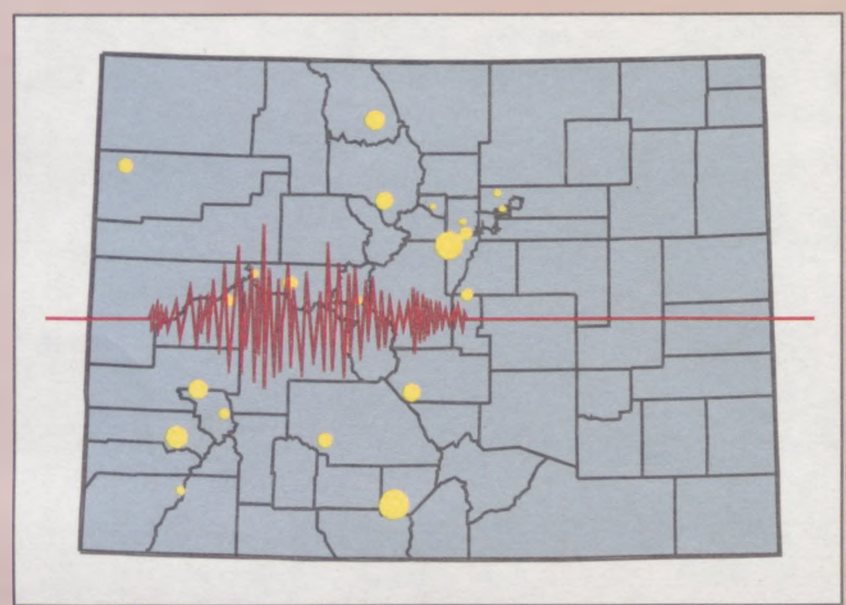
COLORADO EARTHQUAKE HAZARDS

A MAP OF EARTHQUAKES AND RELATED HAZARDS IN COLORADO



COLORADO OFFICE OF EMERGENCY MANAGEMENT, 1999

MAP DEVELOPMENT

This map was created to increase awareness of Colorado's earthquake history and illustrate earthquake related hazards that are present in the state. The map is a product of the Colorado Earthquake Project and was developed by the Colorado Office of Emergency Management as a revision of a 1993 map titled 'Earthquakes and Related Hazards in Colorado'. The map is a composite overlay of nine digital layers of information produced with the computer mapping capabilities of Geographic Information Systems. Each map feature represents digital data collected from different agencies at varying scales. This map is unique in its collective presentation of earthquake hazard databases with terrain and infrastructure data.

MAP EXPLANATION

The map shows locations of earthquakes recorded on seismic instruments and earthquakes felt in Colorado from 1867 to 1996. The map also presents seismic related hazards such as faults and folds that are suspected to have moved within the Quaternary period, or the past 1.6 million years (Widmann, Kirkham and Rogers 1998). Colorado's rugged landscape, displayed with computer terrain modelling as a shaded relief image, is shown to illustrate the relationship between earthquakes, faulting, and topography. Potentially vulnerable infrastructure and population are represented on the map by the high and moderate hazard-class dam locations, transportation corridors, and urbanized areas shown by municipal boundaries.

Instrumentally recorded earthquakes are displayed as Richter magnitude. Seismograms that can measure and locate earthquakes in Colorado were not implemented until 1962. Epicenter locations of earthquakes before 1962 are represented by Modified Mercalli intensity values which are based on human observations and historic reports. These locations are estimates based on the maximum intensity observed, and are considerably less accurate than the instrumentally recorded earthquake epicenters after 1962.

The Colorado Geological Survey has identified 92 faults and 6 folds that moved during the Quaternary Period (the last 1.6 million years). The faults and folds mapped by Widmann, Kirkham, and Rogers (1998) are displayed on this map. Timing of the most recent movement is determined by the age of Quaternary deposits offset or deformed by the fault or fold. Folds usually have a fault associated at depth and are treated as evidence of past stress in the earth's crust. Folds shown in the Carbondale area, however, are thought to be associated with dissolution of underlying evaporite rocks.

