March 31, 2003

PHASE I EVALUATION OF HYDROGEOLOGIC CONDITIONS IN VICINITY OF NZ PROPERTIES NAVAJO AND APACHE COUNTIES, ARIZONA

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SUMMARY AND RECOMMENDATIONS

Based on review and analysis of available data and reports for the vicinity of the NZ Properties area, the summary of hydrogeologic conditions and recommendations for additional investigations are as follows:

SUMMARY

1. Groundwater is the chief source of dependable water supply in the NZ Properties area. Groundwater is obtained from a sequence of water-yielding geologic units including: floodplain alluvium, Bidahochi Formation, Chinle Formation, Moenkopi Formation, Coconino Sandstone, and Supai Formation.

2. The Coconino aquifer underlies the entire study area and comprises the Permian Kaibab Limestone and Coconino Sandstone; the Coconino Sandstone consists of weakly to strongly cemented, well sorted, quartz grains, which typically displays cross-bedding in outcrop. The Coconino aquifer is the most important source of groundwater in the area. The Kaibab Limestone is not present in the NZ Properties area.

3. Water levels in wells completed in the Coconino aquifer range from flowing at land surface to about 400 feet below land surface. In the NZ Properties area, non-pumping water levels generally range from less than 30 feet to nearly 200 feet below land surface; some wells that have shallow groundwater levels reportedly flow during winter months. Well yields in the study area range from less than 50 to more than 2,500 gallons per minute. The Coconino aquifer generally yields more than 500 gallons per minute in the vicinity of the NZ Properties.

4. Groundwater of good chemical quality is available from the Coconino aquifer in the south and southwest parts of the NZ Properties. Groundwater quality deteriorates north from the Little Colorado River, and is highly saline in the northeast part of the property. The potential for long-term salinity change as a result of increased withdrawals from the Coconino aquifer should be evaluated.

5. Groundwater quality in the alluvial aquifers along Milky and Beaver Dam Washes are fair to poor, based on results from two laboratory chemical analyses of groundwater from the alluvium along Milky Wash. Sustainable well yields from the alluvial aquifer are unknown, but are expected to be less than 200 gallons per minute.

RECOMMENDATIONS

Montgomery & Associates recommends the following investigations be completed to develop a better understanding of the hydrogeologic system in the vicinity of NZ Properties:

- Conduct seismic and ground-penetrating radar geophysical surveys along Milky and Beaver Dam Washes to determine favorable locations for test drilling. Test drilling, pumping tests, and water sampling for laboratory chemical analyses should be conducted at selected sites based on favorable geophysical results.

- Field inventory existing wells on the NZ Properties; inventory would include documentation of location, altitude, pumping equipment, water level, measurement of field parameters and, where possible, collection of groundwater sample for laboratory chemical analyses.

- Collect groundwater samples for laboratory chemical analyses from Coconino aquifer wells (A-18-21)12aad and (A-18-24)08bcb to determine detailed chemistry of the highly saline water in the Coconino aquifer near the NZ Properties.

- Conduct aquifer tests on several existing Coconino aquifer wells in the south part of the NZ Properties to determine aquifer characteristics for evaluating long-term yield from wells, and potential water-quality changes.

- Drill a deep test well near the Navajo-Apache County line, near the center of Township 15 North to determine potential well yield and chemical quality of water in the Coconino aquifer in an area that might be used to supply water for creating cavities in the underlying salt beds.

INTRODUCTION

In accordance with arrangements with Mr. Robert M. Worsley, NZ PROPERTIES, this report summarizes results of a PHASE I hydrogeologic evaluation for the vicinity of the NZ Properties in northeast Arizona. The area of study for this investigation includes about 3,200 square miles extending from Township 12 North through Township 20 North and Range 18 East through Range 27 East, as shown on **Figure 1**. The approximate extent of the NZ Properties, as well as the Worsley-owned part of the property, are also shown on **Figure 1**. The NZ Properties area is within the Plateau Uplands Hydrogeologic Province as defined by White and others (1963), and is entirely within the Little Colorado River drainage basin. The area includes the principal population centers of Holbrook, Joseph City, Snowflake, and Concho. Petrified Forest National Park is adjacent to the NZ Properties in the north part of the area. Objectives of this PHASE I investigation were to: 1) accumulate and summarize groundwater and subsurface lithologic data for the area; 2) prepare maps that show general hydrogeologic characteristics of the area; 3) compile and analyze information on aquifer hydraulic parameters, and 4) prepare a summary report on the subsurface geology, and availability and character of groundwater resources.

