Appendix E

Turlock Groundwater Basin Study

TURLOCK GROUNDWATER BASIN WATER BUDGET 1952-2002

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Prepared for
Turlock Groundwater Basin Association

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1.0 INTRODUCTION

1.1 Purpose of the Study

The Turlock Groundwater Basin Association was established to coordinate the common interests of local public agencies in the utilization and protection of groundwater within the Turlock basin. The members include the City of Ceres, City of Hughson, City of Modesto, City of Turlock, Denair Community Services District, Hilmar County Water District, Ballico-Cortez Water District, Eastside Water District, Merced Irrigation District, Turlock Irrigation District, Stanislaus County, and Merced County. A particular common interest of the Association is the groundwater budget for the Turlock basin. This report describes the groundwater budget for the Turlock basin for 1952-2002, which was prepared for the Association. The Delhi County Water District participated in the study, but it is not a member of the Association.

The groundwater budget represents a quantification of the water inflows to, and outflows from the groundwater basin. The inflows represent the replenishment of groundwater. The principal inflow is the deep percolation water from agricultural irrigation. The outflows represent the depletion of groundwater. The principal outflow is groundwater pumping for agricultural and municipal uses. The difference between the inflows and outflows determines the groundwater-level trends within the basin. If the total inflows exceed the total outflows, groundwater levels rise and the volume of groundwater stored increases within the basin. Likewise, if the total outflows exceed the total inflows, groundwater levels decline and the volume of groundwater stored decreases within the basin.

The Turlock groundwater basin comprises an area of about 350,000 acres or 540 square miles. The basin is bounded on the north by the Tuolumne River, on the west by the San Joaquin River, on the south by the Merced River, and on the east by the rocks of the Sierra Nevada foothills (Figure 1.1). These boundaries for the most part isolate the Turlock basin from the groundwater conditions outside its boundaries, and the groundwater conditions outside the Turlock basin for the most part have little impact within the basin. Correspondingly, the groundwater conditions within the Turlock basin for the most part have little impact on the groundwater conditions outside the basin. However, where significant groundwater pumping occurs near the Tuolumne or Merced rivers, that pumping can cause identifiable groundwater impacts on the opposite side of the river.

1.2 Cultural Setting

The Turlock basin contains both large urban and large agricultural areas (Figure 1.1). The urban areas cover about 20,000 acres or 6 percent of the basin. The agricultural areas with irrigated crops cover about 250,000 acres or 72 percent of the basin. The remaining percentage includes areas of non-irrigated crops and native vegetation. The urban and irrigated agricultural areas are located primarily within the western and central parts of the Turlock basin. The native areas are located mostly within the eastern part of the basin.

Nine communities are located within the basin (Figure 1.2). These include the cities of Ceres, Hughson, and Turlock, part of the city of Modesto, and the communities of Delhi, Denair, Hickman, Hilmar, and Keyes. Groundwater is the water-supply source for these communities. The current groundwater pumping for these communities is about 42,000 acre-feet per year (acre-ft/yr). Figure 1.3 shows the annual pumping for 1952-2002.

Four agricultural water agencies are located within the Turlock basin (Figure 1.2). These are the Ballico-Cortez Water District, Eastside Water District, Turlock Irrigation District, and part of the Merced Irrigation District, which currently and collectively includes about 193,000 acres of irrigated land. Groundwater is the sole water-supply source within the Ballico-Cortez and Eastside water districts, except for small areas intermittently irrigated from surface-water sources. Surface water is the principal water-supply source within the Merced and Turlock irrigation districts, but supplemental groundwater is pumped. The Turlock Irrigation District diverts from the Tuolumne River, while the Merced Irrigation District diverts from the Merced River. The annual diversion from the Tuolumne River is about 540,000 acre-ft/yr. The annual diversion from the Merced River to irrigate lands within the Turlock basin is about 20,000 acre-ft/yr. The total groundwater pumping within the four districts is about 300,000 acre-ft/yr. Figure 1.4 shows the combined annual diversions from the Tuolumne and Merced rivers for 1952-2002, and Figure 1.5 shows the combined agricultural irrigation groundwater pumping within the four districts for 1952-2002.

1.3 Geologic Setting

The Turlock groundwater basin represents a subbasin of the San Joaquin Valley groundwater basin, a northward trending trough filled with marine and continental sediments of Cretaceous age (140 million years ago) through Quaternary age (through today) that are as much as 16,000 ft in thickness within the western part of the Turlock basin (California Division of Mines and Geology, 1966a). The Turlock groundwater basin occurs within marine deposits of Eocene age (55 to 34 million years ago) and continental deposits of Miocene age (beginning 24 million year ago) to Holocene age (through today). The continental sediments were deposited as westward-dipping units principally by the Tuolumne and Merced rivers, and their ancestral equivalents (Figure 1.6).

The base unit of the groundwater system is the Ione Formation. The Valley Springs and Mehrten formations overlie the Ione Formation. Three units that represent separate alluvial-fan episodes in turn overlie the Mehrten Formation. Those units are the Turlock Lake, Riverbank, and Modesto formations. Both the Modesto and Turlock Lake formations contain lake and flood-plain deposits. Where those fine-grained deposits occur within the Turlock Lake Formation, they are referred to as the Corcoran Clay. Where those deposits occur in the Modesto Formation, they are referred to as the shallow aquitard. Figures 1.7 and 1.8 show the generalized extent, thickness, and stratigraphic position for the hydrogeologic units comprising the groundwater system, including the Corcoran Clay and shallow aquitard.

The Modesto Formation, which is of late Pleistocene age (about 1 million years ago to today), outcrops in the western one-third of the study area (Figures 1.7 and 1.8) and is as much as 120 ft in thickness. The formation consists of gravel, sand, and silts with rapid coarseness changes, which yields moderate to large quantities of water to wells. The shallow aquitard member of the Modesto Formation occurs only within the western part of that formation (Figure 1.7), and does not crop out at the land surface (Figure 1.8). The unit is comprised of silt and clay with some sand. The shallow aquitard is encountered 30 to 50 ft below the land surface, and is as much as 15 feet in thickness.

The Riverbank Formation, which is of middle Pleistocene age (about 1.5 million to 1 million years ago), underlies the extent of the Modesto Formation and crops out in the central portion of the Turlock groundwater basin (Figures 1.7 and 1.8). The thickness of the unit increases westward, but the thickness generally is less than 200 ft. The formation consists primarily of sand with scattered gravel and silt lenses, and yields moderate to large quantities of water to wells. The unit tends to coarsen upward (Marchand and Allwardt, 1981).

The Turlock Lake Formation, which is of early Pleistocene and late Pliocene age (2.5 million to 1.5 million years ago), underlies the Riverbank Formation and crops out in the eastern part of the Turlock groundwater basin (Figures1.7 and 1.8). The thickness of the unit increases westward, but the thickness generally is less than 600 feet. The formation consists of mostly fine sand and silt (Marchand and Allwardt, 1981), and yields moderate to large quantities of water to wells. The Corcoran Clay member of the Turlock Lake Formation (Figures 1.7 and 1.8) ranges in thickness from 10 to 80 feet. The Corcoran Clay lies in the upper part of the Turlock Lake Formation. The unit does not crop out, and occurs only within the western portion of the Turlock groundwater basin.

The Mehrten Formation, which is of Miocene to late Pliocene age (5 million to 2.5 million years ago), underlies the Turlock Lake Formation and crops out on the eastern edge of the Turlock groundwater basin (Figures 1.7 and 1.8). The thickness of the unit increases westward, but the thickness generally is less than 800 ft. The formation consists of claystone, siltstone, sandstone, and conglomerate; yields small to moderate quantities of water to wells; and is saline within the western and central parts of the Turlock groundwater basin.

The Valley Springs Formation, which is of Miocene age (24 million to 5 million years ago), underlies the Mehrten Formation and crops out on the eastern edge of the Turlock groundwater basin (Figures 1.7 and 1.8). The thickness of the unit increases westward, but the thickness generally is less than 500 ft (Page and Balding, 1973). The formation consists of siltstone and claystone deposited mostly by rivers with occasional ash deposits, and yields small quantities of water to wells due to the fine ash and clay matrix (Page, 1986).

The Ione Formation, which is of late Eocene age (40 million to 34 million years ago), underlies the Valley Springs Formation and crops out on the eastern edge of the Turlock groundwater basin (Figures 1.7 and 1.8). The thickness of the unit increases westward, but the thickness generally is less than 200 ft (Page and Balding, 1973). The formation consists of clay, sand, sandstone, and conglomerate; yields only small quantities of water to wells; and is saline throughout much of the Turlock groundwater basin (Page, 1986).

1.4 Hydrologic Setting

1.4.1 Description of Aquifers

The groundwater system consists of three aquifers. In order of downward occurrence, these are the unconfined aquifer, freshwater confined aquifer, and the saline confined aquifer (Figure 1.8).

The unconfined aquifer occurs within the Modesto and Riverbank formations (Figure 1.8). However, this aquifer is confined locally by a discontinuous shallow aquitard that occurs within the western part of the Turlock groundwater basin. Otherwise, the unconfined aquifer is a water-table aquifer. This aquifer is about 150 ft in thickness, and the depth to its top ranges from less than 10 ft in the western part of the Turlock basin to 50 ft within the central part of the basin. Within the western part of the groundwater basin, the unconfined aquifer is underlain by the Corcoran Clay, which is about 90 ft in thickness. The unconfined aquifer is used extensively as an agricultural and municipal water supply. Wells less than about 200 ft in depth draw from the unconfined aquifer.

The freshwater confined aquifer occurs within the Turlock Lake and Mehrten formations. It is confined by the Corcoran Clay member of the Turlock Lake Formation (Figure 1.8) within the western part of the Turlock groundwater basin. It is semi-confined within the eastern part of the basin, where the Riverbank Formation directly overlies it. It is unconfined in the eastern part of the basin, where the Turlock Lake and Mehrten formations crop out. The freshwater confined aquifer is about 1,300 ft in thickness, and the depth to its top ranges from 200 ft in the western part of the Turlock basin to 100 ft within the eastern part of the basin. The freshwater confined aquifer is used extensively as an agricultural and municipal water supply. Wells greater than about 200 ft in depth draw from the freshwater confined aquifer. However, such wells will draw also from the unconfined aquifer, if the depth to the top of the well perforations is less than 200 ft.

The saline confined aquifer occurs within the Valley Springs and Ione formations (Figure 1.8). The aquifer is confined except where the formations crop out. The saline confined aquifer is about 600 ft in thickness, and the depth to its top ranges from 1,500 ft in the western part of the Turlock groundwater basin to 100 ft within the eastern part of the basin. The deep aquifer is used little as a water supply.

The discontinuous shallow aquitard, and an overlying shallow aquifer, that occurs within the unconfined aquifer causes a high groundwater table in the western part of the groundwater basin. The low vertical permeability of the shallow aquitard restricts the downward percolation of infiltrated precipitation and irrigation applications. The shallow aquifer is a water-table aquifer, and the depth to the groundwater table is generally less than 6 ft. The aquifer is about 40 ft in thickness, and the shallow aquitard forms its base. The shallow aquitard is about 15 ft in thickness.

1.4.2 Groundwater Levels

The Turlock Irrigation District and the California Department of Water Resources have collected groundwater-level data for the Turlock basin since about 1950. The District collected data from wells that monitor shallow groundwater levels within the unconfined aquifer. The Department collected data from wells that monitor intermediate-depth groundwater levels within the unconfined and freshwater confined aquifers. Groundwater-level data are not available for the saline confined aquifer.

Section corner well locations are displayed on Figure 1.9. Figures 1.10a-e show contours of the measured depth to groundwater in section corner wells at July 1960, 1970, 1980, 1990 and 2000. However, contours are not shown where the depth to groundwater is greater than 15 ft. Because the section corner wells are only about 15 feet in depth, a depth cannot be measured if the depth to groundwater is greater than 15 ft. Figures 1.11a-d respectively show temporal groundwater elevation in section corner Well 221, Well 310, Well 351, and Well 401. The locations for these wells are shown on Figure 1.9.

The depth to groundwater within the section corner wells ranges geographically from less than 4 ft to more than 15 ft (Figures 1.10a-e). The depth to groundwater within the wells at any particular time depends on a number of factors. Those include prior irrigation, precipitation, drainage pumping, and irrigation pumping. Irrigation applications and precipitation cause higher groundwater levels. Drainage pumping by the Turlock Irrigation District helps to lower groundwater levels. Private irrigation pumping also causes lower groundwater levels. The interactions between these factors cause the geographic pattern of groundwater levels to vary seasonally and inter-annually. However, groundwater levels within the section corner wells do not display a long-term trend of either increasing or decreasing.

Intermediate-depth monitoring well locations are displayed on Figure 1.12. The wells represent typical irrigation wells used by the California Department of Water Resources for monitoring wells. Figures 1.13a-d show the measured groundwater elevations in intermediate-depth monitoring wells for December 1960, November 1977, November 1986, and November 1998. These particular years were selected due to the availability of monitoring data that provide a good geographic coverage. Figures 1.14a-d respectively show temporal groundwater levels for wells 04S08E22R001M, 04S11E08A001M, 05S11E25A001M, and 06S10E16M001M. The locations for these wells are shown on Figure 1.12.

While groundwater levels within the shallow aquifer do not have a temporal trend, groundwater levels within the intermediate-depth monitoring wells do have a trend toward lower groundwater elevations. Within most of the Turlock Irrigation District the trend is small, and groundwater levels have declined less than 10 ft since 1960. However, within the central part of the Turlock basin, groundwater levels have declined as much as 90 ft since 1960 (Figures 1.13a and 1.13d). These declines occurred mostly during 1970-1990, and the current rate of decline is small (Figures 1.14b and 1.14c).

1.5 Water-Budget Equation

The water-budget equation for a groundwater basin represents an application of the law from physics of mass conservation. The mass conservation law states that for an incompressible fluid the volumetric inflow to a defined region minus the volumetric outflow from that region equals the rate of change in the fluid volume stored within the region. This law is expressed for a groundwater basin by the equation

$$\begin{bmatrix} Groundwater \\ Inflow \end{bmatrix} - \begin{bmatrix} Groundwater \\ Outflow \end{bmatrix} = \begin{bmatrix} Groundwater \\ Storage \\ Change \end{bmatrix}$$

The water budget for a groundwater basin must always balance according to this equation.

For the Turlock groundwater basin, the water budget equation in more detail has the form

$$Q_{ri} + Q_{rni} + Q_{rr} + Q_{rt} + Q_{rf} - Q_{op} - Q_{or} - Q_{oad} - Q_{ov} = \Delta S$$

where

Q_{ri} is groundwater recharge from irrigated areas (acre-ft/yr),
Q_{rni} is recharge from non-irrigated areas (acre-ft/yr),
Q_{rr} is recharge from the Tuolumne, Merced, and San Joaquin rivers (acre-ft/yr),
Q_{rt} is recharge from Turlock Lake (acre-ft/yr),
Q_{rf} is recharge from the Sierra Nevada foothills (acre-ft/yr),
Q_{op} is groundwater discharge from pumping (acre-ft.yr),
Q_{or} is discharge to the Tuolumne, Merced, and San Joaquin rivers (acre-ft/yr),
Q_{oad} is discharge to agricultural drains (acre-ft.yr),
Q_{ov} is groundwater use by riparian vegetation (acre-ft/yr), and
ΔS is the rate of change in groundwater storage (acre-ft/yr).

The compilation of the water budget for the Turlock basin involved quantifying each of the terms in this equation. Data were available to evaluate eight of the ten terms comprising the water-budget equation. Data were not available to independently quantify either the groundwater recharge from the Tuolumne, Merced, and San Joaquin rivers or the groundwater discharge to the rivers.

The water-budget terms other than the net groundwater discharge to the rivers were quantified from compiled data. Data representing the period 1952-2002 were compiled from the City of Ceres, City of Hughson, City of Modesto, City of Turlock, Denair Community Services District, Delhi County Water District, Hilmar County Water District, Ballico-Cortez Water District, Eastside Water District, Merced Irrigation District, Turlock Irrigation District, Stanislaus County, and Merced County, California Department of Water Resources, U. S. Geological Survey, and other organizations. Data were compiled on the hydrogeology of the groundwater basin, the location and construction of wells, groundwater pumping from wells, land use, canal deliveries for irrigation, crop acreages, crop consumptive use, streamflow, groundwater levels, and other subjects. Those data were analyzed to develop estimates of recharge from irrigated areas, non-irrigated areas, rivers, Turlock Lake, and the Sierra Nevada foothills. Additionally, those data were analyzed to develop estimates of discharge from pumping, seepage to rivers, seepage to agricultural drains, and groundwater use by riparian vegetation. Finally, those data were analyzed to develop estimates of changes in groundwater storage.

The net groundwater discharge to the Tuolumne, Merced, and San Joaquin rivers was derived from the quantification of the other terms within the water budget equation. The net groundwater discharge is give by the relation

$$Q_{nor} = Q_{or} - Q_{rr}$$

where Q_{nor} is the net groundwater discharge to the Tuolumne, Merced, and San Joaquin rivers (acre-ft/yr). If this equation is substituted into the water-budget equation, the relation for the net groundwater discharge to the rivers is

$$Q_{nor} = Q_{ri} + Q_{rni} + Q_{rt} + Q_{rf} - Q_{op} - Q_{oad} - Q_{ov} - \Delta S$$

The compilation of the water budget for the Turlock groundwater basin involved using the available data to quantify all right-hand terms in this equation in order to quantify the net groundwater discharge to the rivers.