Secondary hazards triggered by earthquake ground shaking can have severe impacts on life, infrastructure, and property. Much of Colorado's steep terrain is prone to slope failure hazards (e.g., landslides, rockfall, and avalanches) that could be mobilized by earthquakes. Hazard-class ratings on dams reflect potential impacts on life and/or property should failure occur. A Class I dam failure means that lives would be threatened, whereas a Class II would have severe impacts on property. 296 Class I dams and 323 Class II dams exist in the state. These and other secondary earthquake hazards, such as urban and wildland fires, reinforce the need for emergency preparedness and hazard mitigation in the state.

ACKNOWLEDGMENTS

The following state agencies provided data for this project: Colorado Dept. of Local Affairs, Division of Local Government, Office of Emergency Management, Cartography/GIS Section (Municipal Boundaries, County Boundaries, Hydrology); Colorado Dept. of Transportation (Highways); Dept. of Natural Resources: Colorado Geological Survey (Faults and Folds, Earthquake Epicenters), and Division of Water Resources, Office of the State Engineer (Class I and II Dams); Colorado Dept. of Health and Environment (Composite 1:250,000 scale USGS Digital Elevation Model of the state). The Earthquake Subcommittee of the Colorado Natural Hazards Mitigation Council provided text on Colorado earthquake facts. The final map was created by the Cartography/GIS section of the Colorado Office of Emergency Management.

COLORADO EARTHQUAKE INFORMATION

Adapted from the earthquake fact sheet developed by the Earthquake Subcommittee of the Colorado Natural Hazards Mitigation Council

Colorado consists of areas with low and moderate potential for damaging earthquakes, based on research by geologists and geophysicists who specialize in seismology. There are about 90 potentially active faults that have been identified in Colorado, with documented movement within the past 1.6 million years. However, there are several thousand other faults that have been mapped in Colorado that are believed to have little or no potential for producing future earthquakes. Because the occurrence of earthquakes is relatively infrequent in Colorado and the historical earthquake record is relatively short (only about 130 years), it is not possible to accurately estimate the timing or location of future dangerous earthquakes in Colorado. Nevertheless, the available seismic hazard information can provide a basis for a reasoned and prudent approach to seismic safety.

Faulting

Sudden movement on faults is responsible for large earthquakes. By studying the geologic characteristics of faults, geoscientists can often determine when the fault last moved and estimate the magnitude of the earthquake that produced the last movement. In some cases it is possible to evaluate how frequently large earthquakes occurred on a specific fault during the recent geological past.

Geological studies in Colorado indicate that there are about 90 faults that moved during the Quaternary Period (the last 1.6 million years) and should be considered potentially active. The Sangre de Cristo Fault, which lies at the base of the Sangre de Cristo Mountains along the eastern edge of the San Luis Valley, and the Sawatch fault, which runs along the eastern margin of the Sawatch Range, are two of the most prominent potentially active faults in Colorado. Not all of Colorado's potentially active faults are in the mountains and some cannot be seen at the earth's surface. For example, the Cheraw Fault, which is in the Great Plains in southeast Colorado, appears to have had movement during the recent geologic past. The Derby Fault near Commerce City lies thousands of feet below the earth's surface but has not been recognized at ground level.

Several potentially active faults in Colorado are thought to be capable of causing earthquakes as large as magnitude 6-1/2 to 7-1/4. In comparison, California has hundreds of hazardous faults, some of which can cause earthquakes of magnitude 8 or larger. The time interval between large earthquakes on faults in Colorado is generally much longer than on faults in California.

Past and Possible Future Earthquakes

More than 400 earthquake tremors of magnitude 2-1/2 or higher have been reported in Colorado since 1867. More earthquakes of magnitude 2-1/2 to 3 probably occurred during that time, but were not recorded because of the sparse distribution of population and limited instrumental coverage in much of the state. The largest known earthquake in Colorado occurred on November 7, 1882 and had an estimated magnitude of 6-1/2. The location of this earthquake, which has been the subject of much debate and controversy over the years, appears to be in the northern Front Range west of Fort Collins.

Although many of Colorado's earthquakes occurred in mountainous regions of the state, some have been located in the western valley and plateau region or east of the mountains. The most economically damaging earthquake in Colorado's history occurred on August 9, 1967 in the northeast Denver metropolitan area. This magnitude 5.3 earthquake, which was centered near Commerce City, caused more than a million dollars damage in Denver and the northern suburbs. This earthquake is believed to have been induced by the deep injection of liquid waste into a borehole at Rocky Mountain Arsenal. It was followed by an earthquake of magnitude of 5.2 three months later in November of 1967. Although these events cannot be classified as major earthquakes, they should not be discounted as insignificant. They occurred within Colorado's Front Range Urban Corridor, an area where nearly 75% of Colorado residents and many critical facilities are located. Since March of 1971, well after the initial flurry of seismic activity, 15 earthquakes of approximate magnitude 2-1/2 or larger have occurred in the vicinity of the northern Denver suburbs.

