes a seismic hazard study for a company either as an independent contractor or an employee has a duty to the employer to perform that study with the requisite care and report to her employer. If the seismologist is restrained from making a thorough investigation by her employer, then that employer accepts the risk of liability.

For an independent scientist who receives permission to use the company's data and equipment to do a study but is not affiliated with the company in anyway, the nature of the duty will depend upon the extent of the undertaking and whether the company may have been induced to rely on that scientist's assessment and thus have forgone making its own study, or hiring other experts.[193]

Generally, there is no duty to prevent a third person from harming another, absent a special relation between the actor and the wrongdoer or between the actor and the victim.[194] Thus a seismologist who has fulfilled her duty to her employer, client, or any others induced to rely on her assessment probably has no legal duty to inform the general public.[195] The doctrine of respondeat superior imputes fault to the employer for acts of the employee but not the reverse. An employee is not vicariously liable for the torts of the employer.[196]

3. Private Nuisance

A private nuisance is a non-trespassory interference with another's use and enjoyment of his property. The plaintiff must show that the defendant's interference was unreasonable and substantial.[197] It is not enough that the defendant's actions offended the plaintiff's particular aesthetic sense.[198] The interference must be substantial enough to be offensive, inconvenient, or annoying to a normal person in the community.[199]

Both business and residential uses may be enjoined if they constitute a nuisance to an adjoining property owner or resident, regardless of compliance with zoning ordinances or regulations. [200] Colorado does not recognize the defense of “coming to a nuisance.” The owner of land does not have the right to maintain a nuisance merely because he constructed it before someone else moved there.[201]

Liability for a private nuisance is based on one of three types of conduct: 1) an intentional interference; 2) a negligent interference; or 3) conduct so dangerous to life or property, and so abnormal or out-of-place in its surroundings, as to invoke strict liability.[202]

Induced earthquakes causing physical damage would certainly substantially interfere with the use and enjoyment of property.[203] Low magnitude induced seismicity which does not cause any actual physical damage could also constitute a private nuisance in Colorado if it is sufficiently annoying or inconvenient. Vibrations can cause various physical and psychological reactions.[204] Low level seismicity can be especially annoying if felt at frequent intervals, as occurs in induced earthquake swarms, and can raise fears of damaging quakes to come.

Courts in other jurisdictions have ruled that vibrations caused by heavy equipment, quarrying and mining, and other uses of explosives were private nuisances.[205]

4. Strict Liability

Colorado courts have applied strict liability for "ultra hazardous activities" or "abnormally dangerous activities" under very limited circumstances. In the past it was applied to fires caused by locomotives, impoundment of reservoirs, and the use of explosives.

In Union Pacific Railroad v. DeBusk,[206] the Colorado Supreme Court stated that the statute[207] which made railroads strictly liable for fire set by their engines was not a change in law but merely declarative of the common law of England as adopted by the state.[208] But in 1916 the Colorado Supreme Court ruled that the statute "was intended to cover the whole law upon the subject" and thus superseded the common law.[209]

Formerly, the builders and owners of dams and reservoirs were held strictly liable for injuries resulting from flooding. [210] Here, too, the courts stated that the original statute [211] was based on common law.[212] However, the "tort reform" legislation of 1986 changed this. The current statute provides that owners or operators of reservoirs are only liable for injuries caused by water escaping from their reservoir due to overflow or failure of the reservoir if the escape was due to negligence.[213]

The Colorado Supreme Court has consistently applied strict liability to damages resulting from blasting.[214] However, recovery for damages caused by an explosion of stored dynamite requires proof of negligence in this state.[215]

In City of Northglenn v. Chevron, Judge Carrigan of the U.S. District Court for

Colorado[216] surmised that Colorado would extend strict liability to the storage of gasoline in residential areas. His arguments were: 1) that Colorado had denied liability for storage of dynamite in an earlier case (Liber v. Flor) because it had occurred in a sparsely populated, rural county with a long mining history, and 2) that in the intervening years there had been substantial development of strict liability law. He predicted that the Colorado Supreme Court would be persuaded by Sections 519 and 520 of the Restatement (Second) of Torts and Yukon Equipment, Inc. v. Fireman's Fund Insurance Co.[217]

However, Colorado courts have refused to apply strict liability to the transfer of gasoline,[218] the transfer of natural gas[219], and the disposal of caustic chemicals.[220]

Thus, the use of explosives is the only activity which currently triggers common law strict liability in Colorado. While the citation of Watson v. Mississippi and section 519 of the Restatement (Second) of Torts with approval in Garden of the Gods Village[221] suggests the possibility of extending strict liability to other activities, the refusal of the court to apply it in these other situations suggests a general reluctance on the part of the Colorado courts to expand the use of strict liability. While strict liability can be appropriately applied to induced earthquakes under the rule of Rylands v. Fletcher and the "ultrahazardous activities" and "abnormally dangerous activities" standards of the first and second Restatements of Torts[222], this reluctance to expand its use in Colorado leads me to doubt that Colorado courts would apply strict liability to induced earthquakes.