2.0 LAND USE WITHIN THE TURLOCK GROUNDWATER BASIN

The Turlock groundwater basin is comprised of approximately 346,000 acres, including 250,000 acres of irrigated crops, 20,000 acres of urban development, and 72,000 acres of native vegetation. Figure 2.1 shows the Turlock groundwater basin and the boundaries of five subareas for which land-use acreages have been estimated. The Turlock Irrigation District, Eastside Water District, Ballico-Cortez Water District, and Merced Irrigation District comprise four of the subareas. Regions outside the boundaries of these districts comprise the other subarea. The subarea representing the Turlock Irrigation District includes the communities of Ceres, Delhi, Denair, Hickman, Hilmar, Hughson, Keyes, south Modesto, and Turlock.

Figures 2.2a-i show the urbanized and landscaped acreages for the nine urban communities within the Turlock Irrigation District for 1952-2002. The irrigated acreages represent areas of residential, community, and commercial landscaping. The non-irrigated acreages represent, in part, areas with an impervious surface, such as streets, buildings, parking lots, and similar covers. The non-irrigated acreages represent also areas with a pervious surface, such as vacant lots, construction sites, and similar covers.

The land uses within the Turlock Irrigation District include irrigated agricultural land, on-farm non-irrigated land, other non-irrigated land, city urban land, non-city urban land, and highways and roads. The land-use category of irrigated agricultural land is the acreage actually irrigated. The category of on-farm non-irrigated land is the on-farm area occupied by farm roads, buildings, equipment yards, and similar non-irrigated uses. The category of other non-irrigated land includes grazing land, non-irrigated cropland, and similar non-irrigated land uses. The category of city urban land is the urbanized area within a city political boundary. The category of non-city urbanized land comprises urbanized areas outside a city political boundary. The category of highways and roads is the area occupied by highways, roads, and canal and railroad right-of-ways.

Land use within the Turlock Irrigation District is shown on Figure 2.3 for 1952-2002. Figure 2.3 indicates that the total acreage within the District has remained unchanged, but the partitioning of the total acreage among irrigated, urban, and other land uses has changed over time. Most notably is the fact that the urban acreage has increased over time, while the irrigated agricultural acreage correspondingly has decreased over time. These opposite trends are a result of the urbanization of agricultural land.

The land uses within the Eastside Water District, Ballico-Cortez Water District, Merced Irrigation District, and non-district areas include irrigated agricultural land, on-farm non-irrigated land, other non-irrigated land, highways and roads, and non-city urban land. While city urban land occurs within the Turlock Irrigation District, that land-use category does not occur within these other areas. As defined before, irrigated agricultural land is the acreage actually irrigated, exclusive of on-farm non-irrigated areas. On-farm non-irrigated land is the on-farm area occupied by roads, buildings, equipment yards, and similar non-irrigated uses. Other non-irrigated land includes grazing land, non-irrigated cropland, and similar non-irrigated land uses. Non-city urbanized land comprises urbanized areas outside a city political boundary. Based on these categories, the land use within the Eastside Water District, Ballico-Cortez Water District, Merced Irrigation District, and non-district areas is shown on Figures 2.4a-g for 1952-2002.

3.0 OUTFLOWS FROM THE TURLOCK GROUNDWATER BASIN

Discharge from the Turlock groundwater basin occurs because of pumping for wells, groundwater seepage to the Tuolumne, Merced, and San Joaquin rivers, discharges from subsurface agricultural drains, and water use by riparian vegetation. The total discharge for these outflows was about 506,000 acre-ft/yr during the recent five-year period 1998-2002. The discharge for each component is described below.

3.1 Groundwater Pumping

The average groundwater pumping within the Turlock groundwater basin was about 411,000 acre-ft/yr during the recent five-year period 1998-2002, including drainage, agricultural, municipal, and private domestic pumping. The average drainage pumping was about 69,000 acre-ft/yr, while the average agricultural pumping was 296,000 acre-ft/yr. The average municipal pumping was about 42,000 acre-ft/yr. This included pumping for the communities of Ceres, Delhi, Denair, Hickman, Hilmar, Hughson, Keyes, south Modesto, and Turlock. The average private domestic pumping was about 4,000 acre-ft/yr.

To lower the high groundwater table within the western part of the Turlock groundwater basin the Turlock Irrigation District pumps from about 170 drainage wells. The average pumping from the District drainage wells was 69,000 acre-ft/yr during the recent five-year period 1998-2002. Figure 3.1 shows the annual pumping from these wells for 1952-2002.

Growers within the Turlock Irrigation District pump from about 895 wells to supplement canal deliveries. The average pumping from supplemental-source private and improvement district wells within the Turlock Irrigation District was 20,946 acre ft/yr during the recent five-year period 1998-2002. Wells of this type fall into two distinct categories. The first category is comprised of supplemental-source private and improvement district irrigation wells not rented by the Turlock Irrigation District. These are wells owned and operated for private usage. Figure 3.2 shows the annual pumping from non-rented supplemental-source wells for 1952-2002. Water from wells that are not rented irrigates crops near the non-rented well. The second category is comprised of supplemental-source private and improvement district irrigation wells that are rented by the District. These are wells owned privately, but operated publicly to supplement the Tuolumne River diversions. Figure 3.3 shows the annual pumping from rented wells. Water pumped from wells that are rented becomes part of the district-wide water supply as provided by the District.

Some growers within the Turlock Irrigation District choose not to receive annual deliveries and irrigate instead from groundwater. The average pumping from primary-source irrigation wells within the District was about 9,200 acre-ft/yr during the recent five-year period 1998-2002. However, the primary-source pumping has increased from about 4,000 acre-ft/yr in 1998 to about 13,000 acre-ft/yr in 2002. Figure 3.4 shows the annual estimated pumping from these wells.

Growers within the Eastside Water District, Ballico-Cortez Water District, and non-district area pump from about 180 wells. The average pumping from primary-source private irrigation wells within the Eastside Water District, Ballico-Cortez Water District, and non-district areas was about 250,000 acre-ft/yr during the recent five-year period 1998-2002. Figures 3.5 and 3.6 show the annual pumping from these wells, which represents the sole irrigation supply.

Growers within the Merced Irrigation District pump groundwater to supplement canal deliveries. Additionally, some growers within the District choose not to receive annual deliveries and irrigate instead from groundwater. The combined average annual pumping from the supplemental-source and primary-source private irrigation wells was 120 acre-ft/yr during the recent five-year period 1998-2002. Figure 3.7 shows the combined annual pumpage from the supplemental-source and primary-source private irrigation wells within this District for 1952-2002.

The communities of Ceres, Delhi, Denair, Hickman, Hilmar, Hughson, Keyes, south Modesto, and Turlock pump, collectively pump groundwater from approximately 76 wells. The average pumping from municipal wells was about 42,000 acre-ft/yr during the recent five-year period 1998-2002. Figures 3.9a-i show the annual pumping for municipal wells for 1952-2002.

About 3,300 residences within the Turlock groundwater basin use groundwater for domestic usage. The average pumping from private domestic wells was about 4,000 acre-ft/yr during the recent five-year period 1998-2002. Figure 3.10 shows the annual pumping from these wells.

3.2 Groundwater Discharge to Tuolumne, Merced, and San Joaquin Rivers

Groundwater discharges occur along the lower reaches of the Tuolumne and Merced rivers, and along the entire reach of the San Joaquin River. Along the upper reaches of the Tuolumne and Merced rivers, streamflow recharges the groundwater basin. However, the net effect is that the groundwater discharge to the rivers generally exceeds the streamflow recharge to the groundwater basin. Correspondingly, the net groundwater discharge to the rivers is positive. During the recent five-year period 1998-2002, the net discharge was 41,000 acre-ft/yr.

3.3 Groundwater Discharge from Subsurface Agricultural Drains

Some growers within the Turlock groundwater basin have installed subsurface drains to lower the groundwater table. If the depth to the groundwater table is within the root zone of a crop, the crop can be damaged. To prevent such damage, growers have installed perforated subsurface pipes that drain away excess groundwater. About 6,700 acres within the Turlock groundwater basin are underlain with subsurface drains. The average groundwater discharge to the drains was about 14,000 acre-ft/yr over the recent five-year period 1998-2002. Annual total discharges from all drains are shown on Figure 3.11 for 1977-2002.

3.4 Groundwater Consumed by Riparian Phreatophytes

Phreatophytes are plants that can live with their roots below or near the water table and extract their moisture requirements directly from the saturated zone or overlying capillary fringe (Freeze and Cherry, 1979). About 18,500 acres of native phreatophytes occur along the Tuolumne, Merced and San Joaquin rivers. The average groundwater consumption of the riparian phreatophytes is about 41,000 acre-ft/yr over the recent five-year period 1998-2002. The annual groundwater usage of the riparian vegetation is shown on Figure 3.12.

4.0 INFLOWS TO THE TURLOCK GROUNDWATER BASIN

Recharge to the Turlock groundwater basin results from the irrigation of crops and landscape vegetation, precipitation, percolation from the Tuolumne and Merced rivers, leakage from Turlock Lake, an underflow from the Sierra Nevada foothills, and upward seepage from deep geologic fractures. The total recharge from these sources was about 508,000 acre-ft/yr during the recent five-year period 1998-2002. The recharge for each component of the total is described below.

4.1 Groundwater Recharge from Irrigated Land

Groundwater recharge from irrigation results when the applied irrigation water and effective precipitation exceed the consumptive water use of agricultural crops or landscape vegetation. The excess water infiltrates below the root zone and then percolates downward to the groundwater table. Within the central and western parts of the Turlock groundwater basin, the percolation to the water table recharges the unconfined aquifer, because in those parts of the basin the unconfined aquifer is the water-table aquifer. Within the eastern part of the groundwater basin, the percolation recharges both the freshwater and saline confined aquifers, because in that part of the basin those aquifers respectively eastward are the water-table aquifer. Within the western part of the Turlock groundwater basin, the Corcoran Clay separates the freshwater confined aquifer from the overlying unconfined aquifer. The freshwater confined aquifer is recharged in that part of the basin by westward groundwater flow from the eastern part of the basin and locally downward groundwater flow through the Corcoran Clay. However, in the far western part of the freshwater confined aquifer, groundwater tends to move upward through the Corcoran Clay.

Within the Turlock groundwater basin, irrigation produced groundwater recharge of 427,800 acre-ft/yr over the recent five-year period 1998-2002. The recharge from croplands was 422,000 acre-ft/yr. The recharge from landscaping within urban areas was 5,900 acre-ft/yr. Figures 4.1-4.8 show the annual recharge from irrigated land for 1952-2002, which is the recharge that occurs from the combine effects of precipitation and irrigation applications. Also shown on Figures 4.1-4.8 is the recharge that would have occurred from precipitation, based on the assumption that the recharge fraction due to precipitation is the precipitation as a percentage of the total irrigation plus precipitation.

4.2 Groundwater Recharge from Non-irrigated Land

Groundwater recharge from precipitation on dry undeveloped land results when the effective precipitation exceeds the consumptive water use of the annual or perennial vegetation. Within the Turlock groundwater basin, this phenomenon produced groundwater recharge of 42,000 acre-ft/yr over the recent five-year period 1998-2002. Figure 4.9 shows the annual groundwater recharge for 1952-2002.

4.3 Recharge from Tuolumne and Merced Rivers

Streamflow within the Tuolumne and Merced rivers recharges the Turlock groundwater basin. The recharge occurs along the upper reaches of the rivers. Within the lower reaches of the Tuolumne and Merced rivers, groundwater discharges to the rivers. Additionally, groundwater discharges to the San Joaquin River along its entire reach. Within the groundwater budget for the Turlock groundwater basin, the streamflow-groundwater interactions are expressed in terms of the net groundwater discharge to the rivers.

4.4 Recharge from Turlock Lake

Turlock Lake (Figure 1.1), which has a surface area of about 3,300 acres, is an off-channel reservoir used to regulate releases into the Turlock Irrigation District canal network. Because Turlock Lake is underlain by the moderately permeable sediments of the Mehrten Formation, water leaks from the lake into the underlying and adjacent groundwater system. The average leakage is about 36,000 acre-ft/yr over the recent five-year period 1998-2002.

4.5 Recharge from Foothills and Deep Geologic Formations

The Turlock groundwater basin is recharged from subsurface inflows that enter the groundwater basin across its eastern boundary and the base of the groundwater system. The recharge from both sources is about 3,000 acre-ft/yr.

The fractured rocks that constitute Sierra Nevada foothills contain groundwater. The regional direction of groundwater flow is westward. At the eastern boundary of the Turlock groundwater basin, that westward groundwater flow produces subsurface flow into the Turlock groundwater basin. The slope of the groundwater table within the Turlock groundwater basin near its eastern boundary suggests that the subsurface flow is about 1,000 acre-ft/yr.

The marine formations that underlie the Turlock groundwater basin leak water upwards into the Ione formation. Groundwater samples from oil and gas wells indicate the leakage is saline, with dissolved solids as much as 50,000 milligrams per liter (mg/L). The excessive groundwater salinity within the deeper and more westerly parts of the Turlock groundwater basin suggests the upward leakage is about 2,000 acre-ft/yr.

5.0 CHANGE IN GROUNDWATER STORAGE

The change in groundwater storage over the recent five-year period 1998-2002 was 2,000 acre-ft/yr based on measured groundwater levels. This storage change balances the difference between the recharge and discharge for the Turlock groundwater basin, as required by the water-balance equation. The total recharge was 508,000 acre-ft/yr during the recent five-year period 1998-2002, and the total discharge was 506,000 acre-ft/yr. The recharge exceeds the discharge by 2,000 acre-ft/yr.

Groundwater level changes were estimated from the available groundwater-level data. The data included measurements by the Turlock Irrigation District within the section corner wells and measurements by the California Department of Water Resources in intermediate-depth monitoring wells. Based on these data, groundwater-level changes were estimated not only for the five-year period 1998-2002, but also for each consecutive five-year period for 1952-1997. Figures 5.1a-j show resulting contours of groundwater-level change respectively for each of the five-year periods, where the contours indicate the average annual change during a five-year period. The groundwater-storage and basin-wide average groundwater-level changes, for each consecutive five-year period for 1952-2002, are shown in Table 5.1.

Groundwater storage has been depleted within the Turlock groundwater basin. However, storage depletions did not begin until about 1963. As indicated in Table 5.1 and Figures 5.1a-b, groundwater-levels were essentially unchanged during 1952-1962. Correspondingly, groundwater storage was unchanged. However, as indicated on Figures 5.1c-h and Table 5.1, groundwater levels declined during 1963-1992. The cumulative basin-wide average groundwater-level decline was about 45 ft. Correspondingly, the cumulative storage depletion was about 1.6 million acre-ft. Nevertheless, groundwater levels again have been essentially unchanged during 1993-2002.

Groundwater-level changes within the Turlock groundwater basin have occurred mostly within the Eastside Water District, as shown on Figures 5.1c-j. While the basin-wide average groundwater-level decline was about 45 ft during 1963-1992, the maximum decline within the Eastside Water District was about 100 ft.

6.0 SUMMARY WATER BUDGET FOR TURLOCK GROUNDWATER BASIN

The water budget for the Turlock groundwater basin is listed in Table 6.1 for the five-year periods during 1953-2002. For each five-year period, the component inflows to and outflows from the groundwater basin are listed. Additionally, the changes in groundwater storage are listed. The groundwater inflows include recharge from irrigated areas, recharge from non-irrigated areas, seepage from Turlock Lake, underflow from the Sierra Nevada foothills, and upward seepage from deep geologic formations. The groundwater outflows include pumping from wells, groundwater discharge to rivers, groundwater discharge from subsurface agricultural drains, and groundwater consumption by riparian vegetation.

Table 6.1 indicates the groundwater storage within the Turlock groundwater basin was depleted during 1963-1992. The cumulative storage depletion was about 1.6 million acre-ft, which represents an average depletion of about 53,000 acre-ft/yr. However, depletions have mostly ceased. In fact, the storage within the Turlock groundwater basin has increased somewhat. The cumulative increased storage during 1993-2002 was 74,000 acre-ft, which represents an average accretion of about 7,000 acre-ft/yr. Nevertheless, groundwater storage remains substantially depleted with respect to groundwater conditions in 1962.

The slight recovery of the Turlock groundwater basin suggests that an equilibrium state, or steady state, condition has been established. The outflows from the groundwater basin are about balanced by the inflows to the basin. Correspondingly, the year-to-year groundwater storage and groundwater levels are not changing over time. This equilibrium state has been established even though groundwater pumping has increased over the last three decades. While the groundwater pumping during 1953-1957 was 404,000 acre-ft/yr, the groundwater pumping during 1998-2002 was 507,000 acre-ft/yr, which represents a 25 percent increase in pumping. The increased pumping was accompanied by a decrease in the groundwater discharges to the Tuolumne, Merced, and San Joaquin rivers. As indicated in Table 6.1, the average annual net discharge to the rivers was about 85,000 acre-ft/yr during 1953-62, but about 41,000 acre-ft/yr during 1993-2002. The increased pumping was accompanied also by the depletion of groundwater storage. As can be derived from Table 6.1, the average storage-depletion rate during 1953-2002 was about 30,000 acre-ft/yr, which occurred primarily in the eastern part of the Turlock groundwater basin.