Relative to other western states, Colorado's earthquake hazard is higher than Kansas or Oklahoma, but lower than Utah, and certainly much lower than Nevada and California. Even though the seismic hazard in Colorado is low to moderate, it is likely that future and damaging earthquakes will occur. It is prudent to expect future earthquakes as large as magnitude 6.5, the largest event of record. Calculations based on the historical earthquake record and geological evidence of recent fault activity suggest that an earthquake of magnitude 6 or greater may be expected somewhere in Colorado every several centuries.

Summary and Conclusions

Based on Colorado's historical earthquake record and geologic studies in Colorado, an event of magnitude 6-1/2 to 7-1/4 could occur somewhere in the state. Scientists are unable to accurately predict when the next major earthquake will take place in Colorado; only that one will occur. The major factor preventing the precise identification of the time or location of the next damaging earthquake is the limited knowledge of potentially active faults. Given Colorado's continuing active economic growth and the accompanying expansion of population and infrastructure, it is prudent to continue the study and analysis of earthquake hazards. Existing knowledge should be used to incorporate appropriate levels of seismic safety in building codes and practices. The continued and expanded use of seismic safety in critical and vulnerable structures and in emergency planning statewide is also recommended. Concurrently we should expand earthquake monitoring, geological and geophysical research, and mitigation planning.

The information contained herein is intended to provide general information to the public and should not be used for site specific engineering purposes. Seismic hazard assessment for a particular location should incorporate an appropriate engineering evaluation.

COLORADO'S LARGEST HISTORIC EARTHQUAKES (since 1867)

DATE	LOCATION	MAGNITUDE	INTENSITY
1870, Dec. 4	Pueblo-Ft. Reynolds	--	VI
1871, Oct.	Lily Park, Moffat Co.	--	VI
1880, Sep. 17	Aspen	--	VI
1882, Nov. 7	North-Central CO	6.5*	VII
1891, Dec.	Maybell	--	VI
1901, Nov. 15	Buena Vista	--	VI
1913, Nov. 11	Ridgway area	--	VI
1944, Sep. 9	Montrose/Basalt	--	VI
1955, Aug. 3	Lake City	--	VI
1960, Oct. 11	Montrose/Ridgway	5.5	V
1966, Jan. 4	N.E. of Denver	5.0	V
1966, Jan. 23	CO-NM border near Dulce, NM	5.5	VII
1967, Aug. 9	N.E. of Denver	5.3	VII
1967, Nov. 27	N.E. of Denver	5.2	VI

* magnitude estimated for older earthquake; based on historic felt reports

MORE INFORMATION ON COLORADO EARTHQUAKES

Site-specific decisions should not be based on this map. More detailed information on Colorado earthquakes, faults, and geology can be found at the Colorado Geological Survey. The Survey maintains a reference collection on Colorado seismicity that includes reports by consultants or agencies. A listing of the reports can be viewed at the CGS web site, www.dnr.state.co.us/geosurvey.

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Wood, H.O., and Neumann, F., 1931, Modified Mercalli intensity scale of 1931: Seismological Society of America Bulletin, v. 21, no. 4, p. 277-283.

Reference these publications, the Internet or your local library for more information on earthquake preparedness:

Home Builder's Guide to Seismic Resistant Construction, FEMA-232 Document, August 1998. Federal Emergency Management Agency, 81p.

Safety and Survival in an Earthquake. American Red Cross, 1989, 52 pages ($3.00 + $2.00 P&H from ARC).

Reducing Losses From Earthquakes Through Personal Preparedness. W.J. Kockelman, 1984, U.S. Geological Survey Open File Report 84-765, 21 pages (USGS, $2.75).

EARTHQUAKE PREPAREDNESS IN COLORADO

The Colorado Earthquake Project (CEP) is a state sponsored program designed to help reduce the loss of life and decrease the economic losses resulting from Colorado earthquakes and the secondary hazards (e.g., landslides, dam failures) associated with earthquakes. Authorization and funding for the program is a joint effort between the Federal Emergency Management Agency (FEMA) and the Colorado Office of Emergency Management (COEM). The program is jointly managed by COEM and the Colorado School of Mines, which are both located in Golden.

