

BIBLIOGRAPHY OF GEOTHERMAL
RESOURCES IN THE
SAN CARLOS-SAFFORD-DUNCAN
NONPOINT-SOURCE MANAGEMENT
ZONE, ARIZONA

by
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The San Carlos-Safford-Duncan Nonpoint-Source Management Zone (Figure 1) is known to contain significant quantities of geothermal energy resources. Following the energy crisis in the 1970s, these resources were studied in detail. This report includes references pertaining to geothermal energy resources, hot springs and wells, heat flow measurements, and geothermal gradients.

Two geothermal reservoirs are located in Greenlee County. One of Arizona's most important Known Geothermal Resource Areas (KGRA) is at Clifton. References pertaining to geothermal resource evaluations for Greenlee County and the Clifton KGRA include Witcher (1979a), Arizona Geothermal Commercialization Team (1979), Witcher and Stone (1980), Witcher (1981), and Hahman (1979a, b).

The Safford basin, in Graham County, contains at least four proven and potential geothermal reservoirs of less than 1.2 km depth and three inferred moderate to high-temperature reservoirs less than 2.5 km depth (Arizona Geothermal Commercialization Team, 1979). Studies by Witcher, 1979b, 1981, 1982) Hahman, (1979a) and Hahman and others (1979) focused on characterizing the nature and extent of geothermal anomalies in the Safford area.

One of the surface manifestations of geothermal reservoirs is the presence of hot springs and hot artesian wells. The relation of natural hot springs and hot wells to water quality in the upper Gila River was discussed in Harris (1997). The following is excerpted and modified from that report:

Hot Springs

Several hot springs occur within the Management Zone that are known to produce salty water. Perhaps the best known is the Clifton Hot Springs (D-4-30-19,30). These springs issue at temperatures up to 49°C (120°F) from Tertiary volcanic rocks. Total dissolved solids (TDS) is up to 14,548 mg/l and chloride runs 5800 ppm (Eaton and others, 1972) to 6500 mg/l (Witcher, 1981a) in these thermal waters (ppm is used mostly in older literature and is approximately equal to mg/l). An estimated average of 54 tons of dissolved solids per day (19,710 tons per year) is discharged from the springs to the San Francisco River (Hem, 1950).

Eagle Creek Hot Springs (D-4-28-35abb) may be on the same fault zone as Clifton Hot Springs (Witcher, 1981a). Eagle Creek springs discharge water at about 42°C (108°F), with TDS of less than 1000 mg/l. The water is of a mixed sodium bicarbonate-chloride type.

Gillard Hot Springs (D-5-29-27aad), along the Gila River where it cuts through the Gila Mountains east of Safford, is reported to be the hottest springs in Arizona, at 80° to 84°C (176 to 183°F) (Witcher, 1981a). The output of hot, saline water from the springs (TDS 1200-1500 mg/l) is sufficient to raise the temperature of Gila River water about 2°C (3.6°F), and raise the chloride content of the river from 25 mg/l upstream from the springs to 30 mg/l below the springs (Hem, 1950; Witcher, 1981a).

Indian Hot Springs (D-5-24-17add), northwest of Safford, produces about 1000 liters per minute of water at 45 to 48°C (113 to 118°F) (Witcher, 1981b). The water is a sodium chloride type and travertine (calcium carbonate) deposits are present at the springs. TDS ranges from 2570 mg/l to 3004 mg/l. A high level of sulfate in the spring water indicates the presence of gypsum in the sediments.

Indian Hot Springs is on an alignment of faults trending NW on the north side of the Gila River flood plain. This zone of faulting extends from Bylas to northwest of Safford and is thought to be responsible for an alignment of hot springs and hot wells in that area (Witcher, 1981b). Traces of fault segments and associated deformation of sedimentary units are exposed at several localities (Houser, 1990; Houser and others, 1985)