While the groundwater basin currently is in an equilibrium state, that state most likely will not be permanent. The current equilibrium will be disrupted by any change in groundwater recharge or discharge. The most immediate disruption will be caused by increased urbanization of irrigated agricultural land within the Turlock groundwater basin. The effects of urbanization are to increase pumping and to decrease recharge, both of which will produce renewed groundwater-storage depletions. Groundwater pumping can be increased as urbanization converts agricultural land irrigated mostly with surface water to developed land supplied from groundwater. Groundwater recharge can be decreased as urbanization reduces the irrigated area and the corresponding recharge from irrigation and precipitation on irrigated areas. Without urbanization, crops cover nearly 100 percent of the land area. With urbanization, landscape vegetation covers only a small percentage of the original crop area.

Changes in crop acreages and irrigation practices also can disrupt the equilibrium of the groundwater basin. If the acreage of crops irrigated with groundwater were to increase, groundwater pumping necessarily would increase. If the acreage of crops irrigated with surface water were to change to more advanced irrigation practices groundwater recharge could decrease. This occurs because advanced irrigation technologies typically result in increased irrigation efficiency, and reduced recharge. If crops, which historically were irrigated with surface water move to groundwater, along with these advanced irrigation technologies, the impact to groundwater would be two-fold. Not only would there be reduced recharge, but there would also be additional extractions from the groundwater basin. Conversely, changes to advanced irrigation technologies for existing crops irrigated with groundwater will typically have essentially no water-budget impact. This occurs because increased irrigation efficiency through advanced irrigation technologies decreases equally both pumping and the irrigation recharge resulting from the application of the pumped water.

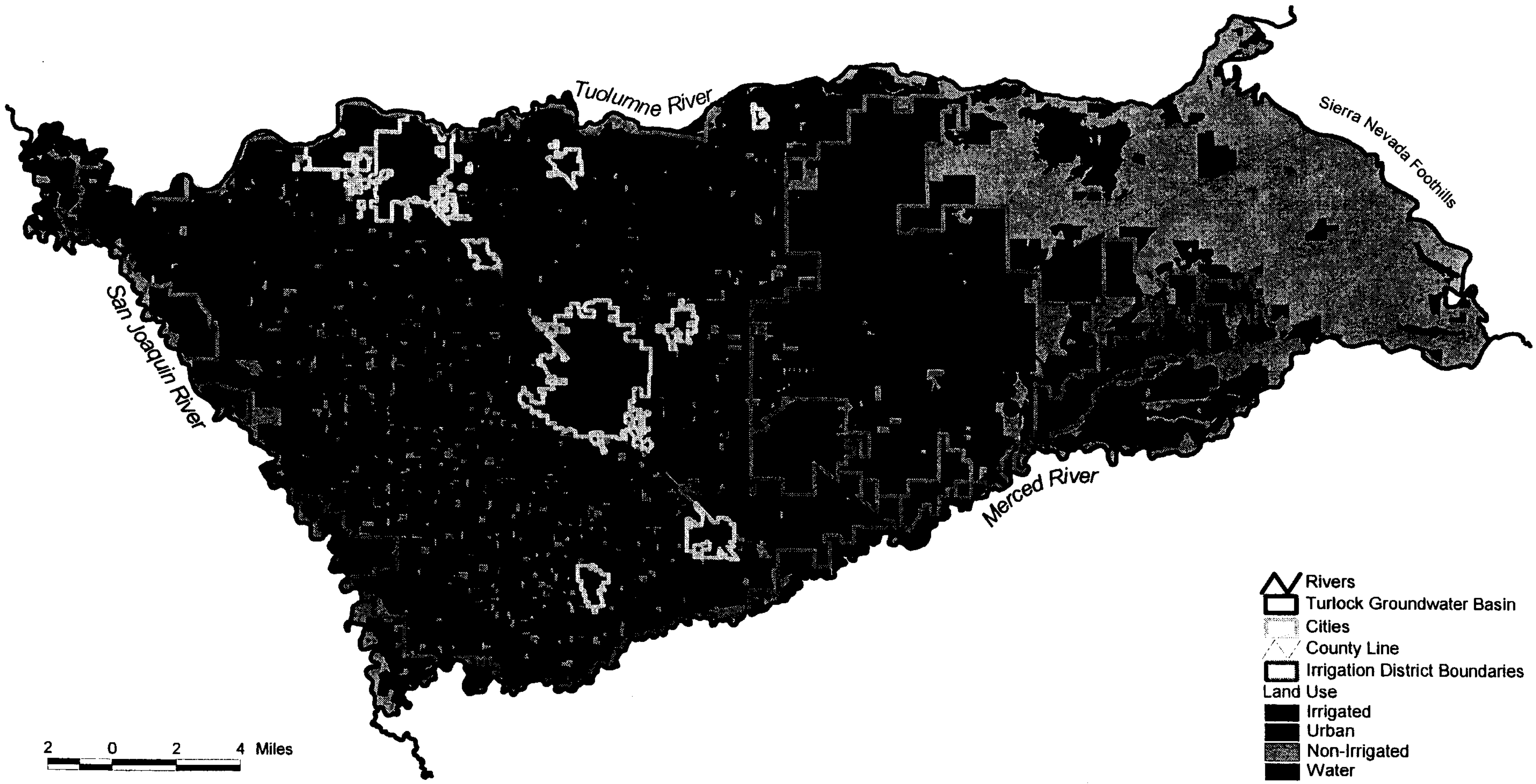

Figure 1.1 Land Use within the Turlock Groundwater Basin for 2000

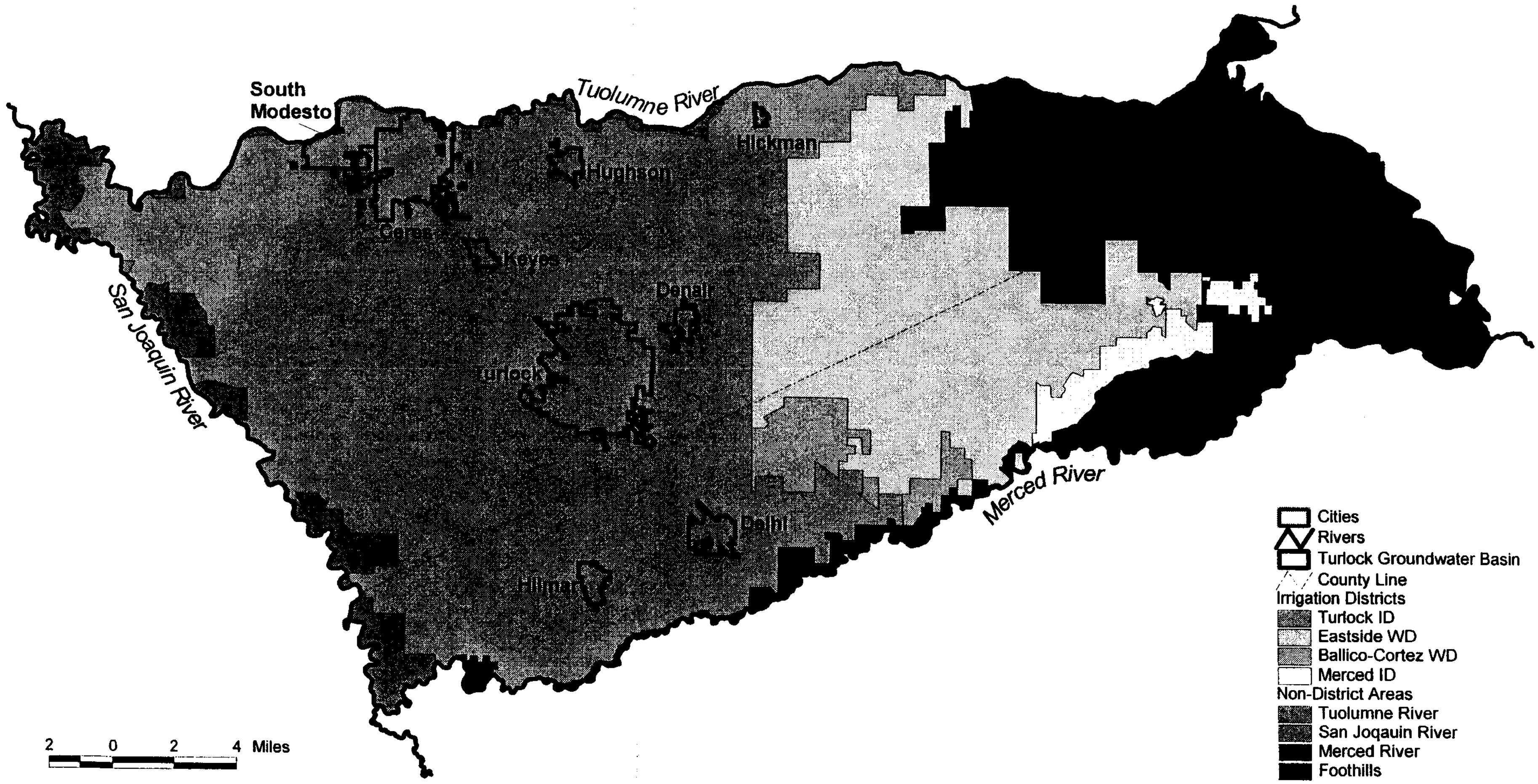

Figure 1.2 Urban Areas, Irrigation Districts, and Non-District Areas within Turlock Groundwater Basin

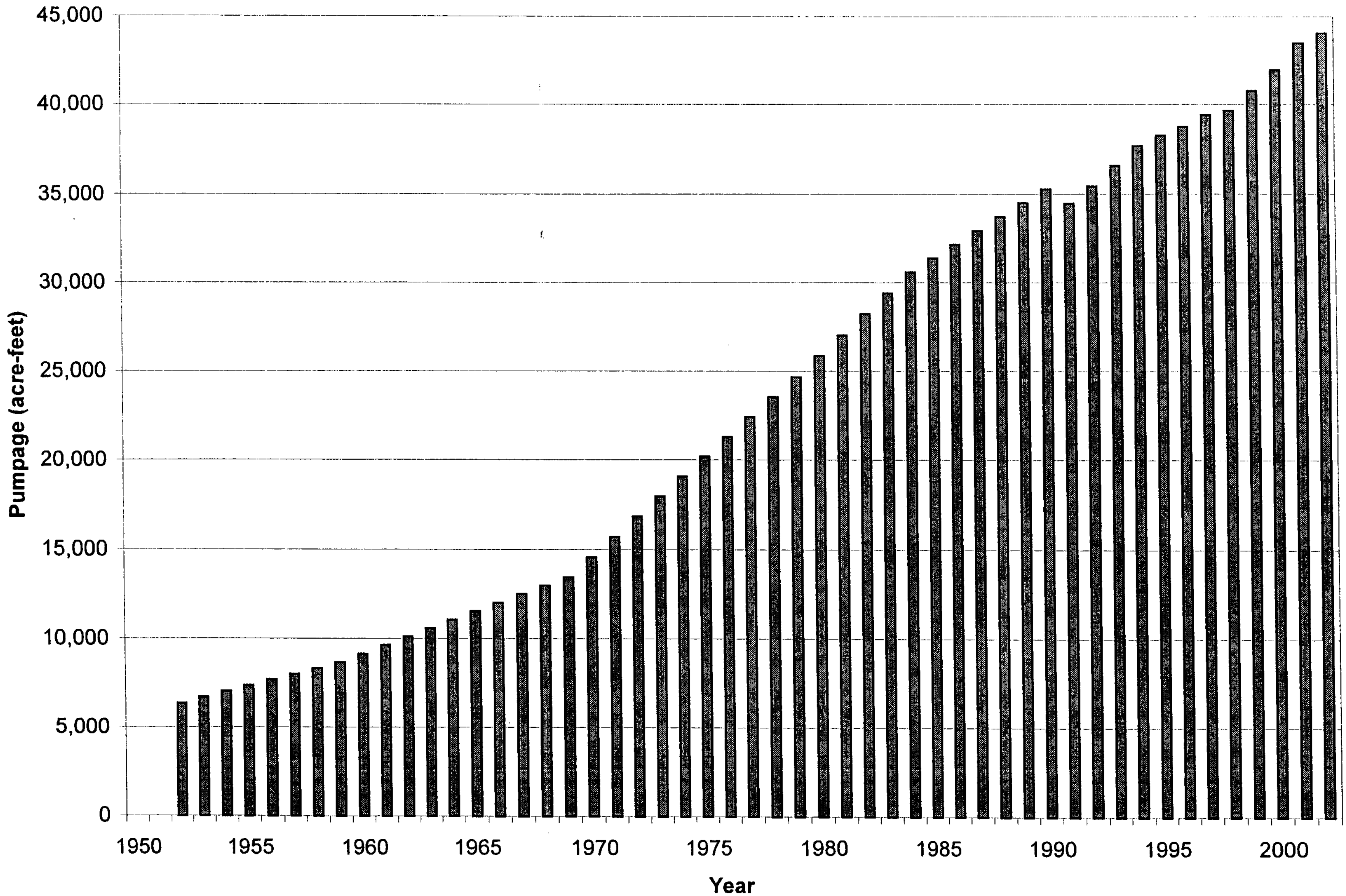

Figure 1.3 Municipal Groundwater Pumping within the Turlock Groundwater Basin, 1952-2002

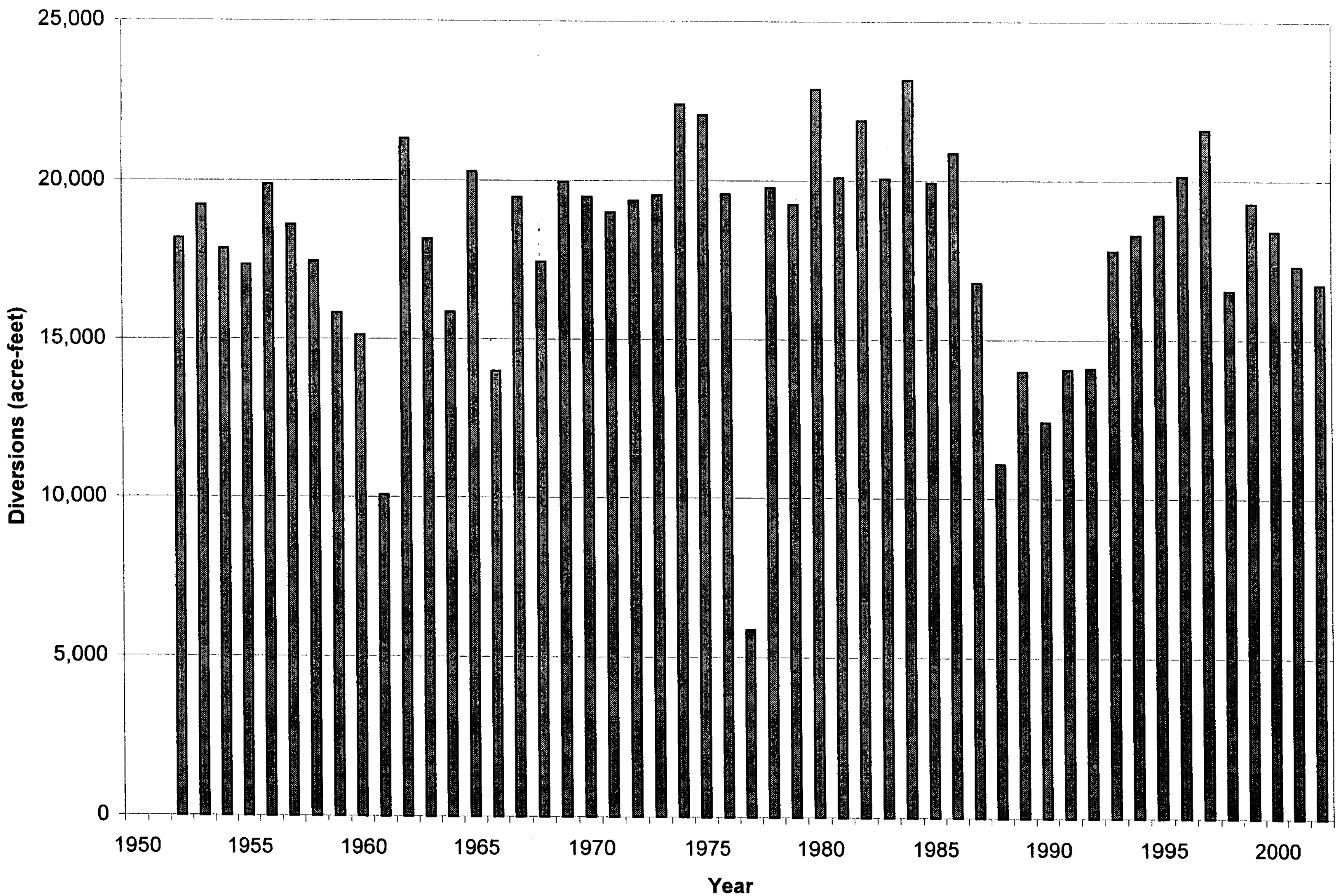

Figure 1.4 Combined Agricultural Diversions from Tuolumne and Merced Rivers, 1952-2002