Topography of the study area is dominated by the northwest-sloping Colorado Plateau, which is cut by numerous steep-walled canyons. Land surface altitude ranges from about 4,900 feet above mean sea level along the Little Colorado River west from Joseph City to about 6,800 feet near Mesa Redonda in Township 12 North, Range 24 East, in the southeast part of the area. Altitude of land surface generally slopes from southeast to northwest; slope of land surface averages about 40 feet per mile. Climate of the area is arid to semi-arid, with average annual precipitation ranging from about 8 inches at Holbrook to about 18 inches in the higher altitude southern part of the area.

The Little Colorado River is the chief surface water drain and flows from the southeast toward the northwest. Principal tributaries are the Puerco River, which drains the northeast part of the area, and Silver Creek, which drains the south central part of the area **(Figure 1)**; minor tributaries include Milky and Beaver Dam Washes. Only selected reaches of the Little Colorado River and Silver Creek continue to contain perennial flow; Puerco River and most tributaries to the major drainages are ephemeral, flowing only in direct response to precipitation events.

HYDROGEOLOGIC FEATURES

Groundwater is the chief source of dependable water supply in the NZ Properties area. Groundwater is obtained from a sequence of water-yielding geologic units that underlie the area. Water-yielding units, in descending order, include: floodplain alluvium, Bidahochi Formation, Chinle Formation, Moenkopi Formation, Coconino Sandstone, and Supai Formation. Other geologic units, such as Quaternary gravels, basaltic lava flows, and Cretaceous sediments are present, but yield little or no groundwater in the study area.

HYDROGEOLOGIC UNITS

Discussion of geologic features in the study area was modified from previous reports by Harrell and Eckel (1939), Akers (1964), Mann (1976), and Mann and Nemecek (1983); discussion of many hydrologic features were also adapted and modified from those reports. Outcrop patterns of hydrogeologic units and locations of principal geologic structures in the study area are shown on **Figure 2**. Records for selected wells are summarized in **Table 1**. The well-numbering system used in this report is described in **Appendix A**.

FLOODPLAIN ALLUVIUM

Holocene floodplain alluvium along the Little Colorado and Puerco Rivers could supply moderate to substantial quantities of groundwater in the study area. The floodplain alluvium aquifer along the Little Colorado River is little used because larger and more dependable supplies are readily available from the underlying Coconino aquifer. Groundwater in floodplain alluvium along the Puerco River has been developed more extensively because groundwater in underlying units is of poor chemical quality. Total withdrawal of groundwater from the floodplain alluvium in Navajo and Apache Counties was estimated to be about 1,500 acre-feet per year (ac-ft/yr) during the 1970s (Mann, 1976; and Mann and Nemecek, 1983).

Floodplain alluvium along Milky and Beaver Dam Washes, which drain a large part of the NZ Properties and are tributary to the Little Colorado River, may yield moderate quantities of groundwater for agricultural use. The chemical quality of groundwater in the alluvium may be marginal for irrigation purposes, but is expected to be substantially better than groundwater in the underlying Coconino aquifer near these two drainages. Test drilling would be required to evaluate the quantity and quality of groundwater available from the floodplain alluvium along Milky Wash and Beaver Dam Wash. Sustainable yields from individual wells completed in the alluvial aquifer are unknown, but are expected to be less than 200 gallons per minute (gpm). This estimate of well yield is based on experience with drainages of similar size, and the existence of abundant fine-grained material in the drainage basins.

BIDAHOCHI FORMATION

The Tertiary Bidahochi Formation is composed of poorly to moderately consolidated sand, silt, and conglomerate. The Bidahochi Formation yields moderate amounts of good quality groundwater north and east of the study area, but is generally not saturated in and near the NZ Properties.