The CEP focuses on education, mitigation and resource assistance to residents and visitors of the state. More specifically, the CEP educates and trains state and local government personnel as well as interested citizens on methods of earthquake mitigation, preparedness, response and recovery. The CEP encourages and supports structural and nonstructural mitigation projects and assists with the coordination of public and private projects that help to enhance seismic safety in the state.

Colorado was the first state to develop a formal organization with a mission to reduce the impacts of future natural disasters: the Colorado Natural Hazards Mitigation Council. Members of the Council's Earthquake Subcommittee, which include experts in seismology, geology, and earthquake engineering, serve as an advisory board to the Colorado Earthquake Program.

Contact the Colorado Office of Emergency Management at (303) 273 - 1622 to learn more about the CEP and how it can help you.

PERSONAL EARTHQUAKE PREPAREDNESS

Earthquakes are difficult to predict, but you can prepare for them. The following tips suggest actions to take before, during, and after an earthquake.

BEFORE AN EARTHQUAKE

1. Conduct a review of possible hazards in your home: unsecured furniture such as bookshelves, heavy objects on shelves, unsecured water heaters, unreinforced masonry chimneys, etc.

2. Take actions to mitigate hazards: secure bookshelves and heavy or valuable objects. Strap your water heater to wall studs. Place furniture away from windows, mirrors, or picture frames. Add safety film to windows.

3. Know the hazards outside your home or workplace. Know what Class I or II dams might affect you. Be aware of potential rockfall or avalanche hazards.

4. Prepare an emergency survival kit that will last for at least 72 hours. Include: water, non-perishable food, radio, flashlight and extra batteries.

5. Establish a family emergency plan, including communications plans in case you or your family are at school or work when the earthquake occurs.

DURING AN EARTHQUAKE

1. Keep calm. Remember that the greatest danger from falling debris is just outside doorways and close to outer walls.

2. If outdoors, stay outdoors and away from buildings and utility wires. If indoors, take cover under a desk, table, bench, or against inside walls and doorways. Stay away from glass, windows, and outside doors.

3. If you are in a moving car, pull off the road and stop. Avoid overpasses and power lines. Stay inside the vehicle until the shaking stops.

4. If you are in a mountainous area, or near unstable slopes or cliffs, be alert for falling rock or other debris that could be loosened by an earthquake.

AFTER AN EARTHQUAKE

1. Check for injuries. Do not attempt to move seriously injured persons unless they are in immediate danger of further injury.

2. Beware of aftershocks! Keep clear of damaged buildings and debris that could topple in future tremors.

3. If the power is out, do not use candles, matches or other open flames.

4. Check utility lines and appliances for damage. If you smell gas, open windows and shut off the main gas valve. Leave the building and don't re-enter until a utility worker says its safe to do so.

5. If water pipes are damaged, shut off the supply at the main valve. Emergency water may be obtained from hot water heaters, toilet tanks, and melted ice cubes. Check sewer lines before flushing toilets.

6. If electric wiring is shorting out, shut off current at the main meter box.

7. If in a car, watch for road hazards such as downed electric or telephone lines, damaged roads and bridges, or rockslides.

MAGNITUDE AND INTENSITY

Magnitude is an index of earthquake energy released at the source. Magnitude is based on the maximum amplitude of earthquake waves recorded on a seismograph (Richter, 1958) and is most commonly expressed using the Richter Scale. The Richter Scale is logarithmic, which means a whole number increase on the scale represents a tenfold increase in recorded amplitude. Therefore a magnitude 7 earthquake is ten times larger than a magnitude 6 and 100 times larger than a magnitude 5. Earthquakes with magnitudes of 2 can barely be felt by people whereas a Richter value of 6 or more are commonly considered major. Great earthquakes have magnitudes of 8 or more on the Richter Scale, which has no upper limit.