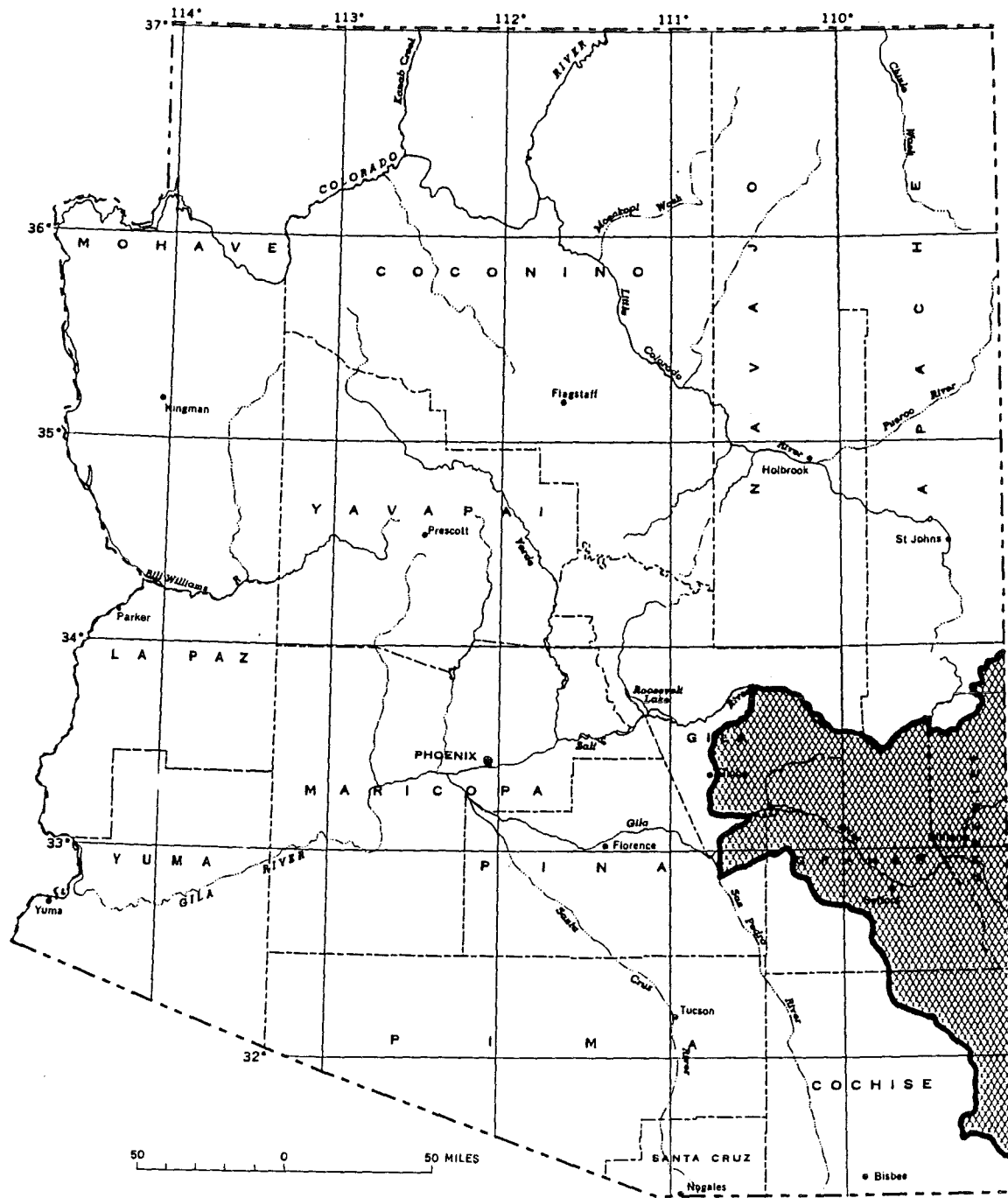


Figure 1. Location of San Carlos-Safford-Duncan Nonpoint-Source Management Zone.

Deep wells

The 3767 foot deep Underwriters Syndicate 1 Mack oil exploration well (D-6-24-13ab; location of wells shown on Plate 1), also known as the Mary Mack well, discharged water similar in chemistry to that of the nearby Indian Hot Springs. (This well is near the fault-controlled alignment of hot springs along the north side of the Gila River.) TDS was measured by Knechtel (1938) at 3351 ppm, and the water temperature was 59°C (138°F). In 1933, the well was flowing at 2250 gpm, but the well is no longer flowing (Witcher 1981b; Stone and Witcher, 1982).

Knechtel (1938) reports that the 2,645-foot deep Gila Oil Syndicate #1 well near Ashurst (D-5-24-30ac) produced substantial artesian flow of hot, mineralized water. Well logs (AZGS oil and gas files; Knechtel, 1938) describe salt water at 590 and 750 feet, but the actual amount was not measured.

Artesian flow of salt water (21 gpm) was noted in a well at Geronimo (D-4-23-19) from the bottom of a 405-foot thick layer of hard clay and lime 90 to 495 feet below surface (Knechtel, 1938). The 28°C (82°F) water had a very high TDS of 14,035 ppm, with a sodium content of 5,076 ppm, chloride content of 6,656 ppm, and sulfate of 1,838 ppm. The well produced fresh water to a depth of 45 feet.