CHINLE FORMATION

The Triassic Chinle Formation ranges in thickness from zero at its erosional margin to about 1,600 feet in the northern part of the NZ properties. The Chinle Formation is comprised of mudstones and siltstones that form the "Painted Desert", and contains abundant petrified wood in the area. Two principal water-yielding members exist in the Chinle Formation, the Shinarump Conglomerate and the Sonsela Sandstone; other members of the formation are poorly to non-water yielding. The Shinarump Conglomerate member at the base of the Chinle Formation commonly yields 5 to 50 gpm of groundwater to wells. Water quality in the Shinarump is fair to poor, and may have large amounts of radioactivity, due to uranium content. The Sonsela

Sandstone member occurs near the middle of the Chinle Formation and is water yielding only in the north part of the NZ Properties. Well yields and water quality from the Sonsela are similar to the Shinarump. Neither the Shinarump nor the Sonsela are expected to provide sufficient yield to wells to be used as a source of groundwater supply for the NZ Properties.

MOENKOPI FORMATION

The Triassic Moenkopi Formation crops out at land surface in much of the south and west parts of the area, including the southwest corner of the NZ Properties. Sandstones in the upper and lower Moenkopi Formation yield 5 to 30 gpm of poor quality groundwater. Because of the poor quality, it is important to prevent this water from draining into the underlying Coconino aquifer by way of improperly constructed wells. The middle part of the Moenkopi Formation generally contains gypsum beds. In areas where the gypsum beds are near land surface, the gypsum mitigates the soil-clotting effect of large sodium concentrations in groundwater from the Coconino aquifer. This mitigation is especially important in the Joseph City area. Gypsum-yielding Moenkopi Formation outcrops occur in the southwest part of the NZ Properties, where the Coconino aquifer yields groundwater containing relatively small amounts of sodium.

COCONINO AQUIFER

The Coconino aquifer underlies the entire study area and comprises the Permian Kaibab Limestone and Coconino Sandstone. The Kaibab Limestone is present only in the southeast and southwest parts of the study area **(Figure 2)** and, owing to the presence of fractures and solution features, is important chiefly as a potential medium for infiltration of water to recharge underlying water-yielding units. The Coconino Sandstone consists of weakly to strongly cemented, well sorted, quartz grains, which typically display cross-bedding in outcrop. The cross-bedding and associated joints generally increase the permeability of the formation. Coconino Sandstone is exposed at land surface only in the southwest part of the study area, chiefly along Silver Creek between Holbrook and Snowflake **(Figure 2)**.

The Coconino aquifer is the principal source of groundwater in the study area and in much of northern Arizona, extending over an area of more than 27,000 square miles in Arizona and New Mexico (Hart and others, 2002). The aquifer ranges in thickness from about 200 to 800 feet in the study area, and is 200 to 300 feet thick underlying the NZ Properties. Depth to the top of the Coconino aquifer ranges from at land surface locally in the southwest part of the area, to more than 1,600 feet in the north part. Altitude of the top of the Coconino aquifer ranges from 4,300 feet above mean sea level in the north part of the study area to more than 6,000 feet at the south, as shown on **Figure 3**. The top of the Coconino aquifer slopes toward the north **(Figure 3)**.

Groundwater in the Coconino aquifer locally may occur under artesian or confined conditions, especially in the north and northeast parts of the area; in other parts of the area groundwater occurs under water table or unconfined conditions. Water levels in wells completed in the Coconino aquifer range from flowing at land surface to about 400 feet below land surface. In the NZ Properties area, non-pumping groundwater levels generally range from less than 30 feet below land surface to nearly 200 feet. Some wells with shallow water levels are reported to flow at land surface during winter months. Well yields range from less than 50 gpm to more than 2,500 gpm. The Coconino aquifer generally yields more than 500 gpm to wells in the vicinity of the NZ Properties.

SUPAI FORMATION

The Supai Formation, of Permian and Pennsylvanian age, underlies the Coconino aquifer throughout the study area. The Supai Formation is not important as a water-yielding unit in the study area, but has a substantial impact on water resources because of the presence of saline evaporite minerals in the upper part of the Supai Formation. The presence of these salt deposits results in adverse affects on groundwater quality through upward movement of water from the Supai Formation into the overlying Coconino aquifer throughout a large area.

GEOLOGIC STRUCTURE

Throughout the area, the dominant structural feature is a regional inclination, or geologic dip, of most sedimentary units to the north at about 40 feet per mile. This general northward dip is altered in several locations by folds and faults, especially the Holbrook Anticline and Dry Lake Syncline in the southwest part of the area **(Figure 3)**. Folding and faulting of the geologic units appear to have only minor effects on the direction of groundwater movement. However, major folding along the Holbrook Anticline, and near St. Johns, appears to allow upward movement of saline groundwater from the Supai Formation to overlying units. Faults are not presently known to occur on the NZ Properties.