Intensity is a measure of earthquake effects felt on the surface of the earth. Intensity is expressed using the Modified Mercalli intensity scale based on observations of earthquake effects on people, buildings, and the environment (see Modified Mercalli scale description). An earthquake of a particular magnitude can have various intensities, depending on the distance from the epicenter, local geology, or type of buildings and infrastructure. Intensity maps display the variances in intensity over a region that has experienced an earthquake. Prior to the development of seismograms, the area that experienced the most intense ground shaking was estimated to contain the earthquakes's epicenter, which is the point on the earth's surface directly above where an earthquake's energy originates.

MODIFIED MERCALLI INTENSITY SCALE OF 1931

Adapted from Sieberg's Mercalli-Cancani scale. Modified and condensed (Wood and Neumann, 1931)

I Not felt - or, except rarely under especially favorable circumstances. Under certain conditions, at and outside the boundary of the area in which a great shock is felt: sometimes birds, animals, reported uneasy or disturbed; sometimes dizziness or nausea experienced; sometimes trees, structures, liquids, bodies of water may sway-doors may swing slowly.

II Felt indoors by few, especially on upper floors, or by sensitive or nervous persons. Also, as in grade I, but more often noticeably; sometimes hanging objects may swing, especially when delicately suspended; sometimes trees, structures, liquids, bodies of water, may sway, doors may swing, very slowly; sometimes birds, animals, reported uneasy or disturbed; sometimes dizziness or nausea experienced.

III Felt indoors by several, motion usually rapid vibration. Sometimes not recognized to be an earthquake at first. Duration estimated in some cases. Vibration like that due to passing of light, or light loaded trucks, or heavy trucks some distance away. Hanging objects may swing slightly. Movements may be appreciable on upper levels of tall structures. Rocked standing motor cars slightly.

IV Felt indoors by many, outdoors by few. Awakened few, especially light sleepers. Frightened no one, unless apprehensive from previous experiences. Vibration like that due to passing of heavy or heavily loaded trucks. Sensation like heavy body striking building or falling of heavy objects inside. Rattling of dishes, windows, doors; glassware and crockery clink and clash. Creaking of walls, frame, especially in the upper range of this grade. Hanging objects swung, in numerous instances. Disturbed liquids in open vessels slightly. Rocked standing motor cars noticeably.

V Felt indoors by practically all, outdoors by many or most: outdoors direction estimated. Awakened many, or most. Frightened few-slight excitement, a few ran outdoors. Buildings trembled throughout. Broke dishes, glassware to some extent. Cracked windows-in some cases, but not generally. Overturned vases, small or unstable objects, in many instances, with occasional fall. Hanging objects, doors, swing generally or considerably. Knocked pictures against walls, or swung them out of place. Opened, or closed, doors, shutters, abruptly. Pendulum clocks stopped, started, or ran fast or slow. Moved small objects, furnishings, the latter to slight extent. Spilled liquids in small amounts from well-filled open containers. Trees, bushes shaken slightly.

VI Felt by all, indoors and outdoors. Frightened many, excitement general, some alarm, many ran outdoors. Awakened all. Persons made to move unsteadily. Trees, bushes shaken slightly to moderately. Liquid set in strong motion. Small bells rang-church, chapel, school, etc. Damage slight in poorly built buildings. Fall of plaster in small amount. Cracked plaster somewhat, especially fine cracks, chimneys in some instances. Broke dishes, glassware, in considerable quantity, also some windows. Fall of knick-knacks, books, pictures. Overturned furniture in many instances. Moved furnishings of moderately heavy kind.

VII Frightened all-general alarm, all ran outdoors. Some, or many, found it difficult to stand. Noticed by persons driving cars. Trees and bushes shaken moderately to strongly. Waves on ponds, lakes, and running water. Water turbid from mud stirred up. Incasing to some extent of sand or gravel stream banks. Rang large church bells, etc. Suspended objects made to quiver. Damage negligible in buildings of good design and construction, slight in poorly built or badly designed buildings, adobe houses, old walls (especially where laid up with mortar), spires, etc. Cracked chimneys to considerable extent, walls to some extent. Fall of plaster in considerable to large amount, also some stucco. Broke numerous windows, furniture to some extent. Shook down loosened brickwork and tiles. Broke weak chimneys at the roof-line (sometimes damaging roofs). Fall of cornices from towers and high buildings. Dislodged bricks and stones. Overturned heavy furniture, with damage from breaking. Damage considerable to concrete irrigation ditches.