The Smithville Canal well, also known as the Mt. Graham Mineral Bath well (D-6-25-36cbb), produced 601 gpm of sodium chloride type water under artesian flow at 46°C (115°F) (Witcher, 1981b). Witcher reports TDS ranging from 4,431 to 8,292 mg/l, and Muller and others (1973) measured total chloride of 480 to 1504 ppm. [Note: the Smithville Canal well was plugged and abandoned in 1997]

About five miles south of Safford, the Idle Oil-Healy #1 well (D-8-26-6bd) produced what Knechtel (1938) called "scalding hot salty water". This artesian well flowed at 1/2 gpm and the main water-bearing bed was at 1600 feet.

This bibliography is derived in part from the comprehensive bibliography for the Management Zone by Trapp and Harris (1996), with additional references.

GEOHERMAL REFERENCES

- Arizona Geothermal Commercialization Team, 1980, Geothermal development plan: Cochise and Santa Cruz Counties: Arizona Bureau of Geology and Mineral Technology Open-File Report 80-09, 40 p.
- Arizona Geothermal Commercialization Team, 1982, Geothermal development plan: Graham and Greenlee Counties: Arizona Bureau of Geology and Mineral Technology Open-File Report 79-10, 37 p.
- Cadigan, R.A., and Felmlee, J.K., 1977, Radioactive springs geochemical data related to uranium exploration: *Journal of Geochemical Exploration*, v. 8, nos. 1-2, p. 381-395.
- Cunningham, J.E., 1981, Preliminary detailed geologic map and cross sections of the Clifton Hot Springs and San Francisco River area: Arizona Bureau of Geology and Mineral Technology Open-File Report 81-22, 1 sheet, scale 1:24,000.
- Everit, R.S., 1925, Hot spring water from Clifton, Arizona: *Economic Geology*, v. 20, no. 3, p. 291-292.
- Fellows, L.D., 1994, Oil show in geothermal test: *Arizona Geology* [Arizona Geological Survey], v. 24, no. 1, p. 1, 4.
- Feth, J.H., 1954, Preliminary report of investigations of springs in the Mogollon Rim region, Arizona, with sections on base flow of streams, by N.D. White, and Quality of water, by J.D.

- Hem: U.S. Geological Survey Open-File Report, 100 p., 4 sheets, scales 1:80,000 and 1:95,000.
- Feth, J.H., 1961, A new map of western conterminous United States, showing the maximum known of inferred extent of Pleistocene lakes: U.S. Geological Survey Professional Paper 424B, p. B110-B112, fig. 47.1.
- Feth, J.H., and Hem, J.D., 1962, Springs along the Mogollon Rim in Arizona, in Weber, R.H., and Peirce, H.W., eds., Guidebook of the Mogollon Rim region, east-central Arizona: New Mexico Geological Society 13th Field Conference Guidebook, p. 129-134.
- Feth, J.H., and Hem, J.D., 1963, Reconnaissance of headwater springs in the Gila River drainage basin, Arizona: U.S. Geological Survey Water-Supply Paper 1619-H, 54 p., 4 sheets, scales 1:500,000, and 1:63,360.
- Goldstone, L.A., and Stone, Claudia, comps., 1982, Temperature-depth profiles, well-location information, and tabulated temperatures for Arizona wells measured between May, 1979 and March, 1982: Arizona Bureau of Geology and Mineral Technology Open-File Report 82-07, 112 p.
- Grose, L.T., 1975, Geothermal energy, geology, exploration, and developments, Part 1, in Betz, Frederick, Jr., ed., Environmental geology: Stroudsburg, Pa., Dowden, Hutchinson, and Ross, Inc., Benchmark Papers in Geology, v. 25, p. 130-143.
- Hahman, W.R., Sr., 1979, Geothermal reservoir site evaluation in Arizona, semiannual progress report for the period July 15, 1978 - January 15, 1979: U.S. Department of Energy Report COO-4362-5, 157 p.
- Hahman, W.R., Sr., 1979, Geothermal reservoir site evaluation in Arizona, semiannual progress report for the period July 15, 1978 - January 15, 1979: Arizona Bureau of Geology and Mineral Technology Open-File Report 79-02, 91 p.
- Hahman, W.R., Sr., 1979, Geothermal studies in Arizona with two area assessments, progress report for the period January 16, 1979 - November 1, 1979: Arizona Bureau of Geology and Mineral Technology Open-File Report 79-07, 173 p.
- Hahman, W.R., Sr., 1979, Geothermal studies in Arizona with two area assessments, progress report for the period January 16, 1979 - November 1, 1979: U.S. Department of Energy Report ID-12009-1, 173 p. [Also released as ABGMT Open-File Report 97-7]
- Hahman, W.R., Sr, Mancini, F., White, D., Chebab, M., Goldstone, L., and Weibel, B., 1980, Evaluation of geothermal energy in Arizona - Final report by Arizona Geothermal Planning Team - Volume 2 of 2, January 1 - December 31, 1979: U.S. Department of Energy, and Four Corners Regional Development Commission, 61 p.
- Hahman, W.R., Sr., Sbar, M.L., Swanberg, C.A., Young, C.T., Gish, D.M., Rybarczyk, S.M., Stone, Claudia, and Witcher, J.C., 1980, Arizona geothermal energy appraisal studies, final report, June 1978 - March 1980: Arizona Bureau of Geology and Mineral Technology Open-File Report 80-01, 144 p.
- Harris, R.C., 1997, Distribution of evaporites and implications for water quality in the San Carlos-Safford-Duncan Nonpoint-Source Management Zone: Arizona Geological Survey Open-File Report 97-3, 56 p.
- Hem, J.D., 1950, Quality of water of the Gila River Basin above Coolidge Dam, Arizona: U.S. Geological Survey Water Supply Paper 1104, 230 p.
- Houser, B.B., 1990, Late Cenozoic stratigraphy and tectonics of the Safford, Tonto, and Payson basins, southeastern and central Arizona, in Gerhels, G.E., and Spencer, J.E., eds., Geologic excursions through the Sonoran Desert region, Arizona and Sonora: Arizona Geological Survey Special Paper 7, p. 20-24.