OCCURRENCE OF SALINE MINERAL EVAPORITE DEPOSITS

Evaporites are present in the upper Supai Formation throughout most of the study area. Extensive deposits of saline evaporite minerals, which include halite, gypsum, and anhydrite, occur in an area that has been referred to as "The Holbrook Salt Basin" (Rauzi, 2000). Aggregate thickness of the sequence of salt deposits in the study area has been estimated by Rauzi (2000) and is shown on **Figure 4**. Maximum thickness of the sequence of salt deposits is about 600 feet, and occurs in the area of the NZ Properties. A zone of potash minerals was also mapped by Rauzi (2000); the potash zone extends over about 600 square miles. Maximum thickness is reported to be about 38 feet. Rauzi (2000) states that "[t]he area underlain by potash is nearly coincident with the approximate center of the Holbrook Salt Basin…" **(Figure 4)**.

Altitude of the top of evaporite deposits has been mapped by Rauzi (2000) and is shown on **Figure 5**. Altitudes range from about 4,000 to more than 5,500 feet above mean sea level. Depth below land surface to the top of evaporite deposits ranges from about 800 to more than 1,800 feet.

Rauzi (2000) reports that caverns have been leached into the salt deposits for storage of liquefied petroleum gas (LPG). The caverns are reported to range from 120 to 220 feet in height with a maximum radius of 118 feet. Cavern volumes are sufficient to store up to 9.6 million gallons of LPG (Rauzi, 2000, p. 17). Potential for development of additional caverns and opportunities for substantial gas storage exist in the area of the salt basin.

GROUNDWATER FEATURES

On a regional scale, groundwater movement in the Coconino aquifer is northward from areas of recharge toward the area of discharge. Recharge chiefly occurs in the higher altitude, southern part of the study area as a result of infiltration of stream runoff and snowmelt. Some groundwater is discharged to the Little Colorado River and Silver Creek within the study area, although this discharge may have decreased during the past 50 years as a result of groundwater pumping. Most groundwater moves northward from the study area as underflow beneath the Little Colorado River, and continues to move north and northwest, toward the ultimate discharge area near Blue Springs, near the mouth of the Little Colorado River.

Altitude of the potentiometric surface for the Coconino aquifer ranges from 4,800 feet near the north limit of the area to 6,000 feet in the recharge area, as shown on **Figure 6**. The gradient of the potentiometric surface for the Coconino aquifer generally is about 20 feet per mile. Thus, the slope of the "water table" is only half as steep as the dip of the aquifer, which is about 40 feet per mile.

GROUNDWATER WITHDRAWALS AND WATER-LEVEL CHANGES

Principal centers of groundwater withdrawal in the study area are in the vicinity of Joseph City, Holbrook, Snowflake, Hay Hollow, and Hunt. Because their locations are near or adjacent to the NZ Properties, withdrawals in the Snowflake, Hay Hollow, and Hunt areas could possibly have discernible impacts on groundwater conditions on the NZ Properties. Total groundwater withdrawals in the study area are estimated to be about 35,500 ac-ft/yr (ADWR, 1994a, 1994b, and 1994c), with the largest demand being for industrial purposes. Groundwater levels in most of the study area are concluded to be largely unchanged from pre-development conditions. Areas of groundwater level decline are limited to near developed areas where groundwater withdrawals occur for irrigation, municipal, and industrial uses.

Records indicate that combined groundwater withdrawal for irrigation, municipal, and industrial uses in the Joseph City area was about 15,000 acre feet in 1997 – an increase of 1,000 acre feet over use in 1984. Hydrographs of groundwater levels in selected wells in the area are shown on **Figure 7**; groundwater-level declines generally have been less than 10 feet since the 1960s. However, review of water-level records for well (A-18-19)17adc, located at Joseph City, indicates decline of more than 30 feet. Groundwater levels in wells (A-17-20)06acb and (A-17-21)10cba **(Figure 7)**, located near Holbrook, indicate no water level change or decline of less than 10 feet.

Combined irrigation, municipal, and industrial groundwater withdrawals in the Snowflake area were estimated to be about 22,600 acre feet in 1972 (Mann, 1976), and about 20,000 ac-ft/yr in the 1990s (ADWR, 1994a and 1994b). Groundwater level in well (A-12-22)19add, located several miles south from Snowflake, indicates no change; groundwater level in well (A-13-21)34dcc_2 , located several miles southwest from Snowflake, indicates decline of about 40 feet has occurred since 1965 **(Figure 7)**. Continued large groundwater withdrawals in this area could eventually affect groundwater levels in the southwest part of the NZ Properties.