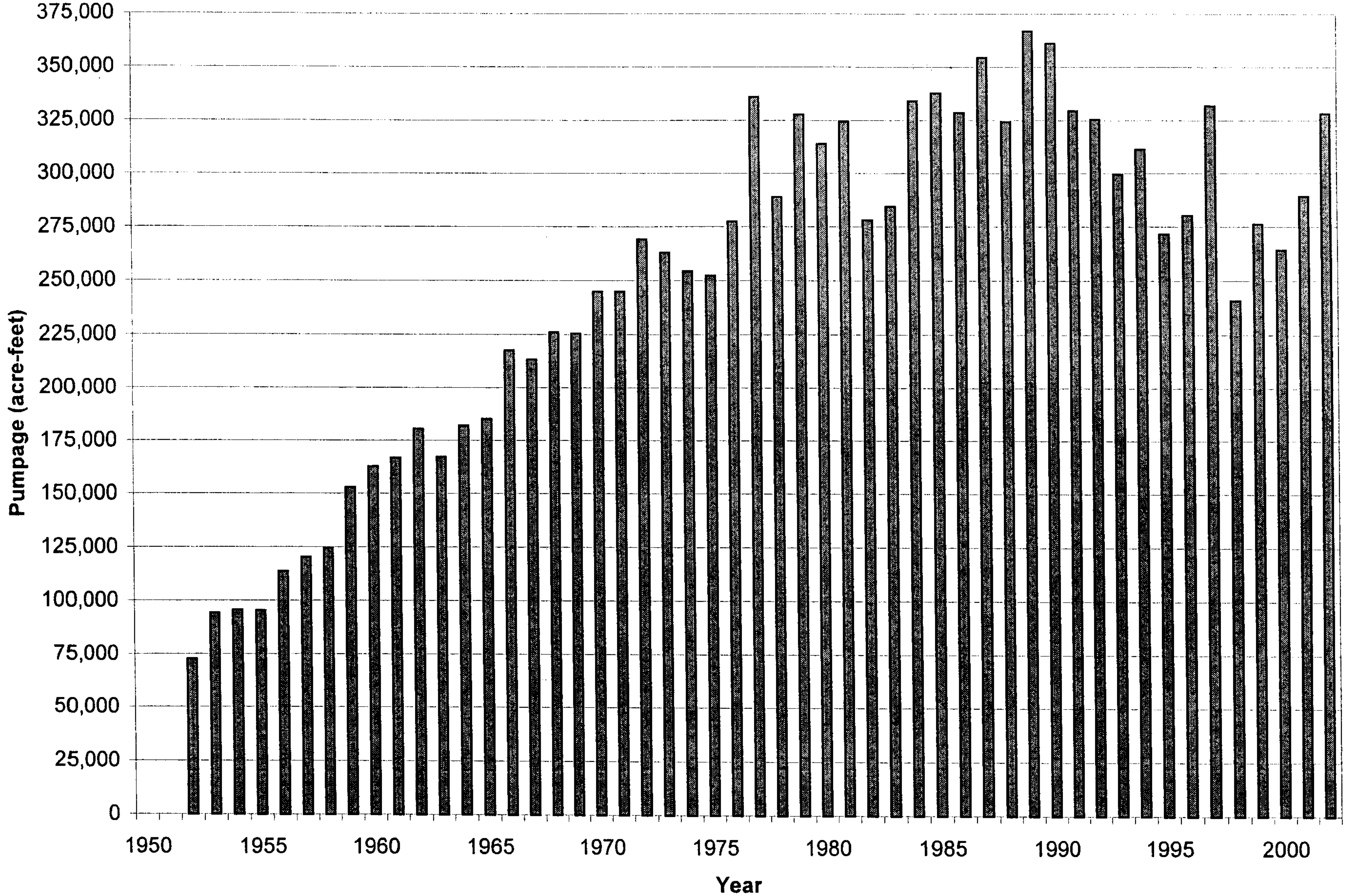

Figure 1.5 Agricultural Groundwater Pumping from Water Districts within the Turlock Groundwater Basin, 1952-2002

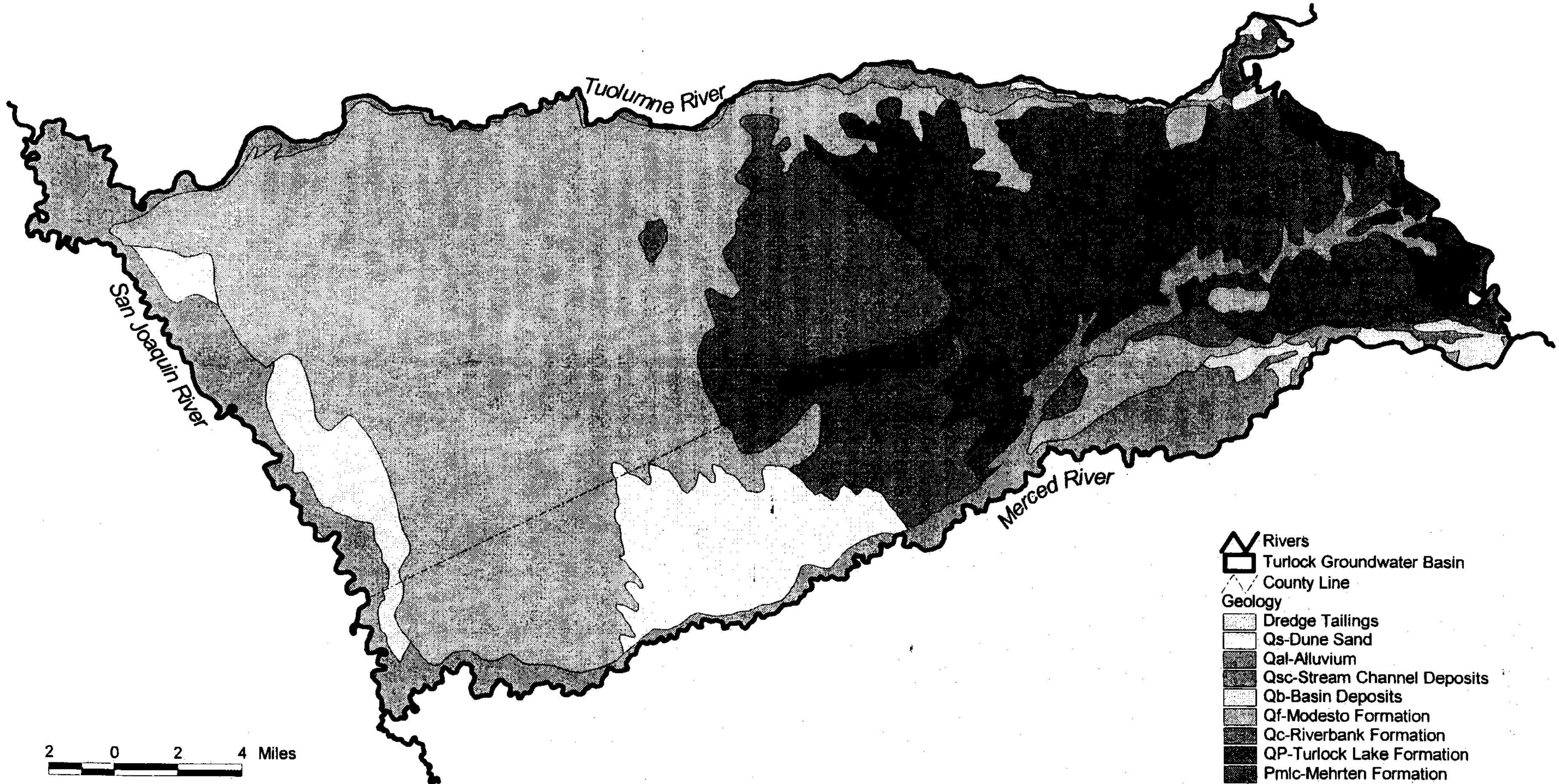

Figure 1.6 Geology of the Turlock Groundwater Basin

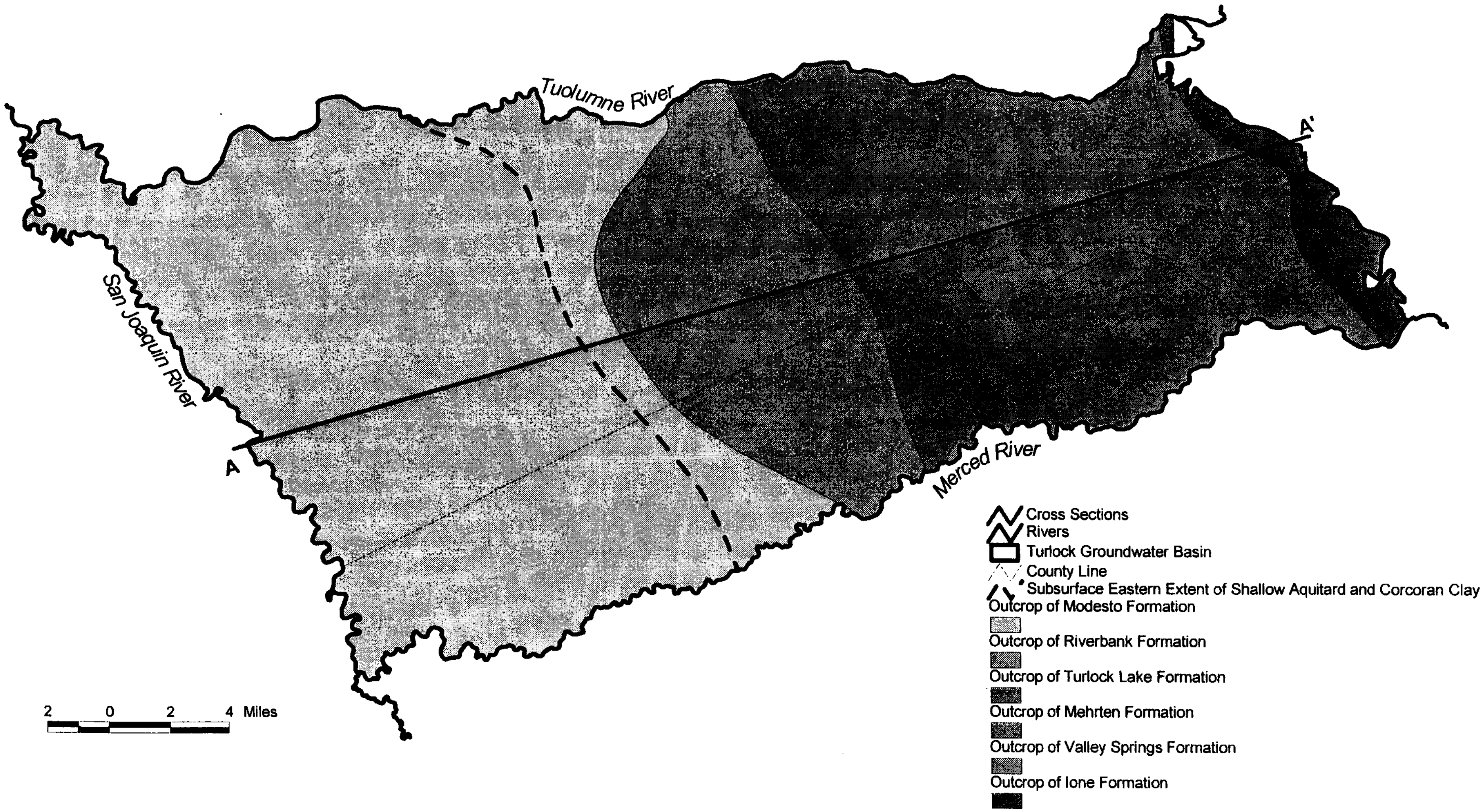

Figure 1.7 Hydrogeologic Units Represented within the Groundwater Model

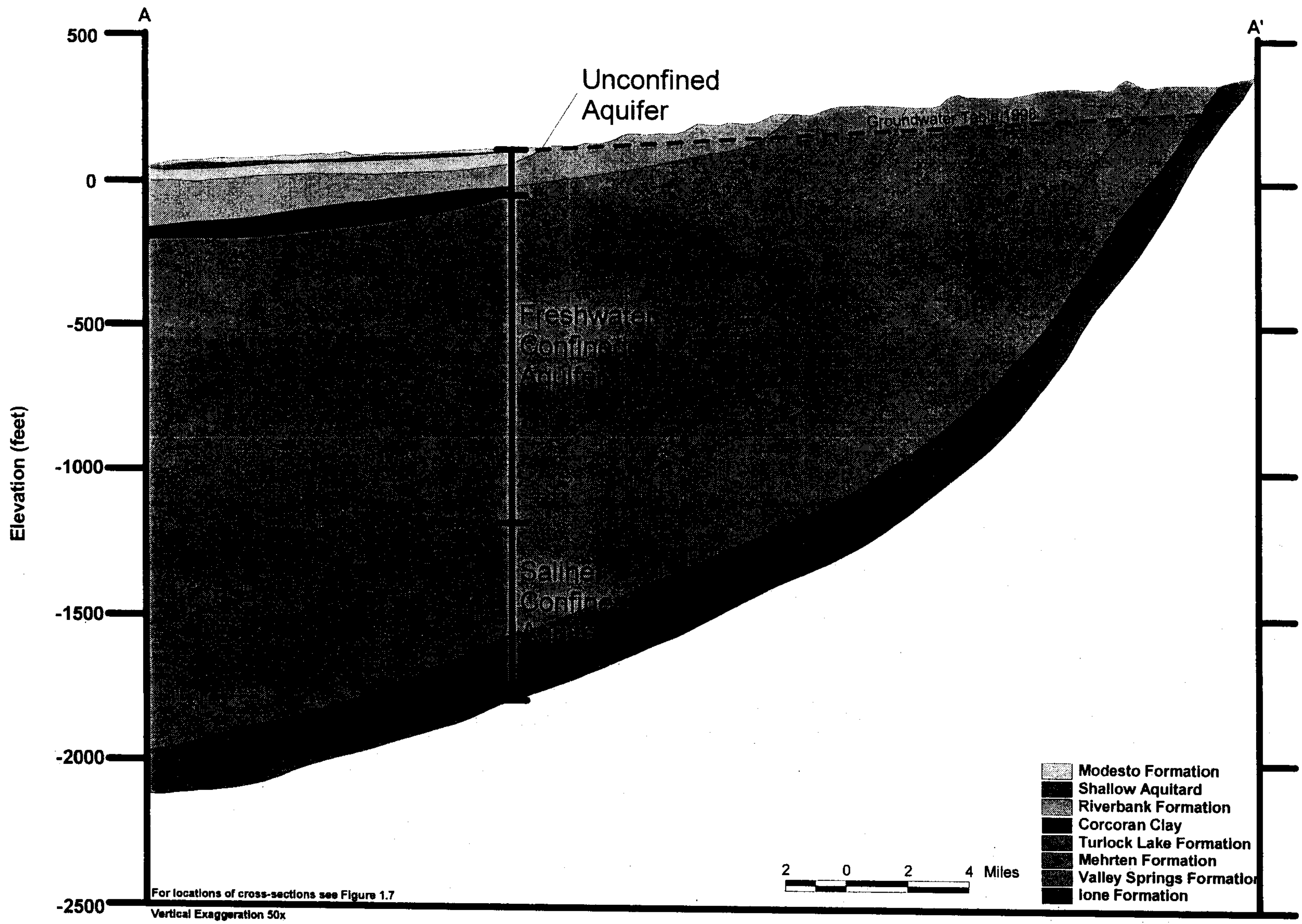

Figure 1.8 East-West Cross-Section Showing Hydrogeologic Units within the Groundwater Basin