- Houser, B.B., Richter, D.H., and Shafiqullah, M. 1985, Geologic map of the Safford quadrangle, Graham County, Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-1617, scale 1:48,000.
- Johannessen and Girard Consulting Engineers, Inc., 1981, Feasibility study for geothermal water space heating for the Safford Federal Prison Camp, Safford, Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 81-27, 55 p.
- Klein, D., Long, C., Christopherson, K., and Boler, F., 1980, Reconnaissance geophysics in the Clifton and Gillard geothermal areas, SE Arizona: U.S. Geological Survey Open-File Report 80-0325, 21 p.
- Lepley, L.K., and Doss, A.K., 1975, Use of Earth Resources Technology Satellite - aeromagnetic, gravity, and thermal data for mapping potential geothermal resources [*abs.*]: American Association of Petroleum Geologists Bulletin, v. 59, no. 5, p. 915.
- Mann, L.J., 1980, Maps showing hydrologic conditions in the San Francisco River area, Greenlee County, Arizona, 1978, a reconnaissance study: U.S. Geological Survey Water-Resources Investigations Open-File Report WRI 80-0441, 2 sheets, scale 1:125,000.
- Mariner, R.H., Presser, D.D., and Evans, W., 1977, Chemical, isotopic, and gas compositions of selected thermal springs in Arizona, New Mexico, and Utah: US Geological Survey Open-File Report 77-654, 42 p.
- Norton, D.L., Gerlach, T., DeCook, K.J., and Sumner, J. S., 1975, Geothermal water resources in Arizona: Feasibility study - Project Completion Report, OWRT project no. A-054-ARIZ: Tucson, University of Arizona, Water Resources Research Center, 50 p., 3 sheets, scale 1:1,000,000.
- Ratté, J.C., 1982, Geologic map of the Lower San Francisco Wilderness Study Area and contiguous roadless area, Greenlee County, Arizona, and Catron and Grant Counties, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1463-B, 1 sheet, scale 1:62,500.
- Ratté, J.C., Landis, E.R., Gaskill, D.L., and Raabe, R.G., 1969, Mineral resources of the Blue Range Primitive Area, Greenlee County, Arizona and Catron County, New Mexico, with a section on Aeromagnetic Interpretation by G.P. Eaton, in Studies Related to Wilderness--Primitive Areas: U.S. Geological Survey Bulletin 1261-E, p. E1-E91, 2 sheets, scale 1:62,500.
- Ratté, J.C., Hassemer, J.R., Martin, R.A., and Lane, Michael, 1982, Mineral resource potential map of the Lower San Francisco Wilderness Study Area, Greenlee County, Arizona and Catron and Grant Counties, New Mexico [*Tillie Hall Peak and Big Lue Mts. 7.5 min*]: U.S. Geological Survey Miscellaneous Field Studies Map MF-1463-C, 6 p., 1 sheet, scale 1:62,500.
- Ratté, J.C., and Hedlund, D.C., 1981, Geologic map of the Hells Hole Further Planning Area (RARE II), Greenlee County, Arizona, and Grant County, New Mexico [*Tillie Hall Peak and Big Lue Mts. 7.5 min*]: U.S. Geological Survey Miscellaneous Field Studies Map MF-1344-A, 1 sheet, scale 1:62,500.
- Rauzi, S.L., 1994, Geothermal test hints at oil potential in eastern Arizona volcanic field: Oil and Gas Journal, v. 92, no. 1, p. 52-54.
- Rauzi, S.L., 1994, Implications of live oil shows in eastern Arizona geothermal test: Arizona Geological Survey Open-File Report 94-01, 17 p., 12 sheets, scale 1:500,000.
- Renner, J.L., White, D.E., and Williams, D.L., 1975, Hydrothermal convection systems, in White, D.E., and Williams, D.L., eds., Assessment of geothermal resources of the United States--1975: U.S. Geological Survey Circular 726, p. 5-57.
- Reiter, Marshall, and Shearer, Charles, 1979, Terrestrial heat flow in eastern Arizona: A first report: Journal of Geophysical Research, v. 84, no. B11, p. 6115-6120.