Current groundwater withdrawals in and near NZ Properties are poorly documented. Groundwater withdrawals in the 1970s and 1980s were estimated to be about 1,100 ac-ft/yr at Hay Hollow and about 4,500 ac-ft/yr near Hunt. ADWR (1994a and 1994b) estimated groundwater withdrawal to be about 2,100 ac-ft/yr at Hay Hollow and 670 ac-ft/yr at Hunt in the early 1990s. Water-level decline of about 50 feet has been documented since 1951 in well (A-15-23)28dcc_1 located near Hay Hollow, and decline of about 25 feet since 1954 was documented in well (A-14-26)18dbc, located at Hunt **(Figure 7)**.

GROUNDWATER QUALITY

Chemical quality of groundwater in the study area differs from one aquifer to another and from place to place within a single aquifer. Total dissolved solids (TDS) content in groundwater in the Coconino aquifer ranges from less than 200 milligrams per liter (mg/L) near the south boundary of the study area, to more than 60,000 mg/L north of the Little Colorado River, as shown on **Figure 8**. TDS of sea water is about 37,000 mg/L. Also shown on **Figure 8** are Stiff diagrams (Stiff, 1951), which are used to classify water samples by their principal chemical characteristics. The shape of the Stiff diagram provides a means of comparing, correlating, and characterizing chemical water types and the width of the diagram is proportional to the total ionic content. Groundwater containing less than 500 mg/L of TDS is generally a calcium-bicarbonate type. Increases in TDS, and a change to sodium-chloride type water, are associated with upward leakage of groundwater from underlying salt beds in the Supai Formation. The increase in TDS occurs in a broad zone near the middle of the NZ Properties **(Figure 8)**.

Mann and Nemecek (1983, p. 15) state that, "…dissolved-solids concentration in water in the Coconino aquifer is related closely to geologic structure…." Leakage of saline water occurs along anticlinal folds that fracture confining beds overlying the salt deposits. Such leakage apparently occurs in the Hunt area, and northwest of Snowflake, along the Holbrook anticline.

Another important influence on groundwater quality is the location of the Little Colorado River, which generally coincides with northward change from good to poor water quality. This change in water quality suggests that groundwater discharge to the Little Colorado has flushed saline water from the aquifer on south side of the River. This flushing occurred primarily in past periods of larger recharge, but may continue at present in the Holbrook-Joseph City area.

Groundwater of good chemical quality, less than 500 mg/L of TDS, occurs in the Coconino aquifer in the south and west parts of the NZ Properties. Groundwater quality deteriorates to the northeast and is unsuitable for most uses in the northeast part of the NZ Properties. Results of laboratory chemical analyses for common constituents in groundwater from the Coconino aquifer in the study area are summarized in **Table 2**. Results of laboratory chemical analyses for trace elements in groundwater from the Coconino aquifer in the study area are summarized in **Table 3**.

Water quality in alluvial aquifers along Milky and Beaver Dam Washes is of interest because of potential use for irrigation. Water from the Coconino aquifer in those areas would be unsuitable for irrigation, except in the lower reaches of the streams. Results of laboratory chemical analyses are available for two groundwater samples from the alluvial aquifer along Milky Wash; TDS concentrations were 947 and 2,160 mg/L. Additional test drilling and water-quality sampling would be necessary to characterize the water quality in the alluvial aquifers.

GROUNDWATER QUALITY CONCERNS

There are several concerns regarding groundwater quality in the vicinity of the NZ Properties:

- Water quality in the Coconino aquifer is poorly defined. Existing data are both sparse and of questionable reliability. Although the analyses may be correct, the chemistry may often reflect the influence of downward leakage from the Moenkopi Formation, because of poorly constructed wells.

- Salinity of groundwater in the Coconino aquifer may increase with depth. Mann (1976) notes several instances of this relationship in Navajo County. Long-term pumping could lead to long-term increases in salinity of pumped water.

- Sustained, large groundwater withdrawals in the south part of the NZ Properties could lead to slow and long-term lateral migration of more saline water from the north. The potential for long-term salinity changes should be evaluated.