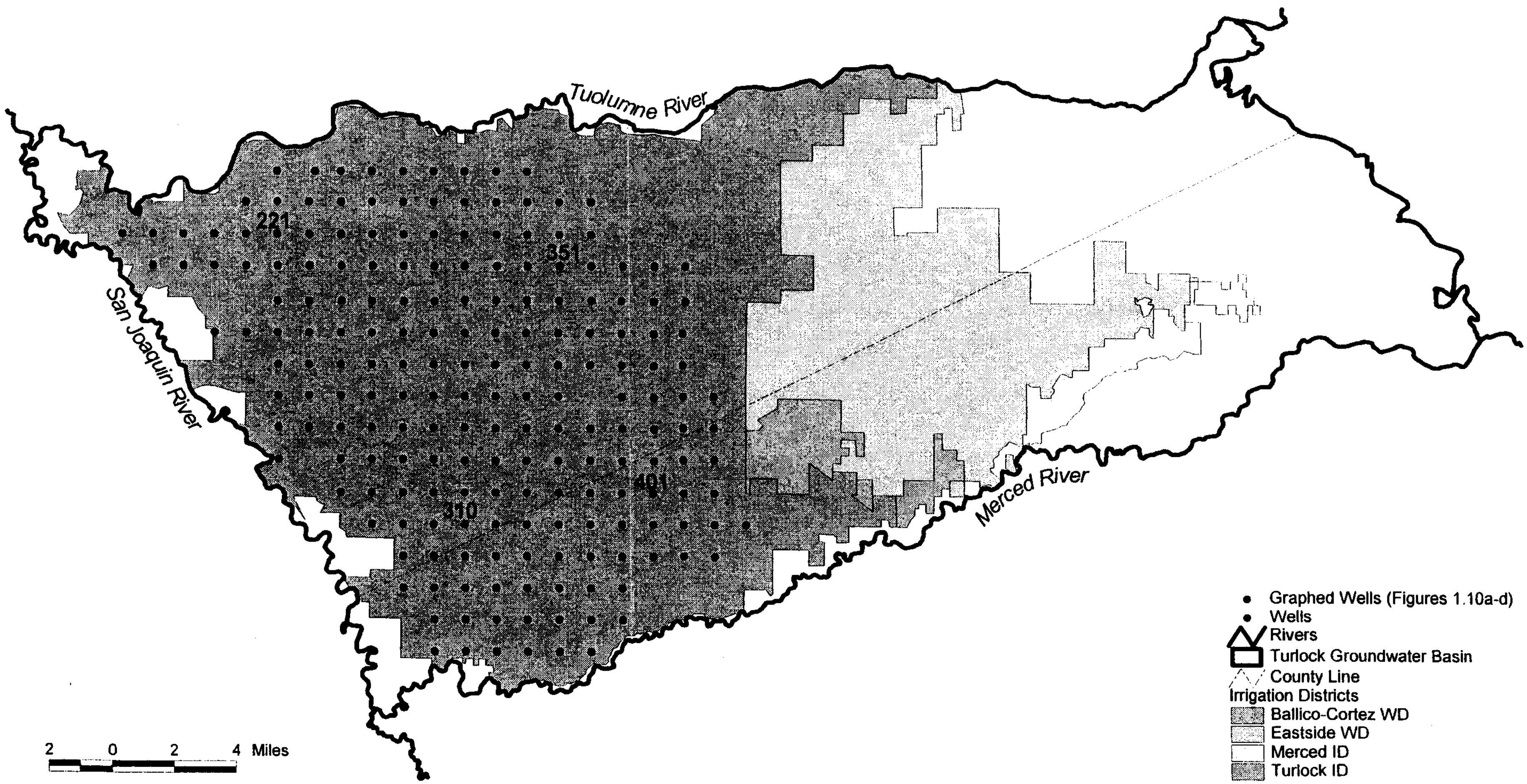

Figure 1.9 Locations of Section-Corner Wells

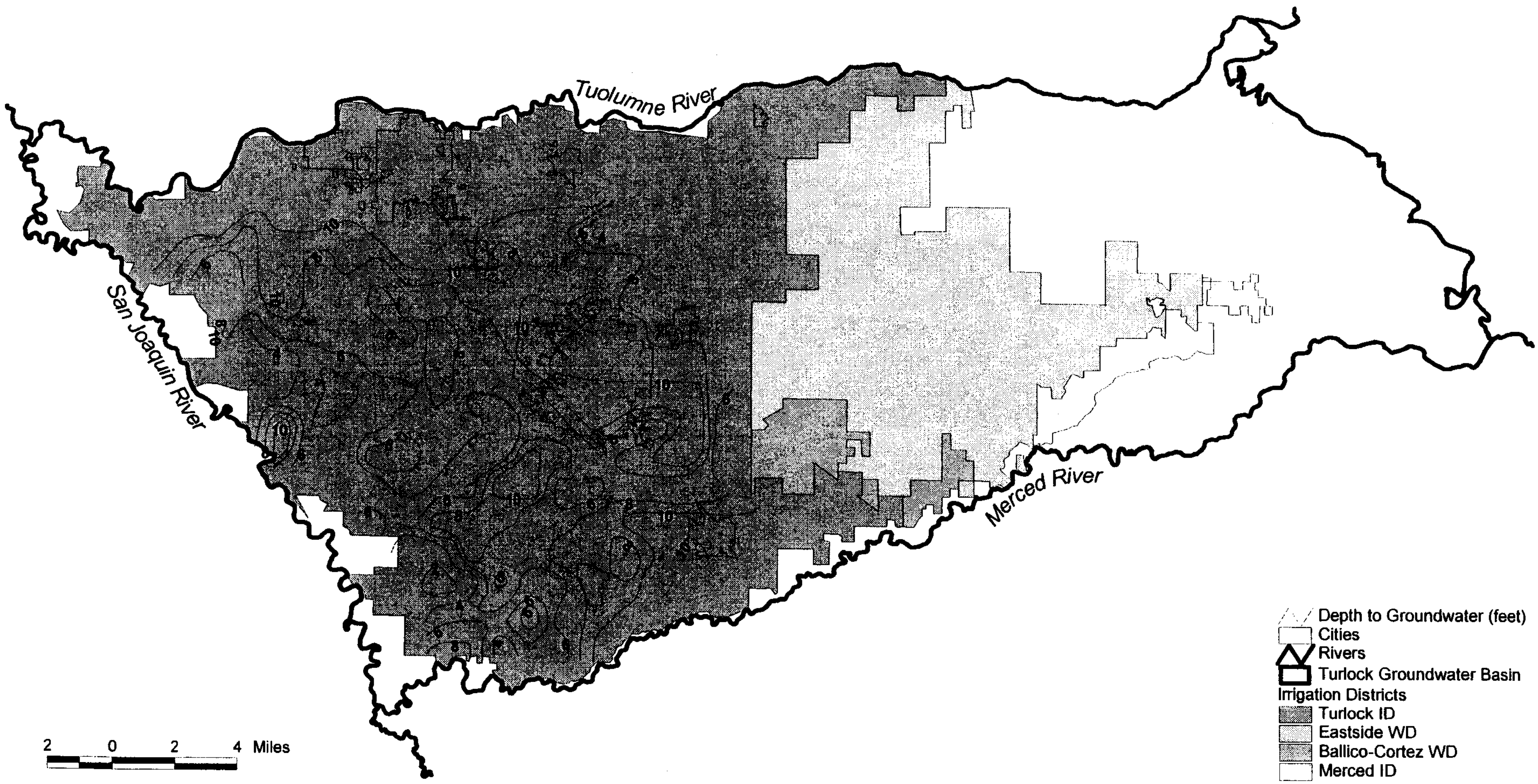

Figure 1.10a Measured Depth to Groundwater in Section-Corner Wells, July 1960

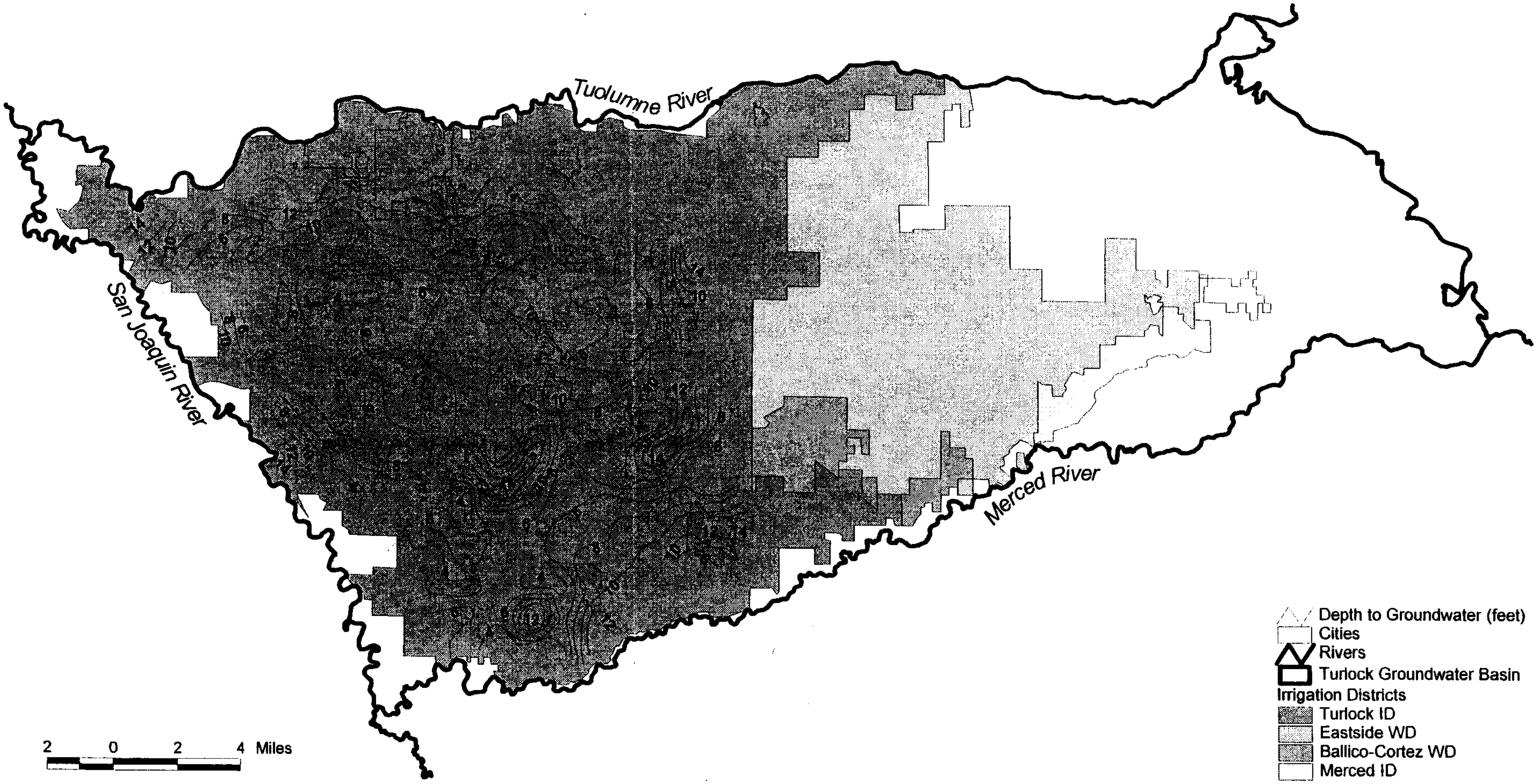

Figure 1.10b Measured Depth to Groundwater in Section-Corner Wells, July 1970

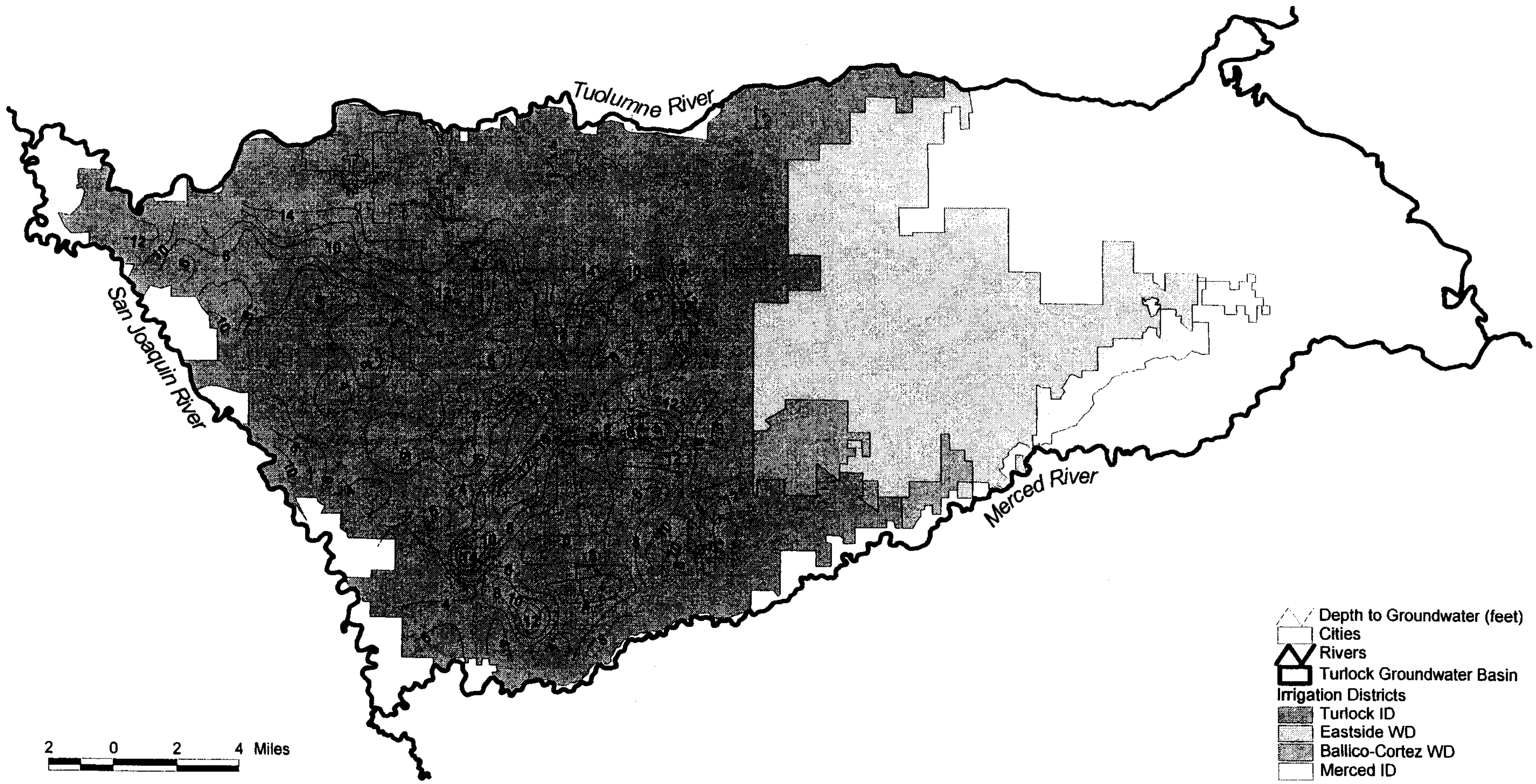

Figure 1.10c Measured Depth to Groundwater in Section-Corner Wells, July 1980

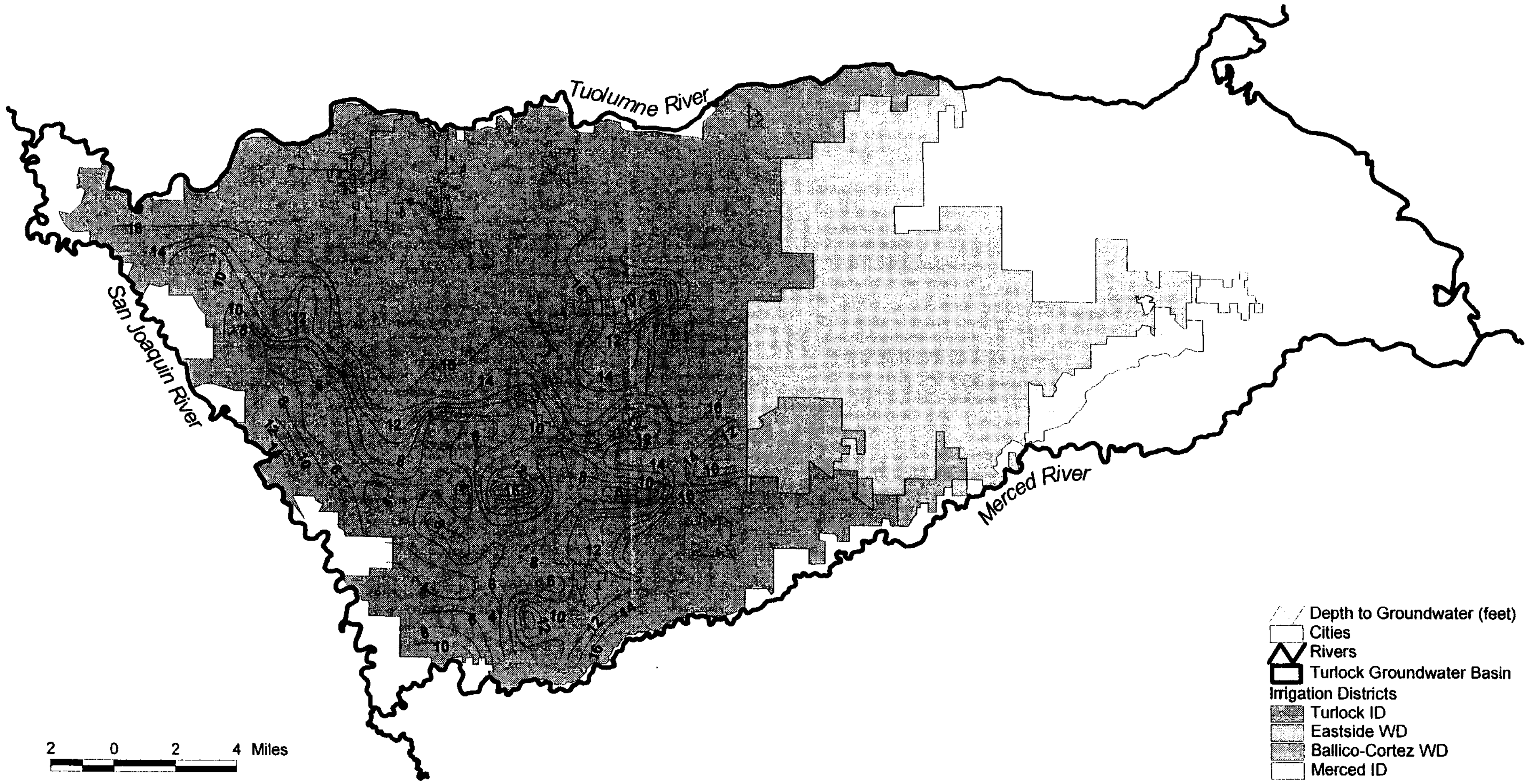

Figure 1.10d Measured Depth to Groundwater in Section-Corner Wells, July 1990

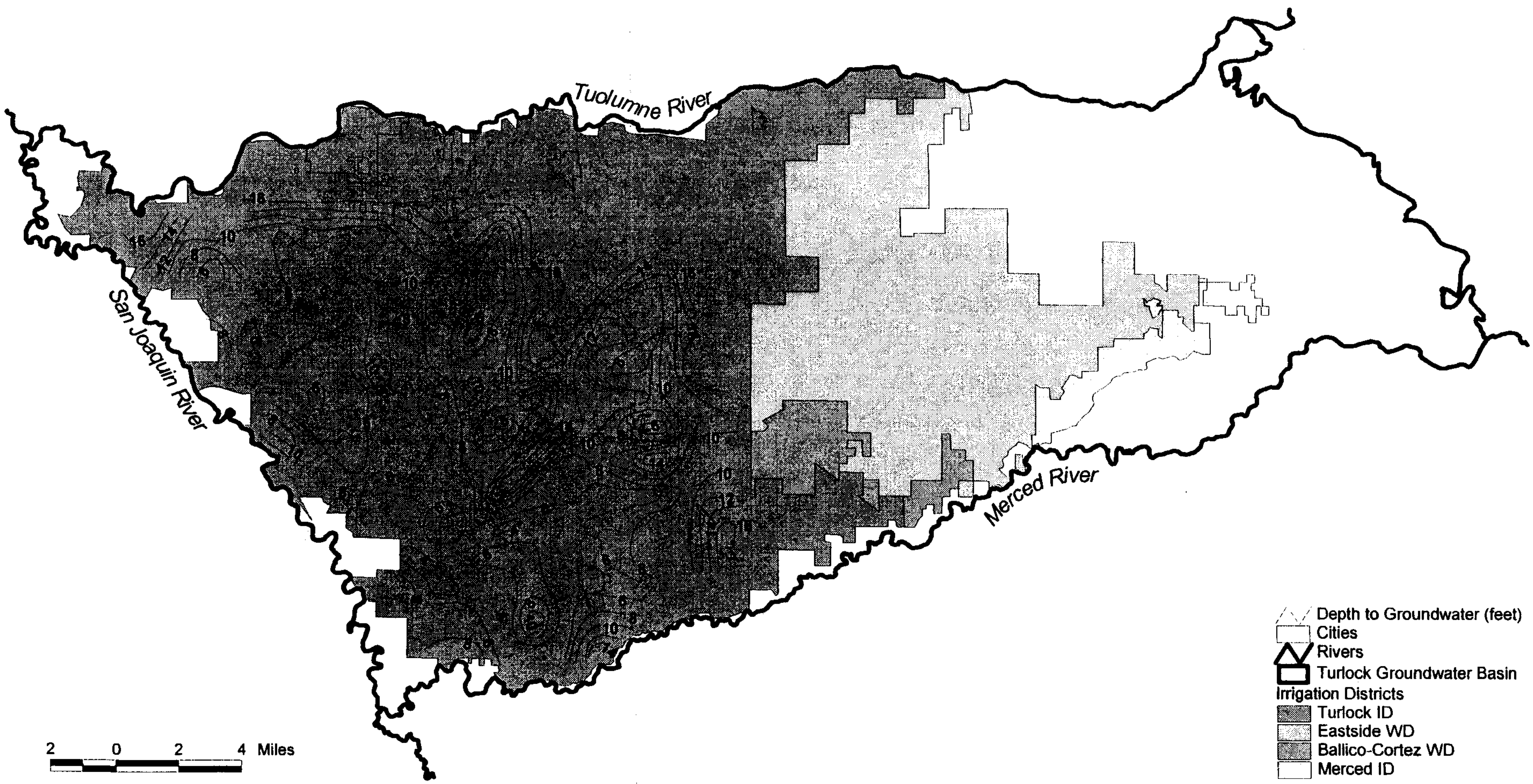