VIII Fright general-alarm approaches panic. Disturbed persons driving cars. Trees shaken strongly-branches, trunks, broken off, especially palm trees. Ejected sand and mud in small amounts. Changes, temporary or permanent: in flow of springs and wells; dry wells renewed flow; in temperature of spring and well waters. Damage slight in structures (brick) built especially to withstand earthquakes. Considerable in ordinary substantial buildings, partial collapse; racked, tumbled down, wooden houses in some cases; threw out panel walls in frame structures, broke off decayed piling. Fall of walls. Cracked, broke, solid stone walls seriously. Wet ground to some extent, also ground on steep slopes. Twisting,fall of chimneys, columns, monuments, also factory stacks, towers. Moved conspicuously, overturned, very heavy furniture.

IX Panic general. Cracked ground conspicuously. Damage considerable in (masonry) structures built especially to withstand earthquakes; Threw out of plumb some wood-frame houses built especially to withstand earthquakes; great in substantial (masonry) buildings, some collapse in large part; or wholly shifted frame buildings off foundations, racked frames, serious to reservoirs; underground pipes sometimes broken. Cracked ground, especially when loose and wet, up to widths of several inches; fissures up to a yard in width ran parallel to canal and stream banks. Landslides considerable from river banks and steep coasts. Shifted sand and mud horizontally on beaches and flat land. Changed level of water in wells. Threw water on banks of canals, lakes, rivers, etc. Damage serious to dams, dikes, embankments. Severe to well-built wooden structures and bridges, some destroyed. Developed dangerous cracks in excellent brick walls. Destroyed most masonry and frame structures, also their foundations. Bent railroad rails slightly. Tore apart, or crushed endwise, pipelines buried in earth. Open cracks and broad wavy folds in cement and asphalt road surfaces.

X Disturbances in ground many and widespread, varying with ground material. Broad fissures, earth slumps, and land slips in soft, wet ground. Ejected water in large amounts charged with sand and mud. Caused sea-waves ("tidal" waves) of significant magnitude. Damage severe to wood-frame structures, especially near shock centers. Great to dams, dikes, embankment often for long distances. Few, if any (masonry), structures remain standing. Destroyed large well-built bridges by the wrecking of supporting piers, or pillars. Affected yielding wooden bridges less. Bent railroad rails greatly, and thrust them endwise. Put pipe lines buried in earth completely out of service.

XI Damage total-Practically all works of construction damaged greatly or destroyed. Disturbances in ground great or varied, numerous shearing cracks. Landslides, falls of rock of significant character, slumping of river banks, etc., numerous and extensive. Wrenched loose, tore off, large rock masses. Fault slips in firm rock, with notable horizontal and vertical offset displacements. Water channels, surface and underground, disturbed and modified greatly. Dammed lakes, produced waterfalls, deflected rivers, etc. Waves seen on ground surfaces (actually seen, probably, in some cases). Distorted lines of sight and level. Threw objects upward into the air.

Acknowledgment of Federal Emergency Management Agency (FEMA) Support: Federal funds from the Federal Emergency Management Agency under assistance agreement award identification number EMD-1999-PA-9901. The contents do not necessarily reflect the views and policies of the Federal Emergency Management Agency, nor does the mention of trade names or commercial products constitute an endorsement or recommendation for use.