Conclusion

The Rocky Mountain Arsenal near Denver, Colorado was the site of some the most damaging induced earthquakes in the United States. Colorado has had other cases of induced seismicity which caused little or no damage. While the Arsenal quakes have ceased, there are currently at least three active cases of induced seismicity in Colorado. Additional cases may be initiated or discovered in the future and currently inducing sites could trigger larger earthquakes. This potential for stronger quakes combined with Colorado's increasing population, makes property damage and personal injury from induced earthquakes more likely in the future unless adequate project assessments are made and precautions taken. The steps taken at Paradox and Ridgway provide models for the assessment and monitoring of potential induced seismicity cases.

Some Colorado statutes and regulations may be useful in encouraging the avoidance of damaging induced seismicity, but the primary source for compensation for injuries would be common law torts. If reasonably prudent precautions are not taken in the siting and operation of potential inducing activities, then those injured may seek compensation under negligence or nuisance law in Colorado. Trespass may also be grounds for compensation for damage from induced earthquakes but strict liability based on the concept of “abnormally dangerous activities” is unlikely to be applied in Colorado.

Appendix

Definitions:

Coal bump: A violent failure of rock within a coal mine that does not cause damage to the mine itself.

Earthquake: A sudden motion or trembling in the earth caused by the abrupt release of slowly accumulated strain.

Earthquake swarm: A series of minor earthquakes, none of which may be identified as the main shock.

Epicenter: The point on the earth's surface directly above the focus of an earthquake.

Fault: A fracture or zone in a rock along which there has been displacement of the sides relative to one another.

Focus of an earthquake: The initial underground rupture point of an earthquake.

Hypocenter: The focus of an earthquake.

Induced earthquake: An earthquake, which, through human intervention, occurs at a different time, or place, or with a greater magnitude or intensity than a natural quake.

Intensity: A measure of the effects of earthquake at a particular place.

Magnitude: A measure of the strength of an earthquake, as determined by seismographic observation.

Microseismicity: Small earthquakes.

Normal stress: The intensity of stress across a fault.

Pore Pressure: The fluid pressure in the pores of rocks.

Rock burst: A violent failure of rock in a mine that causes damage to the excavation.

Seismic: Pertaining to an earthquake or earth vibration, including those artificially induced.

Tectonic: Related to the natural deformation of the earth's crust.

Triggered earthquakes: Seismic activity stimulated by natural or unnatural causes.

Water Flooding: Injection of water into an oil reservoir to increase production.

Partially Derived from: ***Dictionary of Geological Terms*** (Robert L. Bates & Julia A. Jackson, eds., 3rd ed. 1984, Anchor Press).

Notes

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4. Craig Nicholson and Robert L. Wesson, Triggered Earthquakes and Deep Well Activities 139 **Pure & Applied Geophysics** 561 (1992).

5. Scott D. Davis and Cliff Frohlich, Did (or Will) Fluid Injection Cause Earthquakes - Criteria for a Rational Assessment 64 **Seismological Res. Letters** 207 (1993).

6. Maximum magnitude 3.0 reached in December 1983; no damage. Craig Nicholson and Robert L. Wesson, Triggered Earthquakes and Deep Well Activities 139 **Pure & Applied Geophysics** 561 (1992).

7. Maximum magnitude 3.6 reached July 1987; no damage reported. Craig Nicholson and Robert L. Wesson, Triggered Earthquakes and Deep Well Activities, 139 Pure & Applied Geophysics 561 (1992).

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Near Kermit, Texas: Maximum magnitude 3.4 reached August 14, 1966; Max. Intensity VI; Damages reported in Kermit included broken windows and dishes, cracked walls and broken jars in grocery stores. **Scott D. Davis, et al, A Compendium of Earthquake Activity in Texas** (1989).

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10. Maximum magnitude was .8, reached in November of 1973; The tremor was not felt. Craig Nicholson and Robert L. Wesson, Triggered Earthquakes and Deep Well Activities 139 **Pure & Applied Geophysics** 561 (1992).

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The Fall City area experienced its largest quake on July 20, 1991. The magnitude was 3.6. Pleasanton's largest quake was 3.9 and occurred March 3, 1984. Damages were minor, including cracked plaster and widening of concrete cracks. **Scott D. Davis, et al, A Compendium of Earthquake Activity in Texas** (1989).