Figure 1.10e Measured Depth to Groundwater in Section-Corner Wells, July 2000

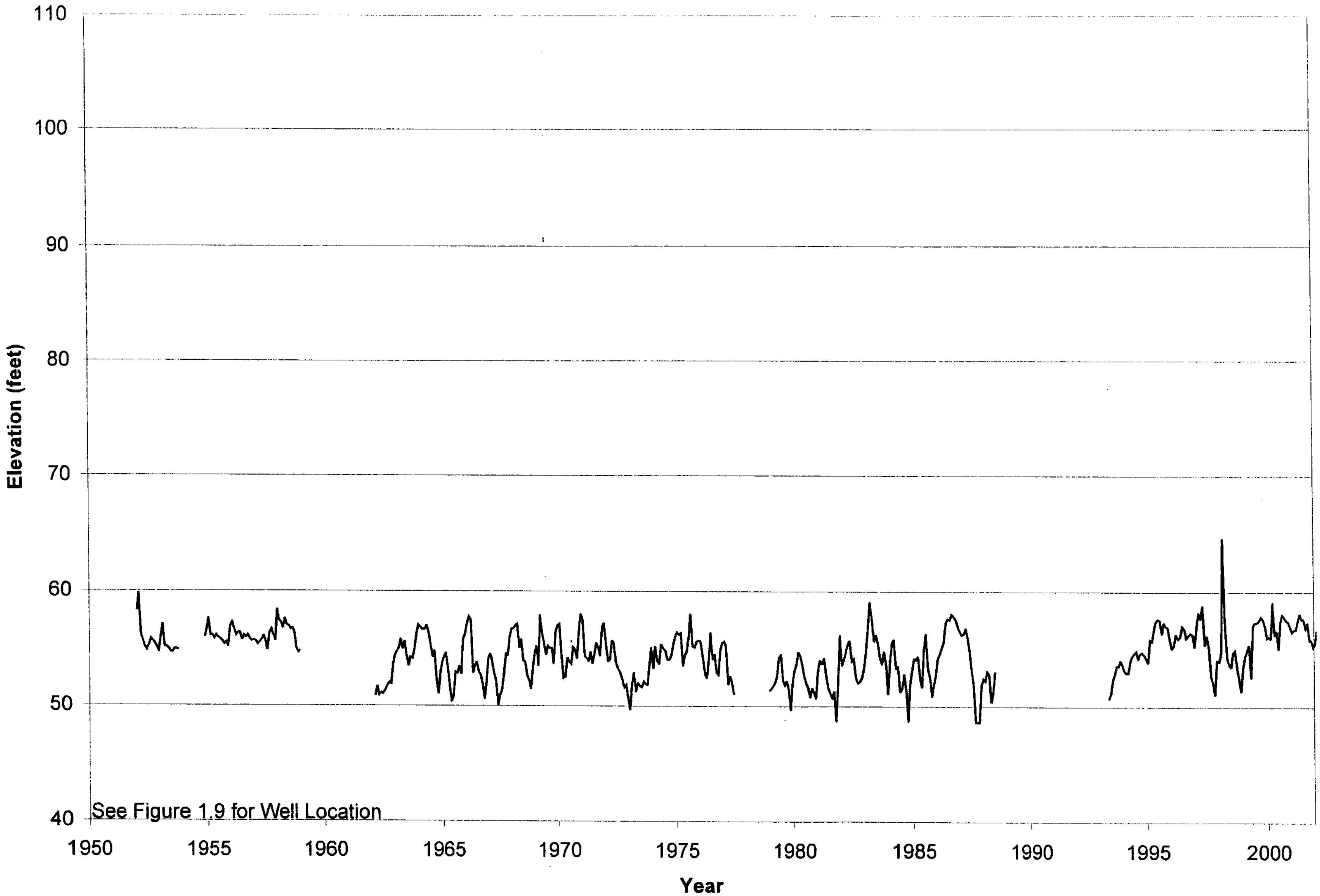

Figure 1.11a Measured Temporal Groundwater Levels in Section-Corner Well 221

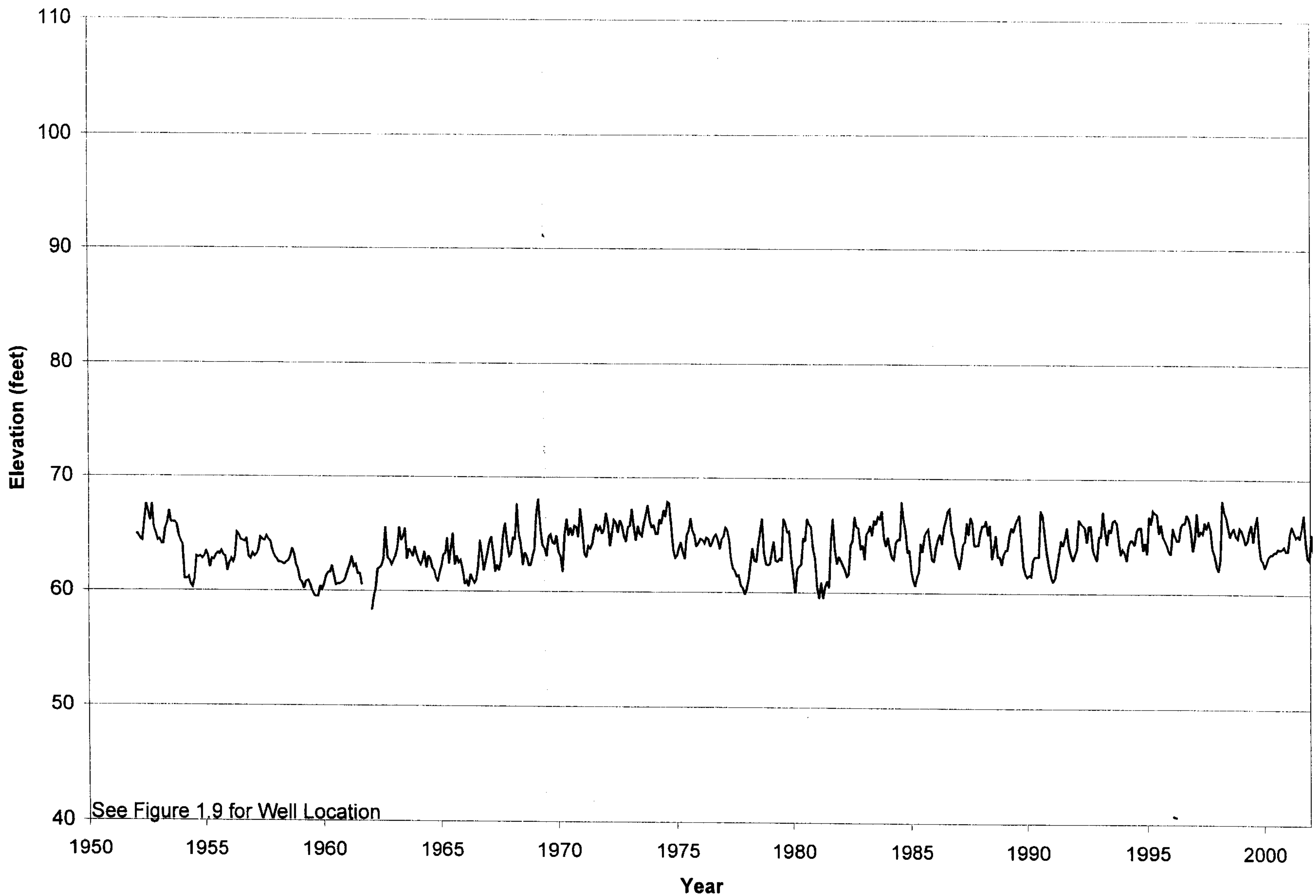

Figure 1.11b Measured Temporal Groundwater Levels in Section-Corner Well 310

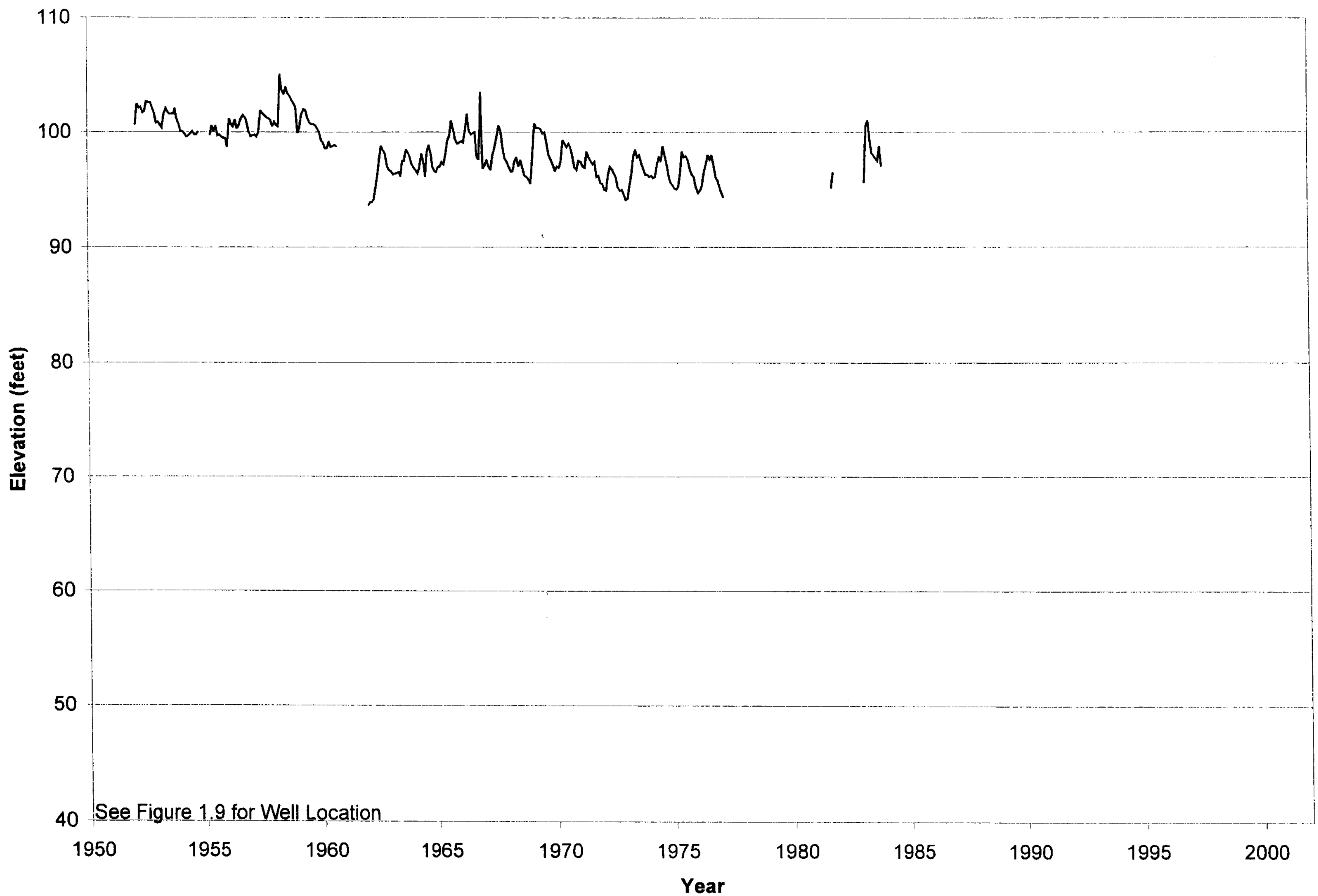

Figure 1.11c Measured Temporal Groundwater Levels in Section-Corner Well 351

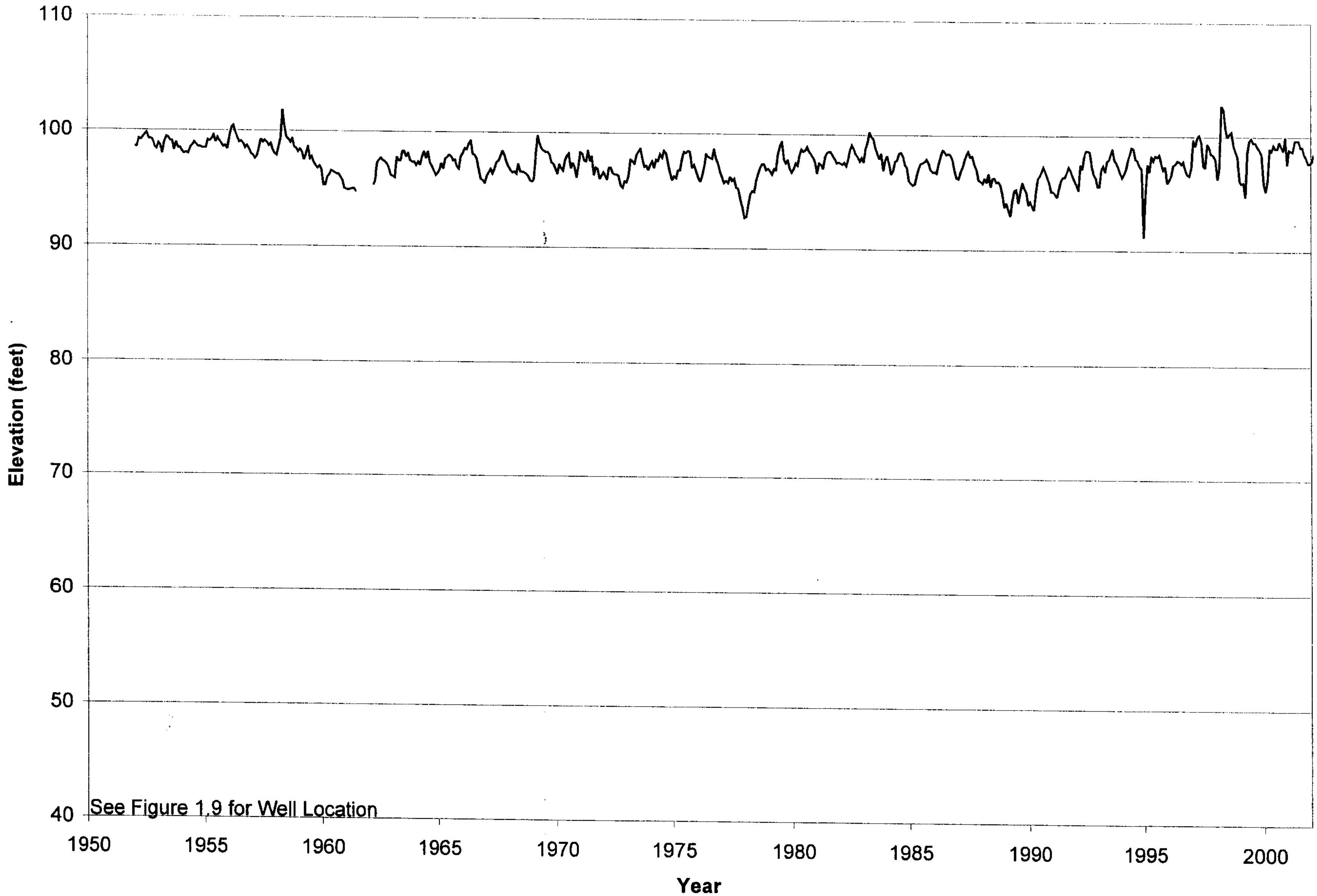

Figure 1.11d Measured Temporal Groundwater Levels in Section-Corner Well 401

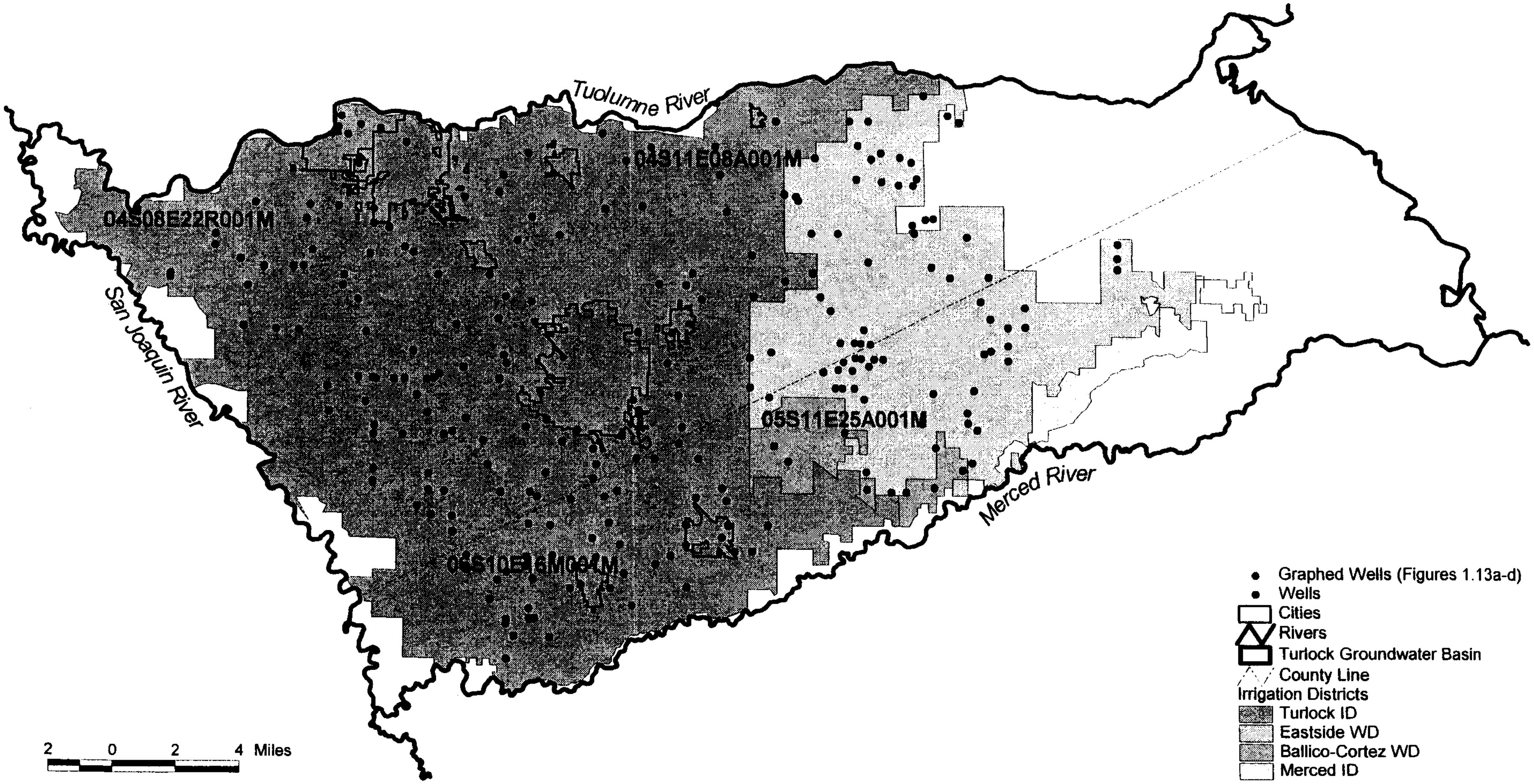

Figure 1.12 Locations of Intermediate-Depth Monitoring Wells