- Sbar, M.L., 1980, Analysis of short-term microearthquake activity related to potential geothermal areas in Arizona, in Hahman, W.R., Sr., and others, Arizona geothermal energy appraisal studies, final report, June 1978 - March 1980: Arizona Bureau of Geology and Mineral Technology Open-File Report 80-01, p. v, vi, 1-11.
- Sbar, M.L., 1980, Analysis of short-term microearthquake activity related to potential geothermal areas in Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 80-01c, 13 p. [also included in Arizona Bureau of Geology and Mineral Technology Open-File Report 80-01].
- Shearer, Charles, and Reiter, Marshall, 1981, Terrestrial heat flow in Arizona: Journal of Geophysical Research, v. 86, no. B7, p. 6249-6260.
- Stone, C., 1978, Geothermal leasing and drilling activity in Arizona, in Hahman, W.R., Sr., ed., Low-temperature geothermal reservoir site evaluation in Arizona - Quarterly progress report, February 1-April 30, 1978: U.S. Department of Energy Report COO-4362-4, p. 92-108.
- Stone, C., 1980, Heat flow along the southern Colorado Plateau margin, east-central Arizona [abs.]: Eos, Transactions, American Geophysical Union, v. 61, no. 17, p. 363.
- Stone, Claudia, 1989, A summary appraisal of the principal geothermal resource areas in Arizona, in Jenney, J.P., and Reynolds, S.J., eds., Geologic evolution of Arizona: Arizona Geological Society Digest 17, p. 817-825.
- Swanberg, C.A., 1978, Chemistry, origin and potential of geothermal resources in southwestern New Mexico and southeastern Arizona, in Callender, J.F., Wilt, J.C., Clemons, R.E., and James, H.L., eds., Land of Cochise, southeastern Arizona: New Mexico Geological Society 29th Field Conference Guidebook, p. 349-351.
- Swanberg, C.A., Morgan, P., Stoyer, C.H., and Witcher, J.C., 1977, An appraisal study of the geothermal resources of Arizona and adjacent areas in New Mexico and Utah and their value for desalinization and other uses: New Mexico Energy Institute [NM State University] Report 6, 76 p.
- Tellier, A., 1974, Arizona, Gillard Hot Springs: Geothermal Energy Magazine, v. 2, p. 20-31.
- Tellier, A.H., 1973, Geothermal waters of Arizona: Tempe, Arizona State University, M.S. thesis, 30 p.
- Waring, G.A., Blankenship, R.R., and Bentall, R., 1965, Thermal springs of the United States and other countries of the world - a summary: US Geological Survey Professional Paper 492, 83 p.
- White, D.H., and Goldstone, L.A., 1982, Geothermal development plan, Graham and Greenlee Counties: Arizona Geological Survey Open-File Report 79-10, 37 p.
- Witcher, J.C., 1979, A progress report of geothermal investigations in the Clifton area: Arizona Bureau of Geology and Mineral Technology Open-File Report 79-02b, 16 p.
- Witcher, J.C., 1979, A preliminary report on the geothermal energy potential of the Safford basin, southeastern Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 79-02c, 31 p.
- Witcher, J.C., 1979, A geothermal reconnaissance study of the San Francisco River Between Clifton, Arizona and Pleasanton, New Mexico, in Hahman, W.R., Sr, ed., Geothermal studies in Arizona with two are assessments: Arizona Bureau of Geology and Mineral Technology Open-File Report 79-7, p. 156-173.
- Witcher, J.C., 1979, Proven, potential, and inferred geothermal resources of Arizona and their heat contents: Arizona Bureau of Geology and Mineral Technology Open-File Report 79-05, 64 p., 1 sheet, scale 1:1,000,000 [also published in Pasadena, California Institute of Technology, Jet Propulsion Laboratory Publication 80-41, p. A-3 to A-74].