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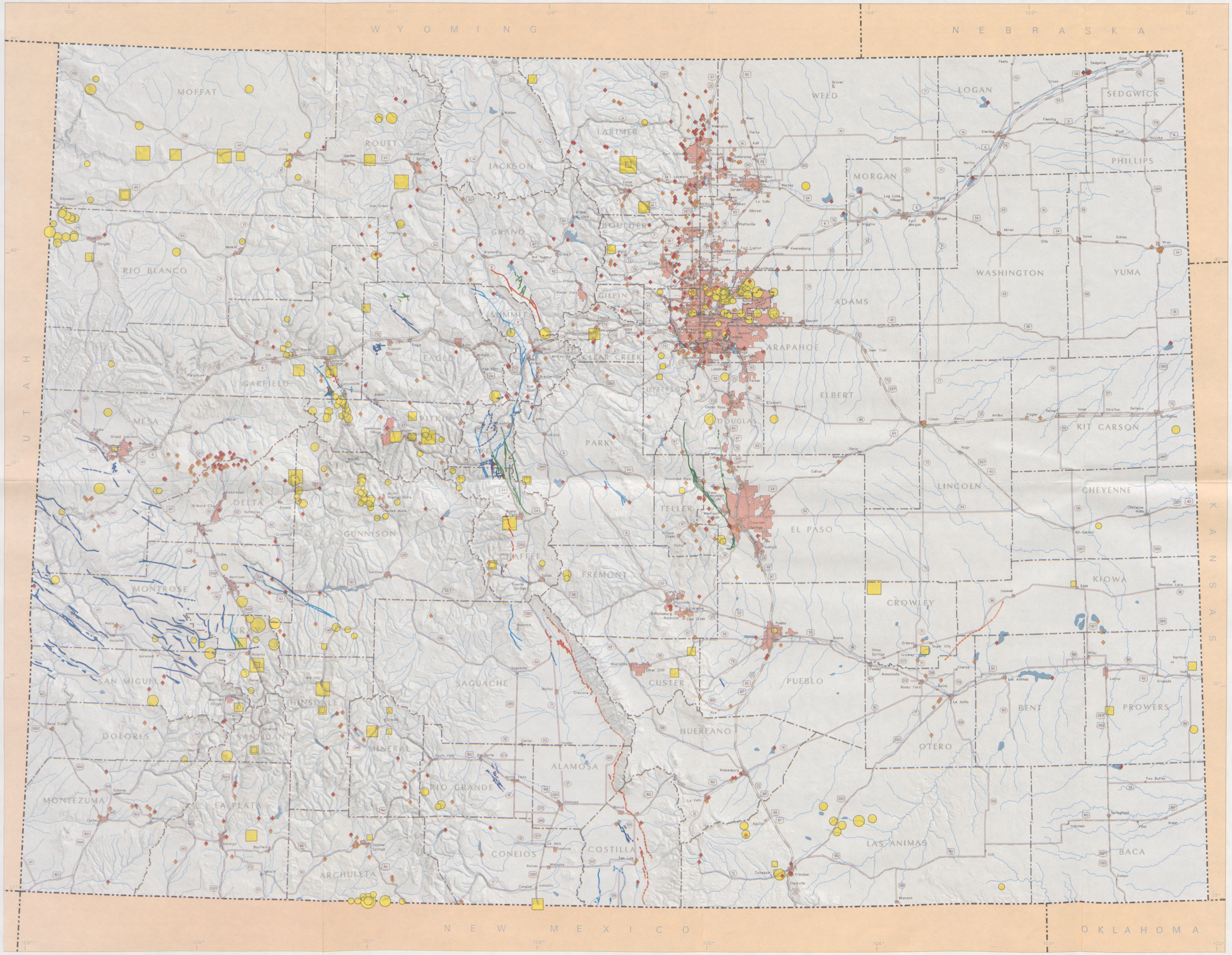

EARTHQUAKE EPICENTERS

Instrumentally located epicenters 1962-1996. Size of dot indicates Richter magnitude.

- 5-5.5
- 4-4.9
- 3-3.9
- 2-2.9
- 1-1.9

Approximate location of pre-instrumental earthquake epicenters 1867-1961. Square size indicates the modified Mercalli intensity.

- VII
- VI
- V
- IV
- I-III

QUATERNARY FAULTS and FOLDS

Suspected movement within past 1.6 million years. Color indicates timing of most recent paleoevent; dashed where inferred; dotted where concealed.

- Holocene and post-glacial (<15 thousand years)
- Late Quaternary (<130 thousand years)
- Middle and late Quaternary (<750 thousand years)
- Quaternary (<1.6 million years)
- Folds -Age indicated by fold axis color.

HIGH CONSEQUENCE DAMS

Classified by failure consequence

- CLASS I (potential loss of life)
- CLASS II (potential property loss)

City and town boundaries

Data Sources

Earthquake epicenters: Colorado Geological Survey; Kirkham and Rogers, 1999.
Faults and Folds: Colorado Geological Survey; Widmann, Kirkham, and Rogers, 1998.
Dams: Colorado Division of Water Resources Dams database.
Highways: Colorado Department of Transportation.
County and Municipal Boundaries, Hydrography: Colorado Department of Local Affairs.

This map does not meet U.S. National Map Accuracy Standards and is intended for general reference only.

Scale 1:1,150,000

0 10 20 30 40 50 Miles

0 20 40 60 80 Kilometers

Map Compilation:
Colorado Office of Emergency Management, August 1999