Figure 1.13a Measured Groundwater Elevations in Intermediate Depth Monitoring Wells, December 1960

Figure 1.13b Measured Groundwater Elevations in Intermediate Depth Monitoring Wells, November 1977

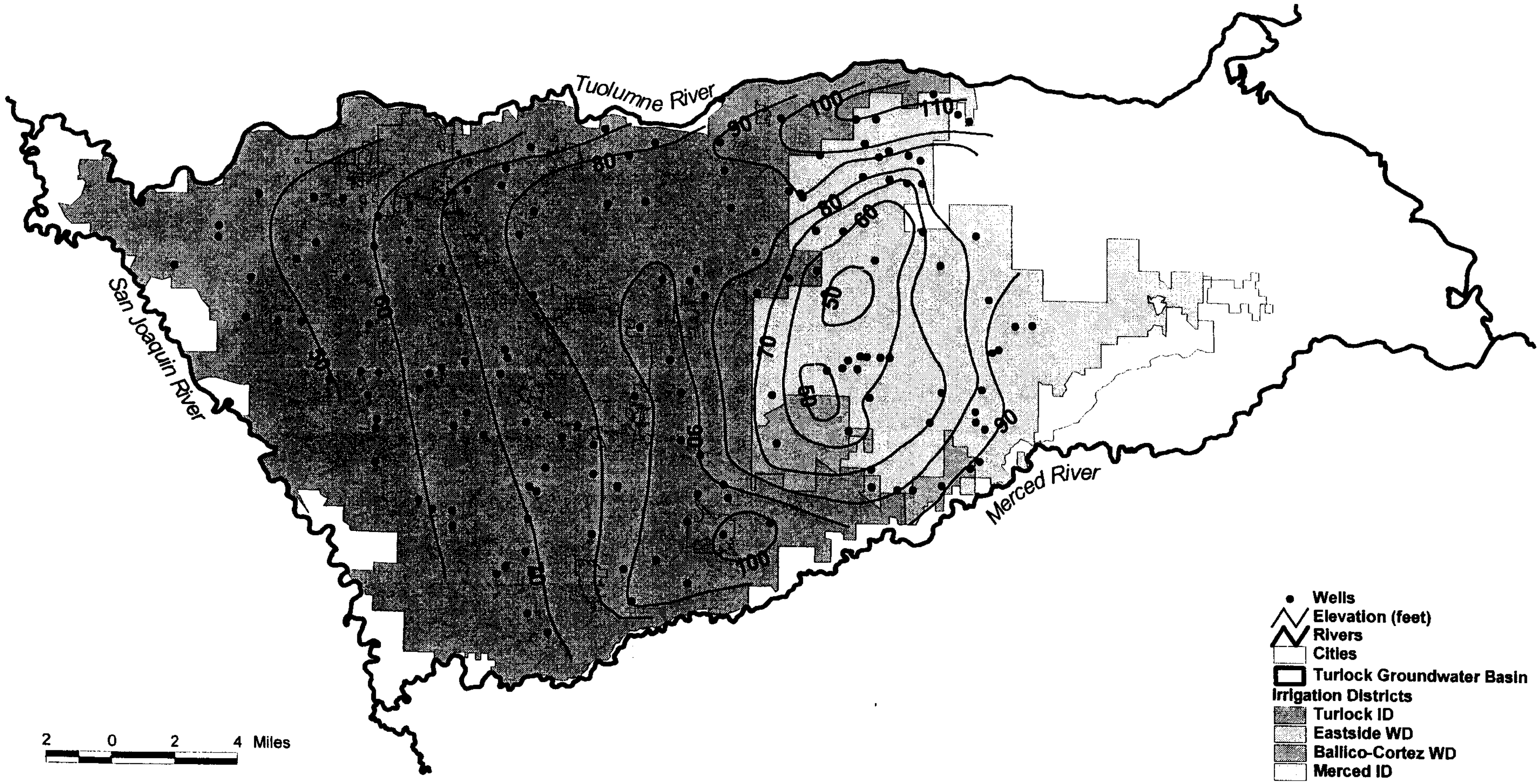

Figure 1.13c Measured Groundwater Elevations in Intermediate Depth Monitoring Wells, November 1986

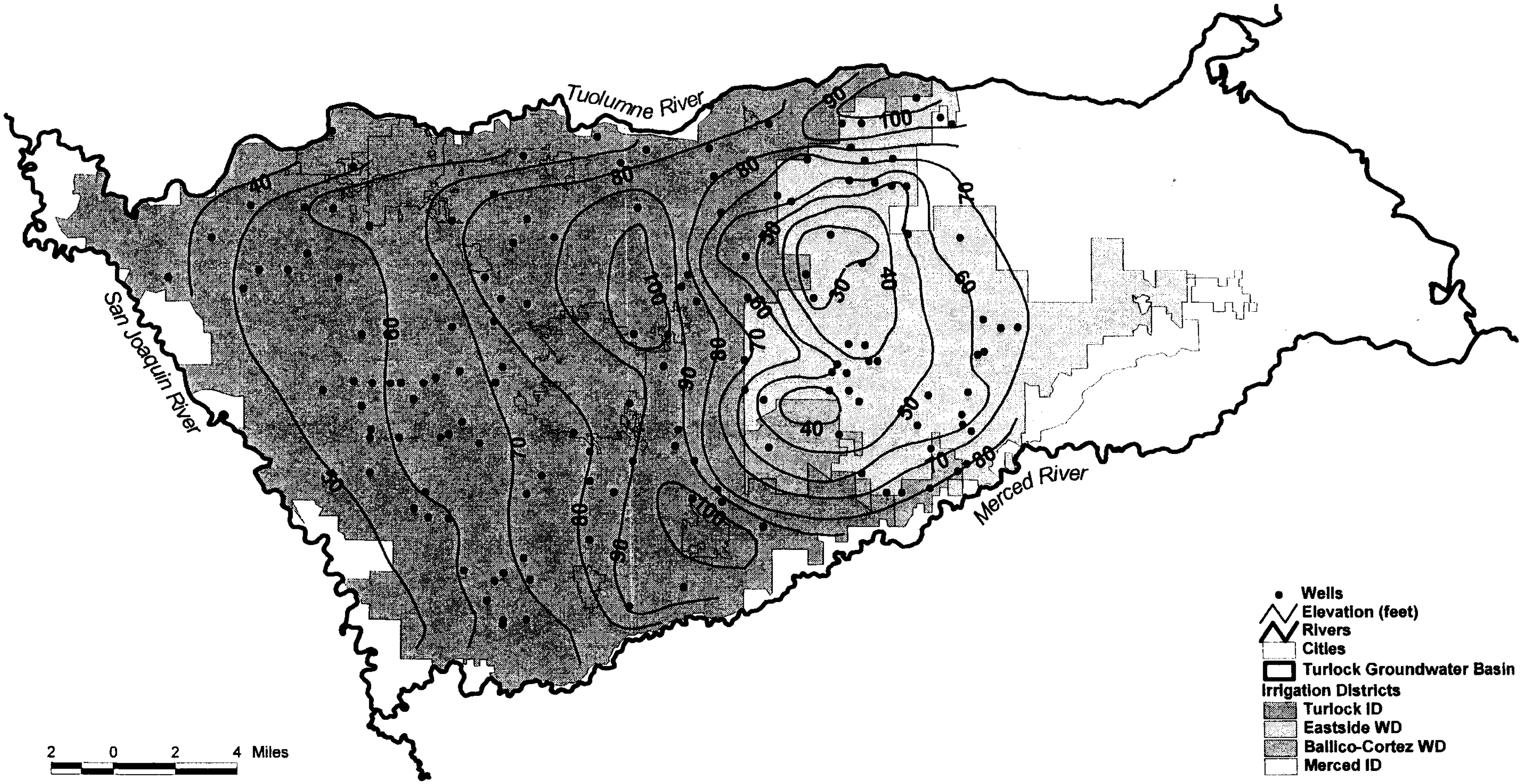

Figure 1.13d Measured Groundwater Elevations in Intermediate Depth Monitoring Wells, November 1998

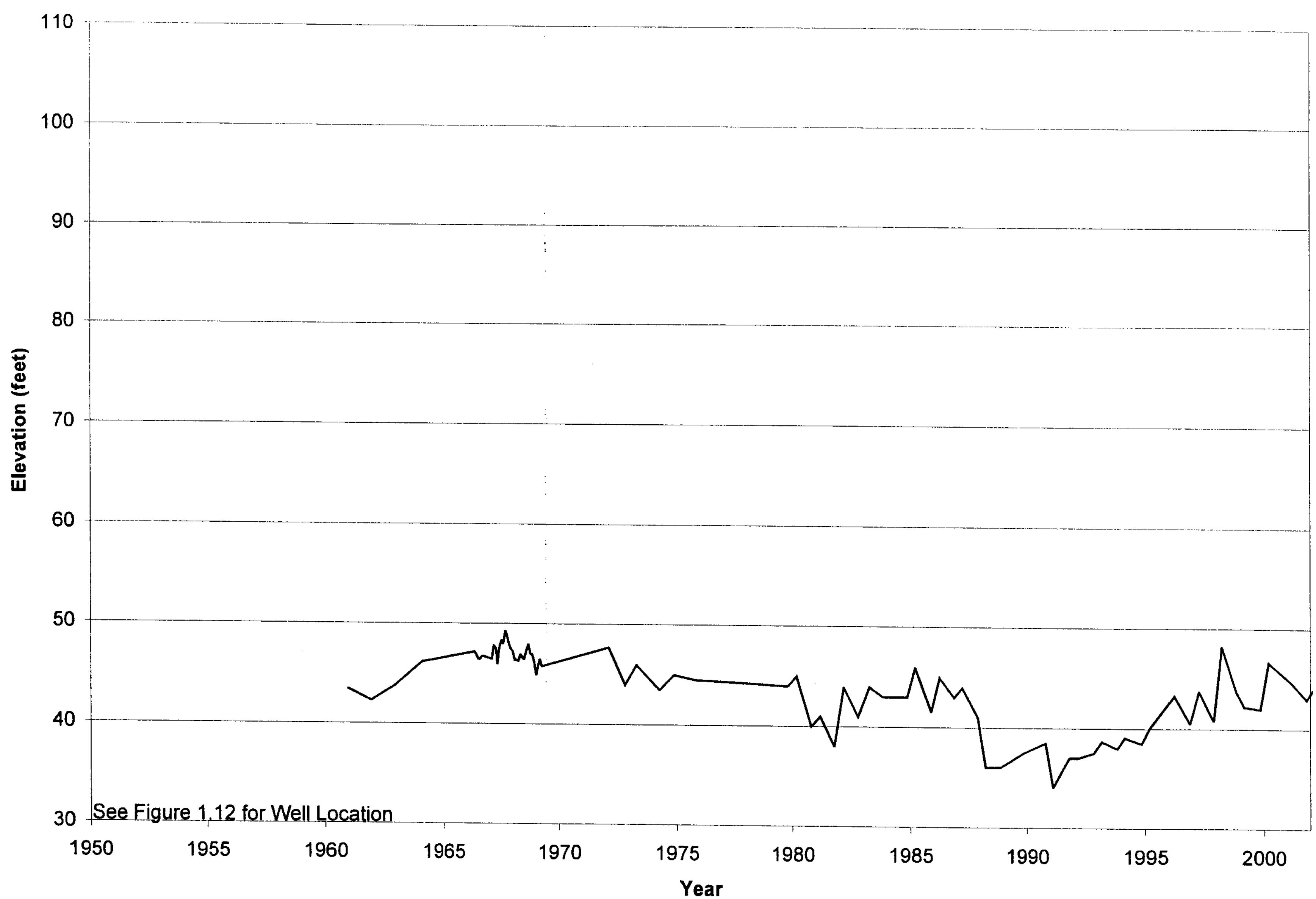

Figure 1.14a Measured Temporal Groundwater Levels in Monitoring Well 04S08E22R001M