- The quality and quantity of groundwater in alluvial aquifers along Milky and Beaver Dam Washes is essentially undefined. Both the quality and quantity of water available from the alluvial aquifers should be evaluated if irrigated agriculture is contemplated in those areas.

REFERENCES CITED

Akers, J.P., 1964, **Geology and ground water in the central part of Apache County, Arizona:** U.S. Geological Survey Water-Supply Paper 1771, 107 p.

Arizona Department of Water Resources, 1994a, **Inventory of irrigation, reservoirs, and stockponds in the upper Little Colorado River Watershed:** Arizona Department of Water Resources, Phoenix, Little Colorado Settlement Committee Group "A" -- In-basin Negotiating Committee, July 1994, 14 p.

______, 1994b, **Inventory of irrigation and reservoirs in the lower Little Colorado River Watershed:** Arizona Department of Water Resources, Phoenix, Little Colorado Settlement Committee Group "A" -- In-basin Negotiating Committee, September 1994, 16 p.

______, 1994c, **Inventory of industrial/commercial, mining, and power uses in the Little Colorado River system:** Arizona Department of Water Resources, Phoenix, Little Colorado Settlement Committee Group "A" -- In-basin Negotiating Committee, July 1994, 15 p.

Brown, D.E., Carmony, N.B., and Turner, R.M., **Drainage map of Arizona showing perennial streams and some important wetlands:** Arizona Game and Fish Department unnumbered map report, 1 sheet, scale 1:1,000,000.

Harrell, M.A., and Eckel, E.B., 1939, **Ground-water resources of the Holbrook Region, Arizona:** U.S. Geological Survey Water-Supply Paper 836-B, 86 p.

Hart, R.J., Ward, J.J., Bills, D.J., and Flynn, M.E., 2002, **Generalized hydrogeology and ground-water budget for the C-aquifer, Little Colorado River basin and parts of the Verde and Salt River basins, Arizona and New Mexico:** U.S. Geological Survey, Water-Resources Investigations Report 02-4026, 47 p.

Mann, L.J., 1976, **Ground-water resources and water use in southern Navajo County, Arizona:** Arizona Water Commission Bulletin 10, 106 p.

Mann, L.J., and Nemecek, E.A., 1983, **Geohydrology and water use in southern Apache County, Arizona:** Arizona Department of Water Resources Bulletin 1, 86 p.

Rauzi, S.L., 2000, **Permian salt in the Holbrook basin, Arizona:** Arizona Geological Survey Open-file Report 00-03, 21 p.

Stiff, H.A., Jr., 1951, **The interpretation of chemical water analysis by means of patterns:** Journal of Petroleum Technology, V. 3, No. 10, p.15-17.

White, N.D., Stulik, R.S., Morse, E.K., and others, 1963, **Annual report on ground water in Arizona, spring 1962 to spring 1963:** Phoenix, Arizona State Land Department Water-Resources Report Number 15, 136 p.

Wilson, E.D., Moore, R.T., and O'Haire, R.T., 1960, **Geologic map of Navajo and Apache Counties, Arizona:** Arizona Bureau of Mines, University of Arizona, Tucson, Arizona, 1 sheet, scale 1:375,000.

APPENDIX A

WELL NUMBERING SYSTEM

The well numbers used in this report are in accordance with the Bureau of Land Management's system of land subdivision. The land survey in Arizona is based on the Gila and Salt River meridian and base line, which divide the state into four quadrants. These quadrants are designated, counter-clockwise, by the capital letters A, B, C, and D. All land north and east of the point of origin is in quadrant A; all land north and west of the origin is in quadrant B; all land south and west of the origin is in quadrant C; and all land south and east of the origin is in quadrant D. The first digit of a well number indicates the township, the second digit the range, and the third digit the section in which the well is located. The lowercase letters a, b, c, and d after the section number indicate the well location within the section. The first letter denotes a particular 160-acre tract or quarter section; the second letter denotes the 40-acre tract or quarter-quarter section; and the third letter denotes the 10-acre tract or quarter-quarter-quarter section. These letters are also assigned in a counter-clockwise direction, beginning in the northeast quarter. As shown on **Figure A-1**, well number (A-15-23)26dcc$_1$ designates the well as being located in the Southwest ¼, Southwest ¼, Southeast ¼ of Section 26, Township 15 North, Range 23 East. Where more than one well is located within a 10-acre tract, consecutive numbers beginning with "1" may be added as suffixes.