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75. Jon Ake, et al, Microseismicity by Fluid Injection in the Paradox Valley of Southwestern Colorado, 63 **Seismological Research Letters** 19 (Jan-Mar 1992).

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77. Jon P. Ake, personal communication, Sept. 1995.

78. Jon Ake, et al, Microseismicity by Fluid Injection in the Paradox Valley of Southwestern Colorado, 63 **Seismological Research Letters** 19 (Jan-Mar 1992).

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83. Ute R. Vetter, et al, Seismicity Near Ridgway Dam, Southwestern Colorado, 66 **Seismological Res. Letters** 48 (1995); **Richard A. Martin, Ridgway Seismographic Network: Preliminary Results of Network Operation for the Period June 4, 1985 through April 30, 1987, Seismotectonic Report No. 87-1**, Seismotectonic Section, U.S. Bureau of Reclamation 2 (June 1987)

84. Jon P. Ake, et al, Possible Reservoir-Induced Seismicity (RIS) Associated with Ridgway Dam and Reservoir, 63 **Seismological Res. Letters**, 19-20 (1992).

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87. **Issue Paper from Dam Safety Office: Continued Funding of Micro Seismic Networks at Jackson Lake Dam and Ridgway Dam**, U.S. Bureau of Reclamation 1 (January 31, 1994).

88. Ute R. Vetter, Seismicity Near Ridgway Dam, Southwestern Colorado, 66 **Seismol. Res. Letters** 48 (1995) and **William Lettis, Draft Report, Seismotectonic Evaluation, Colorado River Storage Project & Smith Fork Project, West-Central Colorado**, U.S. Bureau of Reclamation (October 1995).

89. **Issue Paper from Dam Safety Office: Continued Funding of Micro Seismic Networks at Jackson Lake Dam and Ridgway Dam**, U.S. Bureau of Reclamation 2 (January 31, 1994).

90. Memorandum from Rick L. Gold acting for Charles Calhoun, Upper Colorado Regional Office, Bureau of Reclamation, U.S. Dept. of Interior, Salt Lake City, Utah (June 2, 1994).

91. Ruth B. Simon, Seismicity, **Geologic Atlas of the Rocky Mountain Region**, 51 (W.W. Mallory, et al, eds. 1972).

92. **Frank W. Osterwald, et al, Instrumentation Studies of Earth Tremors Related to Geology and to Mining at the Somerset Coal Mine, Colorado**, U.S. Geological Survey Professional Paper #762 9 (1972)

93. id. at 1.

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95. id at 18.

96. **C. Richard Dunrud, Some Engineering Geologic Factors Controlling Coal Mine Subsidence in Utah and Colorado**, U.S. Geological Survey Professional Paper #969, 27-29 (1976)

97. John Horgan, Peaceful Nuclear Explosions, 275 Sci. Am. 14, 16 (June 1996). During the first two Rio Blanco production tests in November 1973 and February 1974 the only radioactive elements detected were tritium and krypton (as gas or triturated water). However, there was no communication between the upper and lower chimneys. A well was drilled into the bottom chimney. During a short flow test from the bottom chimney in December 1974, Tritium, Krypton 85, Cesium 137 and Strontium 90 were detected. **Project Rio Blanco**, Colorado Department of Public Health and Environment, Radiation Control Division (http://www.state.co.us/ gov_dir/cdphe_dir/rc/en_riobl.htm) (1996).

98. **Richard Navarro, Rio Blanco Seismic Effects**, U.S. Geologic Survey Open-File Report (1974); **Earthquake Potential** supra note 44, at 107.

99. **Earthquake Potential** supra note 44, at 107.

100. id.

101. **Project Rulison**, Colorado Department of Public Health and Environment, Radiation Control Division (http://www.state.co.us/ gov_dir/cdphe_dir/rc/en_rulison.htm) (1996).

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103. **Earthquake Potential** supra note 44 at 107; **Richard Navarro, Kenneth W. King, et al, Rio Blanco Seismic Effects**, U.S. Geol. Survey Open-File Report, 2 (1974)

104. **Richard Navarro, et al, Rio Blanco Seismic Effects**, U.S. Geol. Survey Open-File Report, 4-5 (1974).

105. **Earthquake Potential**, supra note 44 at 108 (1981).

106. **Richard Navarro, et al, Rio Blanco Seismic Effects**, U.S. Geol. Survey Open-File Report, 37 (1974).

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108. id at 40.

109. id at 37.

110. id at 46.

111. Project Rio Blanco, Colorado Department of Public Health and Environment, Radiation Control Division (http:// www.state.co.us/gov_dir/cdphe_dir/rc/en_riobl.htm] (1996).