- Witcher, J.C., 1981, Geothermal resource potential of the Safford-San Simon basin, Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 81-26, 131 p., 4 sheets, scale 1:250,000.
- Witcher, J.C., 1981, Geothermal energy potential of the lower San Francisco River region, Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 81-07, 141 p., 3 sheets, scale 1:250,000.
- Witcher, J.C., 1982, Exploration for geothermal energy in Arizona Basin and Range - A summary of results and interpretation of heat flow and geochemistry studies in Safford basin, Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 82-05, 51 p.
- Witcher, J.C., 1982, Geothermal potential of Willcox area, Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 82-04, 39 p.
- Witcher, J.C., 1994, Alpine 1/Federal, Final report, Executive summary: Arizona Geological Survey Contributed Report CR-94-D, 20 p.
- Witcher, J.C., Hahman, W.R., and Swanberg, C.A., 1994, Alpine 1/Federal corehole -- Subsurface stratigraphy of the eastern White Mountains, Apache County, Arizona, *in* Chamberlin, R.M., Kues, B.S., Cather, S.M., Barker, J.M., and McIntosh, W.C., eds., Mogollon Slope, west-central New Mexico and east-central Arizona: New Mexico Geological Society 45th Field Conference Guidebook, p. 233-240.
- Witcher, J.C., Hahman, W.R., and Swanberg, C.A., 1994, Alpine 1/Federal final report - Part 2, temperature gradients, geothermal potential, and geology: Arizona Geological Survey Contributed Report CR-94-F, 127 p.
- Witcher, J.C., Pisto, Larry, Hahman, W.R., and Swanberg, C.A., 1994, Alpine 1/Federal final report - Part 1, drilling report: Arizona Geological Survey Contributed Report CR-94-E, 92 p.
- Witcher, J.C., and Stone, Claudia, 1980, Heat flow and the thermal regime in the Clifton, Arizona area, *in* Hahman, W.R., Sr., and others, Arizona geothermal energy appraisal studies, final report, June 1978 - March 1980: Arizona Bureau of Geology and Mineral Technology Open-File Report 80-01, p. 117-146.
- Witcher, J.C., Stone, C., and Hahman, 1982, Geothermal Resources of Arizona: Arizona Geological Survey Map M-15-2, scale 1:500,000.
- Witcher, J.C., and Stone, Claudia, 1980, Heat flow and the thermal regime in the Clifton, Arizona area: Arizona Bureau of Geology and Mineral Technology Open-File Report 80-01a, 28 p.
- Witcher, J.C., Swanberg, C.A., and Hahman, W.R., 1994, Geothermal potential of the Alpine divide area, *in* Cather, S.M., and others, Second-day road log from Quemado Lake to Mangas Mountains, Omega, Quemado, Tejana Mesa and Red Hill, New Mexico, and Springerville and Alpine, Arizona, *in* Chamberlin, R.M., and others, eds., Mogollon Slope, west-central New Mexico and east-central Arizona: New Mexico Geological Society 45th Field Conference Guidebook, p. 76-77, 116-120.
- Witcher, J.C., Swanberg, C.A., and Hahman, W.R., 1994, Thermal regime of Alpine divide and petroleum implications, *in* Cather, S.M., and others, Second-day road log from Quemado Lake to Mangas Mountains, Omega, Quemado, Tejana Mesa and Red Hill, New Mexico, and Springerville and Alpine, Arizona, *in* Chamberlin, R.M., and others, eds., Mogollon Slope, west-central New Mexico and east-central Arizona: New Mexico Geological Society 45th Field Conference Guidebook, p. 74-76, 116-120.