Where a section is more than 1 mile in any dimension, the section number applies as usual. The oversized section is divided so that a full square-mile unit of the section is adjacent to a normal section within the same township; the remainder is considered as a separate unit of land. Appropriate N, S, E, or W letters are assigned to the units, depending on where they lie in relation to the full square-mile unit. A well would be designated with the appropriate letter following the section number in which the well is located.

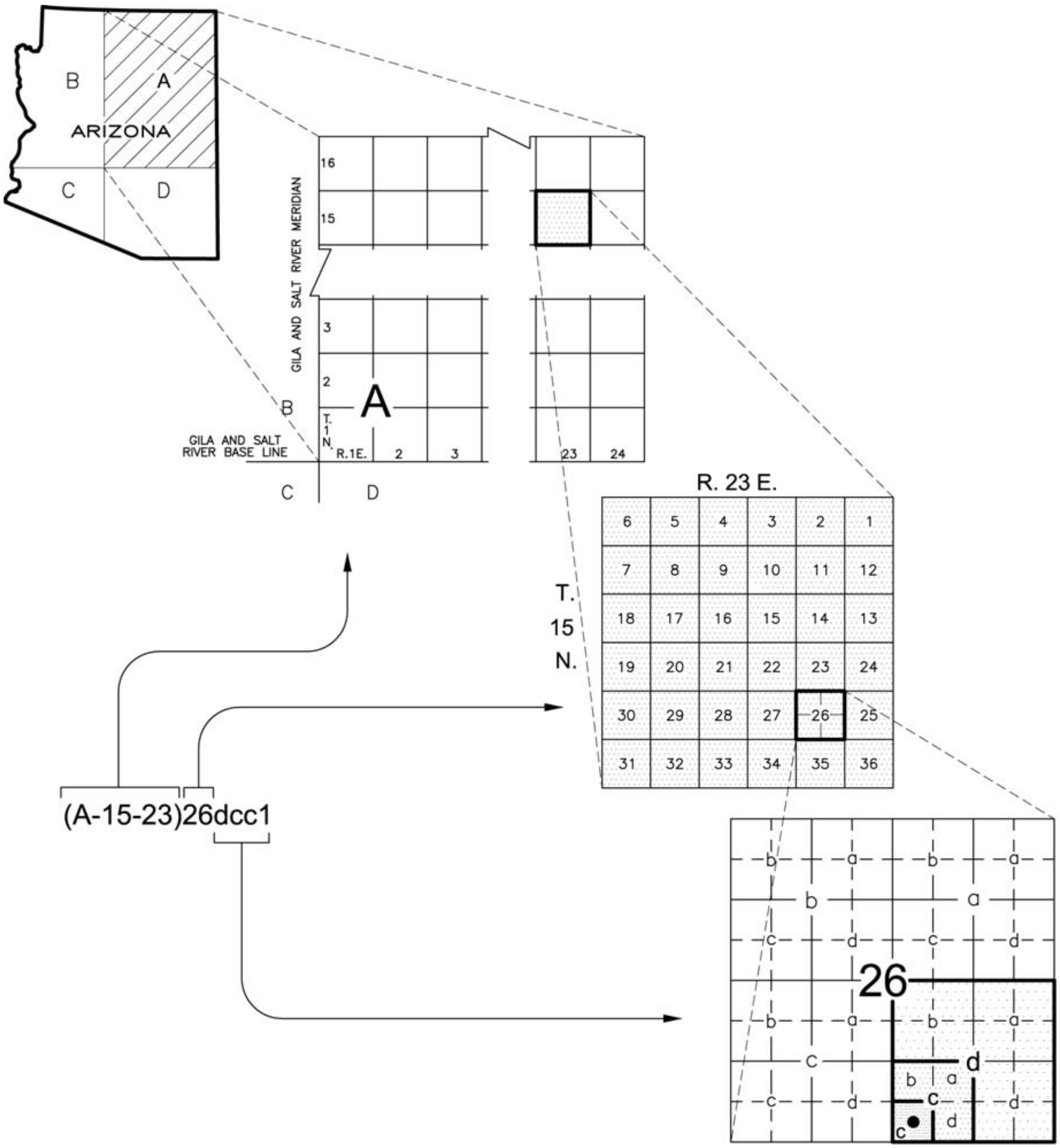

FIGURE A-1. WELL NUMBERING DIAGRAM