112. **Micro Geophysical Corp., Strontia Springs Reservoir Seismicity Report, Final Report**, 23-24 (Sept. 1983); David Butler, Seismic Hazard Estimation at the Two Forks Dam Site Near Denver, Colorado, **Geotechnical Investigations in Geophysics**, 107 (1990); and **Dames & Moore, Geological and Seismologic Investigations for Rocky Flats Plant for U.S. Department of Energy: Final Report**, Appendix G (1981).

113. **Earthquake Potential** supra note 44 at 108; Ruth B. Simon, Seismicity of Colorado--Consistency with Those of the Historical Record, 165 **Science** 897, 898 (1969); Ruth B. Simon, Seismicity, **Geologic Atlas of the Rocky Mountain Region,** 51 (W.W. Mallory et al, eds. 1972).

114. David M. Evans, Man-made Earthquake--A Progress Report, **Geotimes** 19 (July Aug. 1967).

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116. **L.M. Hadley, Seismicity of Colorado --Vicinity of Cabin Creek Pumped-Storage Hydroelectric Plant** (1975) (Unpublished Master's Thesis #T-1713, Colorado School of Mines).

117. Ruth B. Simon, Seismicity of Colorado--Consistency with Those of the Historical Record, 165 **Science** 897 (1969); Ruth B. Simon, Seismicity, **Geologic Atlas of the Rocky Mountain Region**, (W.W. Mallory et al, eds. (1972).

118. L.A. Warner, Strain Rates, Stress Distribution and Seismic Potential in Central Colorado, **Contributions to Colorado Seismicity and Tectonics: A 1986 Update**, Co. Geol Survey Sp. Pub. #28, 30 (W. P. Rogers & R. M. Kirkham, ed., 1986).

119. Ivan G. Wong & James R. Humphrey, The 14 August 1983 Cimarron, Colorado Earthquake and the Cimarron Fault, 23 **Mountain Geologist** 14 (Jan. 1986).

120. Ruth B. Simon, Seismicity of Colorado--Consistency with Those of the Historical Record, 165 **Science** 897 (1969); Ruth B. Simon, Seismicity, **Geologic Atlas of the Rocky Mountain Region**, (W.W. Mallory et al, eds. (1972).

121. **Stanley J. Johnson & Ellis L. Krinitzsky, Reservoirs and Induced Seismicity at Corps of Engineers Projects**, Corps of Engineers Misc. Papers S-77-3, at 8 (1977).

122. See **MicroGeophysical Corp., Seismological Investigations of the South Platte River Canyon: Foothills Treatment Plant** 41(Sept. 1977); **MicroGeophysical Corp., Strontia Springs Reservoir Seismicity Report: Sept. 13, 1982-March 15,1983** (1983); and **Earthquake Potential** supra note 44 at 119.

123. **William Spence, Review of the Denver Water Department Induced Seismicity Program at Strontia Springs, Colorado**, U.S. Geological Survey Open File Report 82-64 (1982).

124. Nathan R. Hopton & Farrukh M. Mazhar, Geotechnical Aspects of Strontia Springs Arch Dam, **HydroPower: Recent Developments**, (ed. A. Zagars, 1985).

125. **MicroGeophysical Corp., Strontia Springs Reservoir Seismicity Report, Final Report**, (Sept. 1983).

126. **MicroGeophysical Corp., Seismological Investigations of the South Platte River Canyon: Foothills Treatment Plant** 41 (Sept. 1977); **MicroGeophysical Corp., Strontia Springs Reservoir Seismicity Report: Sept. 13, 1982-March 15,1983 (1983)**; **Earthquake Potential** supra note 44, at 119.

127. Scientists from MicroGeophysics Corp. criticized this study: "However, the interpretation

of the results of this paper is open to question. The 'type I events' they detect are most consistent with either cars, airplanes, or other cultural interferences. Similar events are detected by most seismic networks and are usually disregarded." **MicroGeophysics Corp., Seismological Investigations of the South Platte River Canyon: Foothills Treatment Plant**, 41-44 (Sept. 1977). While the Leyden mine study is far from conclusive this criticism ignores the statements in the paper that the investigators recorded "numerous tremors caused by aircraft and railroad trains" (The Denver and Rio Grande Western line runs just north of the mine.) and that "the records from these sources are quite distinct and cannot be confused with the records of the two types of local seismic tremors." **Frank W. Osterwald, et al, Preliminary Investigation of Seismic Tremors in the General Area of the Leyden Coal Mine Gas-Storage Reservoir, Colorado**, U.S. Geological Survey Open File Report #1760 at 11 (1973) Furthermore, vibrations from cars are more likely to have been recorded by the seismometers near Colorado Highways 93 and 72. However, these seismometers did not pick up the Type I tremors. The Type I tremors were only recorded by seismometers over the mine which is a rural area where there are only a few dirt roads. id. at 14.

128. **Frank W. Osterwald, et al, Preliminary Investigation of Seismic Tremors in the General Area of the Leyden Coal Mine Gas-Storage Reservoir, Colorado**, U.S. Geological Survey Open File Report #1760 (1973) and **Earthquake Potential** supra note 44 at 118.

129. Complaint, McQueary v. Laird, No. C-1461, (D. Colorado, filed June 4, 1969) (unpublished, available at the National Archives, Denver Federal Center, Lakewood, Colo.) 449 F.2d 608 (1971). One of the plaintiffs was Byron Johnson, a U.S. Representative from Colorado. Two of attorneys for the plaintiffs were Democrats Richard Lamm, future governor of Colorado, and Gary Hart, future U.S. Senator for Colorado. This information, together with the fact that no attempt was made to respond to the motion to dismiss before the deadline, suggests that the case may have been filed for political reasons.

130. Order filed September 11, 1970, McQueary v. Laird, No. C-1461, (D. Colorado, cased filed June 4, 1969) (unpublished; available at the National Archives, Denver Federal Center, Lakewood, Colo.) 449 F. 608 (1971). In support of the Motion to Dismiss, the Defendants submitted several affidavits including one by Albert H. Rock, Chief of the Safety Office at Rocky Mountain Arsenal. In his affidavit, Mr. Rock stated: "as regards earthquake activity during the period of years 1942-1969 there has been no earth tremors or movements which have caused any damage at Rocky Mountain Arsenal." This sworn statement is contrary to newspaper accounts published in 1967. See sources at notes 47-53.

131. McQueary v. Laird, 449 F.2d 608 (10th Cir. 1971) Plaintiffs' attorneys also tried to raise the National Environmental Protection Act as a basis for jurisdiction during oral arguments on appeal. The Court of Appeals ruled that the needs of national security prohibited NEPA from forming a basis for jurisdiction. id. at 612.

132. "These challenges raised by the appellants in this case fall within that narrow band of matters wholly committed to official discretion...." McQueary v. Laird at 612

133. 28 U.S. Code §2680(a). A two prong analysis determines whether the discretionary function exception applies. First the act must involve an element of judgment, choice or discretion. It must not be contrary to a specific statute or regulation. Second, the discretion must be based on considerations of public policy. Daigle v. Shell Oil Co., 972 F.2d 1528, 1537-1543 (10th Cir. 1992).

134. "A local insurance agent said that no damage reports had been received at this office but he explained that less than one percent of Boulder homeowners carry earthquake insurance which requires a separate endorsement on a homeowner's policy." **Boulder Daily Camera**, Nov. 27, 1967 at 2.

135. Letter from Nancy Ritchy, Western Insurance Information Service, to author, July 18, 1991 (on file with author).

136. Colo. Rev. Stat. §24-10-101 et seq.

137. Colo. Rev. Stat. §24-10-106(f)

138. Another possibility would be a claim under Article 2 Section 15 of the Colorado Constitution which prohibits taking or damaging property without just compensation. The Governmental Immunity Act does not apply to inverse condemnation actions. Jorgenson v. City of Aurora, 767 P.2d 756 (Colo. App. 1988).

139. Colo. Rev. Stat. §24-10-106(4).

140. 28 U.S.C. §1346 (b).

141. 28 U.S.C. §2680 (a).

142. Berkovitz v. U.S., 486 U.S. 531 (1988).

143. id.

144. Ayala v. U.S., 980 F.2d 1342 (10th Cir. 1992) (Ayala V).

145. Ayala v. U.S., 49 F.3d 607 (10th Cir. 1995) (Ayala VII).

146. Colo. Rev. Stat. §87-37-101 et seq and 2 Colo. Code. Reg. §402-1.

147. 2 Colo. Code Rev. §402-1 5.A. (6)(a).

148. Colo. Rev. Stat. §37-87-107.

149. 2 Colo. Code Rev. §402-10 Rule 5.10.

150. 2 Colo. Code Rev. §402-10 Rule 5.12.

151. Colo. Rev. Stat. §34-60-106.

152. 42 U.S.C. §300f et seq and the regulations at 40 C.F.R. §144.26. The UICP regulations include information, siting and operating requirements that could be used to limit some activity that might induce earthquakes. However, the regulations were primarily written to prevent injected wastes from entering sources of drinking water. A well that meets all the requirements of the UICP could still induce damaging earthquakes.

153. 2 Colo. Code Reg. §404-1 Rule 325 (1997).

154. 2 Colo. Code Reg. §404-1 Rule 325(a)(7) (1997).

155. Gerrity Oil & Nat. Gas Corp. v. Bob Magnes, 923 P.2d 261 (Colo. App. 1995) cert. granted 9/9/96.

156. Colo. Rev. Stat. §34-60-114.

157. Burt v. Beautiful Savior Lutheran Church, 809 P.2d 1064, 1067 (Colo. App. 1990) cert. den. (May 6, 1991) This case essentially overrules the misreading of Colorado trespass law by the U.S. Tenth Circuit Court of Appeals in Haas v. Levin, 635 F.2d 1384 (1980). In Haas v. Levin, the Court of Appeals ruled that dust and dirt blowing from an improperly tilled field was an "indirect invasion" and thus not a trespass. The federal court made no reference to Colorado trespass cases, but rather based this decision purely a general tort reference (Harper & James, The Law of Torts) and its discussion of an old English case.

158. Burt v. Beautiful Savior Lutheran Church, 809 P.2d 1064, (Colo. App. 1990) cert. den. (May 6, 1991) (discharge of water onto neighbor's property); Cobai v. Young, 679 P.2d 121 (Colo. App. 1984)(snow sliding off roof and hitting neighbor's house); Docheff V. City of Broomfield, 623 P.2d 69 (Colo. App. 1980) cert. den. (Feb. 2, 1981) (discharge of water onto neighbor's property); Miller v. Carnation Co., 564 P.2d 127 (Colo. App. 1977) cert. den. (Dec. 24, 1973) (invasion by flies bread in chicken manure).

159. Cobai v. Young, 679 P.2d 121, 123 (Colo. App. 1984).

160. id. The houses were located in Crested Butte, Colorado, which receives 300-500 feet of snow per year. While the court stated that it rejected the contention that the usual amount of snow an area receives should affect liability, id. at 122, the likelihood of future injury (which is crucial to the injunction) is higher in Crested Butte than at a place that only receives a couple of inches of snow per year.

161. Docheff v. City of Broomfield, 623 P.2d 69 (1981) cert. den. (Feb. 2, 1981). In accord, Hankins v. Borland, 431 P. 2d 1007 (1967).

162. Burt v. Beautiful Savior Luth. Church, 809 P. 2d 1064 (Colo. App. 1990).

163. The court stated that holding that the plaintiff's "moved to the nuisance" and thus failed to mitigate damages would allow the defendant's to "condemn" part of the neighboring property by making it unrentable by their trespass. id. at 1069.

164. 285 P.2d 596 (1955).

165. E.g., Watson v. Mississippi River Power Co., 156 N.W. 188 (Iowa 1916), Exner v. Sherman Power Const. Co., 54 F.2d 510 (2d Cir. 1931), Enos Coal Mining Co. v. Schuchart, 188 N.E. 2d 406 (Ind. 1963).

166. E.g. McNeill v. Redington, 154 P.2d 428 (Cal. Ct. App. 1945) (vibrations from a drop forging plant constituted a trespass).

167. Generally, Colorado courts will only grant an injunction if there is an imminent danger of substantial, irreparable injury and the remedy at law is inadequate. American Investors Life Insurance Co. v. Green Shield Plan, Inc. 358 P.2d 473 (Colo. 1961). If no quakes have occurred, proving that there is an imminent danger of substantial injury may be difficult. There must be more than a mere fear or possibility that injury will occur. Martinez v. Winner, 548 F. Supp. 278. (D. C. Colo, 1982). Unfortunately, enjoining the inducing activity may not immediately end the seismicity. For example, the three largest of the Rocky Mountain Arsenal quakes occurred over a year after the Army stopped injecting fluid into the well. Small quakes continued in the area till 1982. The pressure wave created underground by the fluid injection could not just be "turned off" and took years to dissipate.

168. Leake v. Cain, 720 P.2d 152, 155 (Colo. 1986). Accord: Palmer v. A.H. Robins CO., Inc., 684 P. 2d 187, 209 (Colo. 1984) and Calvaresi v. National Development Co., Inc., 772 P.2d 640, 644 (Colo. App. 1988).

169. Metropolitan Gas Repair Serv., Inc. v. Kulik, 621 P.2d 313, 317 (Colo. 1981). Accord: Palmer v. A. H. Robins Co. Inc. 684 P.2d 187 (Colo. 1984); Leake v. Cain, 720 P.2d 152, 160, (Colo. 1986); and Calvaresi v. National Development Co., Inc., 772 P.2d 640, 644 (Colo. App. 1988) cert. den. (April 10, 1989).

170. Aldrich Enterprises, Inc. v. U.S., 938 F. 2d 1134 (10th Cir. 1991). A lessor's liability for the conditions created by a lessee is limited to activities the lessor knew would be carried on at the time of the lease, and had reason to know would involve an unreasonable risk or require special precautions that the tenant would not take. 938 F.2d at 1141. In accord, Moore v. Standard Paint & Glass., 358 P.2d 33 (Colo. 1960).

171. Metropolitan Gas Repair Serv., Inc. v. Kulik, 621 P.2d 313, 317 (Colo. 1981).

172. Moore v. Standard Paint & Glass., 358 P.2d 33, 36 (Colo. 1960).

173. Calvaresi v. National Development Co., Inc., 772 P.2d 640, 644 (Colo. App. 1988) cert. den. (April 10, 1989).

174. Public Service Co. v. Williams, 270 P. 659, 660 & 663 (Colo. 1928).

175. Denver, S.P. & P.R. Co. v. Conway, 5 P. 142, 147 (Colo. 1884).

176. Calvaresi v. National Development Co., Inc., 772 P.2d 640, 644 (Colo. App. 1988) cert. den. (April 10, 1989).

177. Public Service Co. v. Williams, 270 P. 659, 660 & 663 (Colo. 1928).

178. LaVine v. Clear Creek Skiing Corp., 557 F. 2d 730 (10th Cir. 1977).

179. Pearce v. Mountain States Telephone & Telegraph Co., 173 P. 871, 872 (Colo. 1918).

180. See, Yampa Valley Elec. v. Telecky, 862 P.2d 252, 257 (Colo. 1993) and Blueflame Gas, Inc. v. Van Hoose, 679 P.2d 579, 591 (Colo. 1984).

181. Moore v. Standard Paint & Glass Co., 358 P. 2d 33, 37 (Colo. 1960)

182. Blueflame Gas, Inc. v. Van Hoose, 679 P.2d 579 (Colo. 1984).

183. Electricity: Denver Consolidated Electric Company. V. Simpson, 41 P. 499 (Colo. 1895) ; Denver Consol. Elec. Co. v. Lawrence, 73 P. 39 (Colo. 1903); Arkansas Valley Ry., Light & Power Co. v. Ballinger, 178 P. 566 (Colo. 1919); Blankette v. Public Service Co. of Colorado, 10 P.2d 327 (1932); Federal Insurance Co. v. Public Service Co., 570 P.2d 239 (Colo. 1977); Smith v. Home Light & Power, 734 P.2d 1051 (Colo. 1987); Yampa Valley Elec. Assoc., Inc. v. Telecky, 862 P.2d 252 (Colo. 1993); Mladjan v. Public Service Co. of Colorado, 797 P.2d 1299 (Colo. App 1990). Propane gas: Blueflame Gas, Inc. v. Van Hoose, 679 P.2d 579 (Colo. 1984); Grange Mutual Fire Ins. Co. v. Golden Gas Co., 298 P.2d 950 (1956); U.S. Fidelity & Guaranty Co. v. Salida Gas Service Co. 793 P.2d 602 (Colo. App. 1989). Nitroglycerin: E. I. DuPont De Nemours & Co. v. Cudd, 176 F.2d 855 (10th Cir. 1949); Amusement Park rides: Hook v. Lakeside Park Co., 351 P.2d 261 (1960). Other jurisdictions have also applied this standard to butane gas, gasoline, natural gas and anhydrous ammonia. See Blueflame Gas, 679 P.2d 579, 588.

184. Mannhard v. Clear Creek Skiing Corp., 682 P.2d 64, 66 (Colo. App. 1983) cert. den. (May 29, 1984).

185. Western Stock Center, Inc. v. Sevot, Inc., 578 P.2d 1045 (1978).

186. Imperial Dist. Services v. Forrest, 741 P.2d 1251, 1255 (Colo. 1987).

187. Holmes v. Gamble, 655 P.2d 405 (Colo. 1982)

188. Hook v. Lakeside Park Co.,351 P.2d 261, 269 (Colo. 1960), Scott v. Greeley Joslin Store Co., 243 P. 2d 394, 397 (Colo. 1952), Gylling v. Hinds, 222 P.2d 413, 415 (Colo. 1950) and Zimmerman v. Franzen, 220 P.2d 344, 352 (1950).

189. Boulder Valley Coal v. Jernberg, 197 P.2d 155, 156 (?)

190. The res ipsa loquitur doctrine has also been rejected in cases where injuries occurred during the shooting of an oil and gas well. See E.I. Dupont de Nemours & Co. v. Cudd, 176 F. 2d 855, 858 (10th Cir. 1949).

191. Greenwell v. Gill, 660 P.2d 1305, 1307 (Colo. App. 1982).

192. E.g., C.B. Raleigh, Earthquakes and Fluid Injection, **Underground Waste Management and Environmental Implications**, 273 (1972); Scott D. Davis & Cliff Frohlich, Did (or Will) Fluid Injection Cause Earthquakes: Criteria for a Rational Assessment, 64 **Seismological Res. Letters** 207 (1993); Harsh K. Gupta, Damsite Investigations, **Reservoir-Induced Earthquakes**, 319 (1992).

193. Jefferson County School District R-1 v. Justus, 725 P.2d 767, 770-772 (Colo. 1986). See also Lester v. Marshall, 352 P.2d 786, 790-791 (Colo. 1960). Even this possibility of liability may be limited by Colo. Rev. Stat. Sec. §13-21-116(2)(a) which states, "a person shall not be deemed to have assumed a duty of care where none otherwise existed when he performs a service or an act of assistance, without compensation or expectation of compensation, for the benefit of another person." A similar provision applies to public entities and public employees. Colo. Rev. Stat. §24-10-106.5.

194. Leake v. Cain 720 P.2d 152,160 (Colo. 1986). Accord: University of Denver v. Whitlock, 744 P.2d 54 (Colo. 1987).

195. Rest. 2d of Torts Sec. 314. There may be a moral duty, however.

196. Jackson Marine Corp. v. Blue Fox, 845 F.2d 1307 (5th Cir. 1988)

197. Allison v. Smith, 695 P. 2d 791, 793-794 (Colo. App. 1984).

198. Allison v. Smith, 695 P. 2d 791, 794 (Colo. App. 1984)

199. Northwest Water Corporation v. Pennetta 479 P.2d 398, 400 (Colo. 1970).

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200. City of Englewood v. Kingsley, 497 P.2d 1004, (Colo. 1972); Hobbs v. Smith, 493 P.2d 1352, 1354 (1972).

201. Allison v. Smith, 695 P.2d 791,794 (Colo. App. 1984); Krebs v. Hermann, 6 P.2d 907, 908 (1931).

202. Lowder v. Tina Marie Home, Inc., 601 P.2d 657, 658 (Colo. App. 1979).

203. Darlene A. Cypser & Scott D. Davis, Liability for Induced Earthquakes, 9 J. Envtl. L. & Litig. 551, 584 (1994).

204. id at n.177.

205. The source of these vibrations have included rocket engines, ice plants, railroad engines, oil and gas wells, gas turbines, as well as explosives. See D.A. Cypser & S.D. Davis, 9 J. Envtl. L. & Litig. 551 (1994) note 166. One case, Dixon v. New York Trap Rock Corp., 58 N.E2d 517 (N.Y. 1944), should be especially noted since the Trap Rock Quarry was later found to be inducing earthquakes and some of the concussions complained of by the plaintiff could have been induced earthquakes. id. at 584-585.

206. 12 Colo. 294 (1889).

207. Colorado General Statute §2798, was enacted in 1874 and was similar to the current statute Colo. Rev. Stat. §40-30-103 (1996).

208. 20 P. 754, 754 (1889). The court further stated that the statute was "but a re-enactment pro tanto of the ancient common law." id. at 759. Colorado adopted the common law of England by statute as it existed (with some exceptions) in 1607 A.D.. See Colo. Rev. Stat. §2-4-211 (1996).

209. Rhinehart v. Denver & R.G.R. Co., 158 P. 149, 154-5 (1916).

210. Barr v. Game, Fish and Parks Commission, 497 P. 2d 340 (1972); Ryan Gulch Reservoir Co. v. Swartz 263 P. 728 (Colo. 1928).

211. Colo. Rev. Stat. §148-5-4 (1964).

212. Sylvester v. Jerome, 34 P. 760, 762 (1893) But see Garnet Ditch & Reservoir Co. v. Sampson, 110 P. 79 (Colo. 1910) in which the Supreme Court stated that common law was not controlling on the issue, only the Colorado statute applied, and Kane v. Town of Estes Park, 786 P.2d 412, 415 (Colo. 1990) in which the Colorado Supreme Court said that the statutory provisions were comprehensive and had preempted the common law.

213. Colo. Rev. Stat. §37-87-104.

214. Cass Company Contractors v. Colton, 279 P.2d 415 (Colo. 1955); Garden of the Gods Village, Inc, v. Hellman, 294 P.2d 597 (Colo. 1956).

215. Liber v. Flor, 415 P.d 332 (Colo. 1966).

216. 519 F. Supp. 515 (1981).

217. 585 P.2d 1206 (Alaska, 1978).

218. Ward v. Aero-spray, Inc., 458 P.2d 744 (1969).

219. Hartford Fire Ins. Co. v. Public Service Co., 676 P.2d 25 (Colo. App. 1983).

220. Forrest v. Imperial Dist. Services, Inc., 712 P.2d 488 (Colo. App. 1985).

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