Figure 1.14b Measured Temporal Groundwater Levels in Monitoring Well 04S11E08A001M

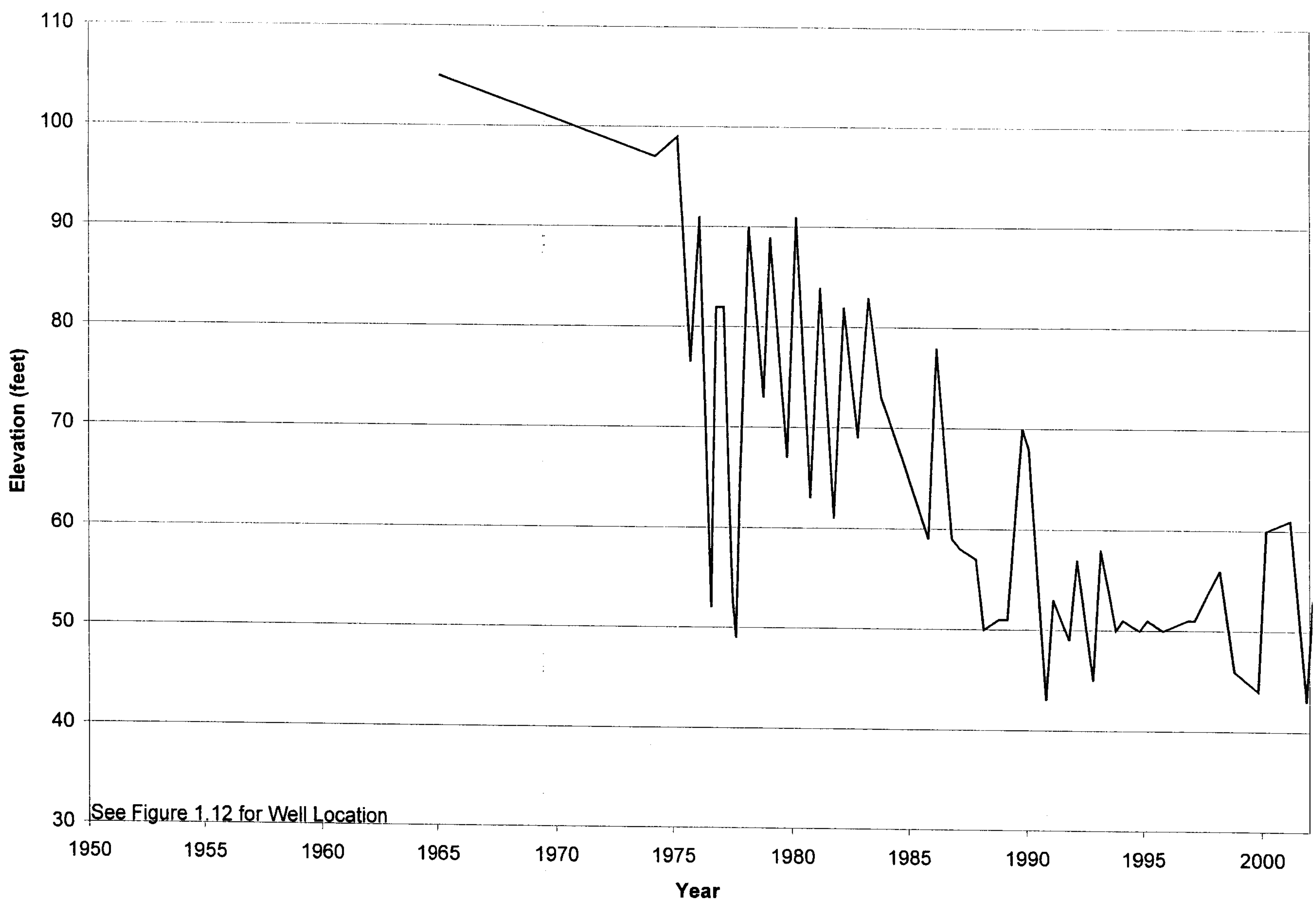

Figure 1.14c Measured Temporal Groundwater Levels in Monitoring Well 05S11E25A001M

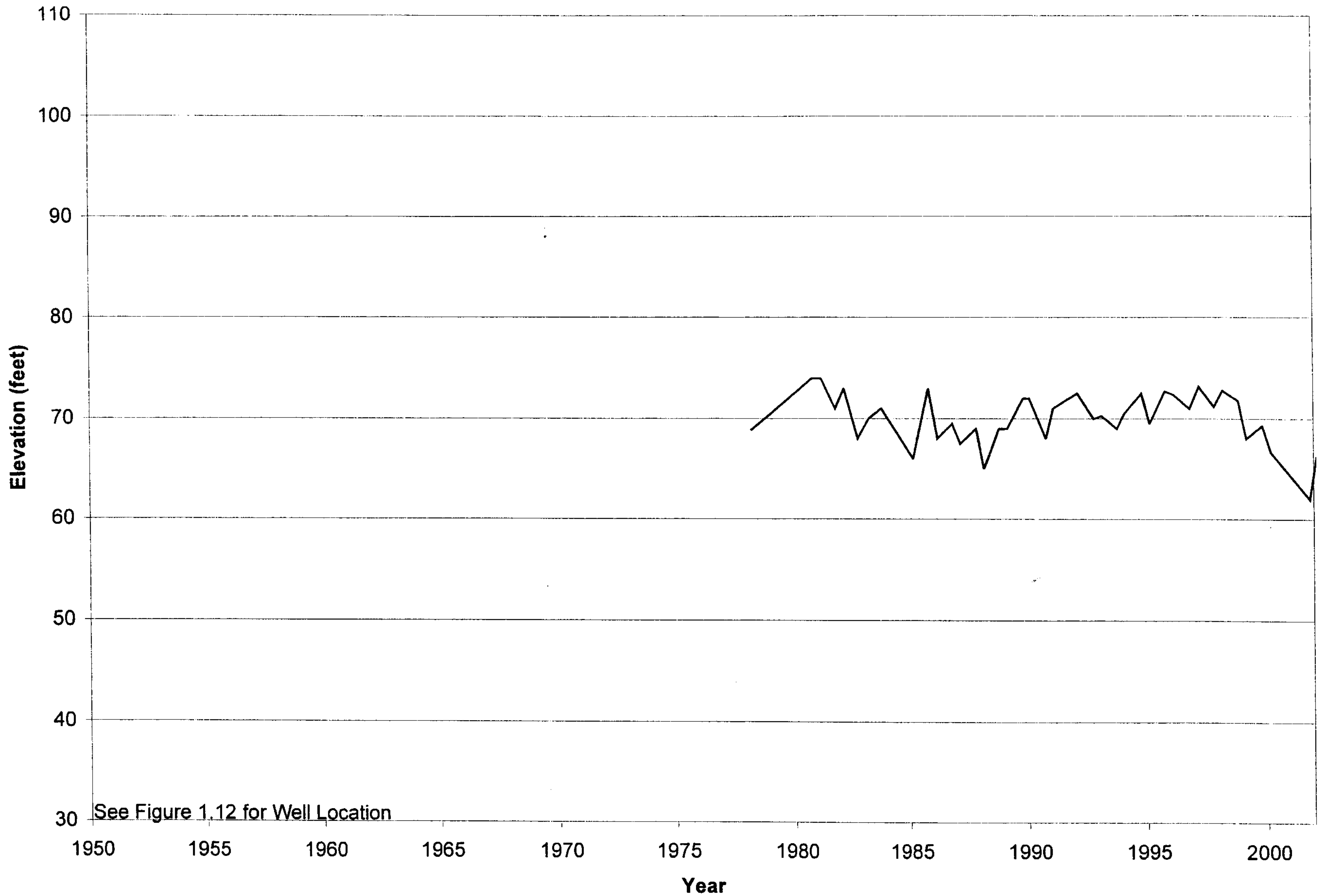

Figure 1.14d Measured Temporal Groundwater Levels in Monitoring Well 06S10E16M001M

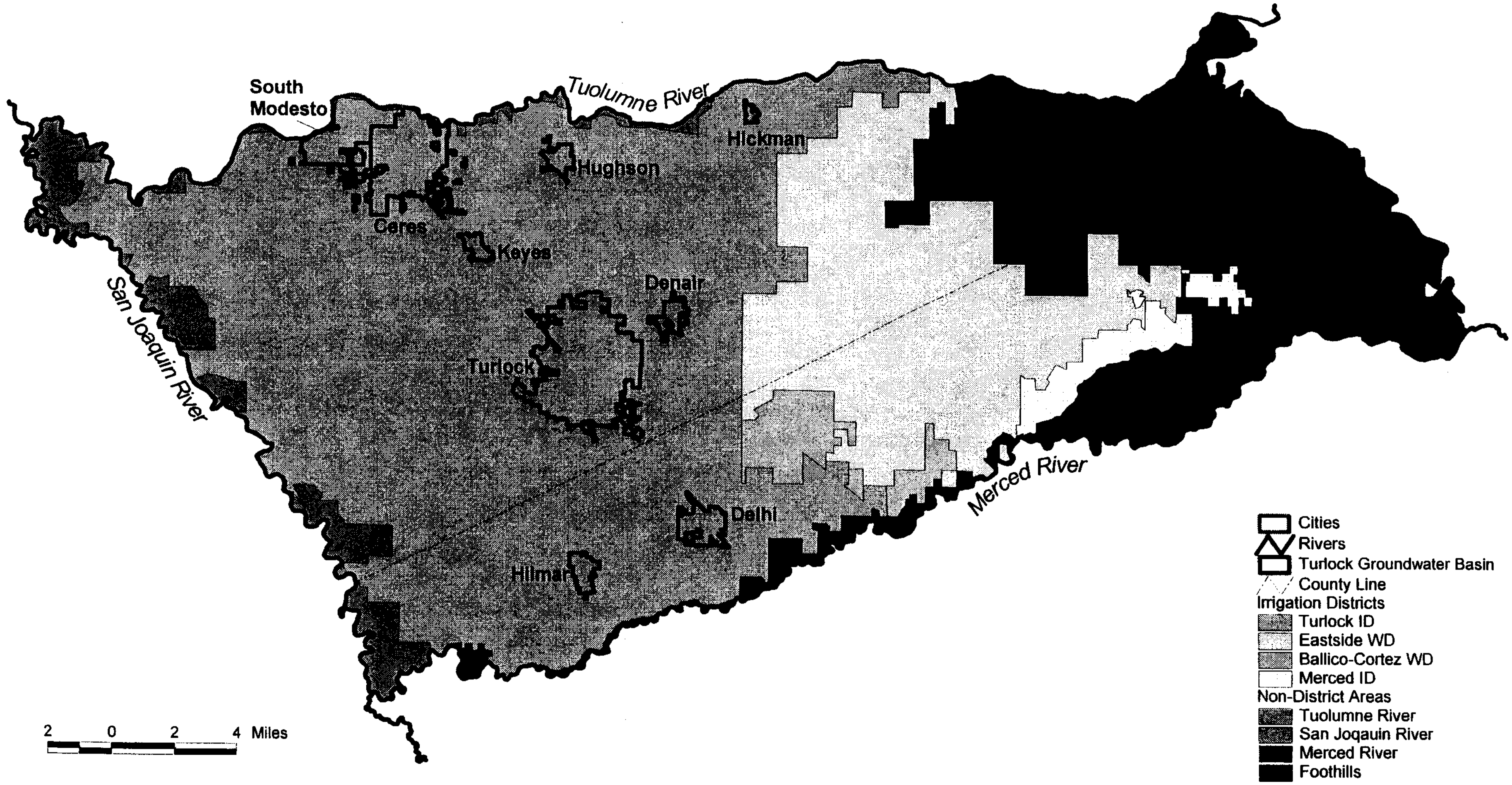

Figure 2.1 Urban Areas, Irrigation Districts, and Non-District Areas within Turlock Groundwater Basin

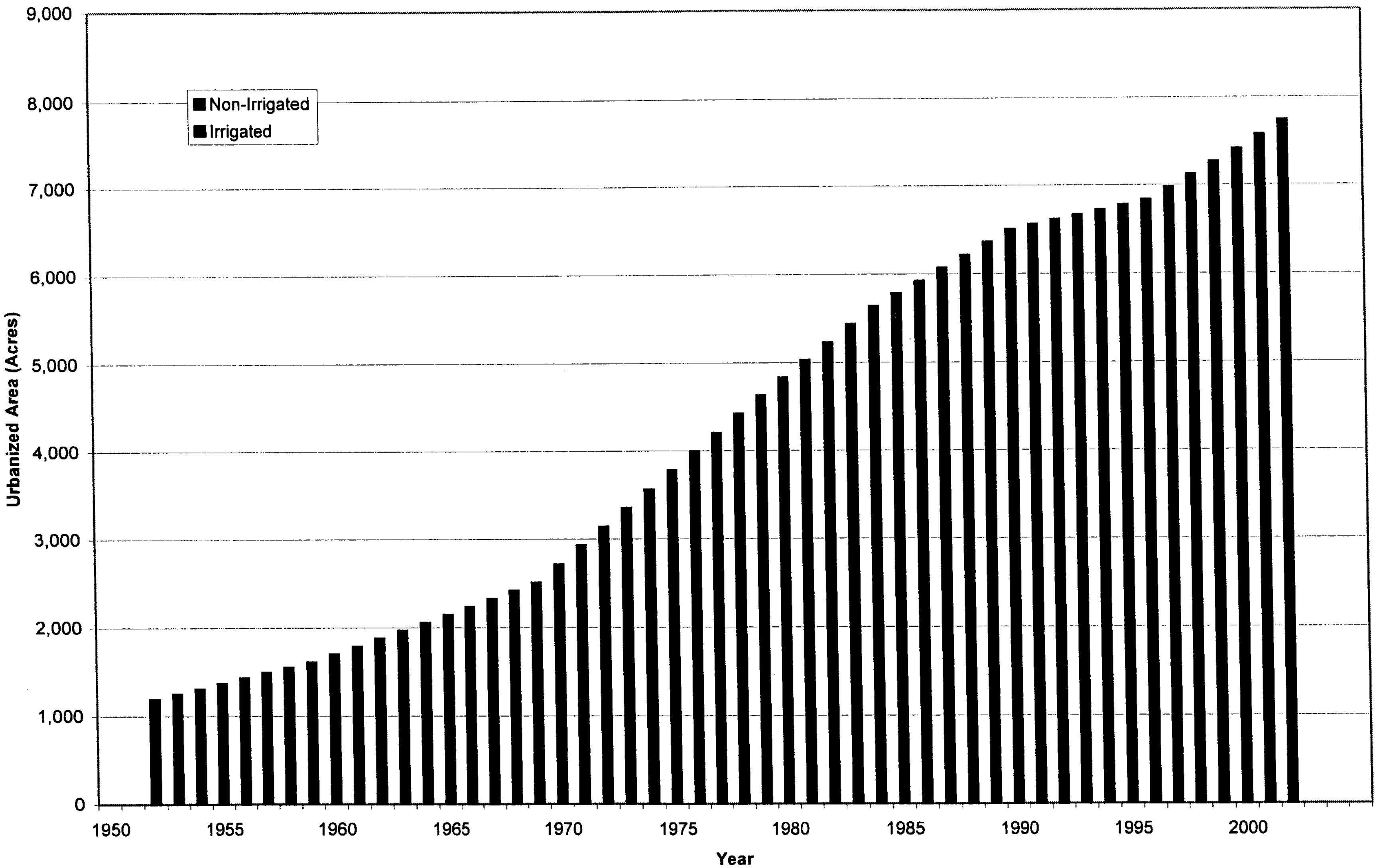

Figure 2.2a Urbanized and Landscaped Area within the Turlock Groundwater Basin, 1952-2002, for Turlock

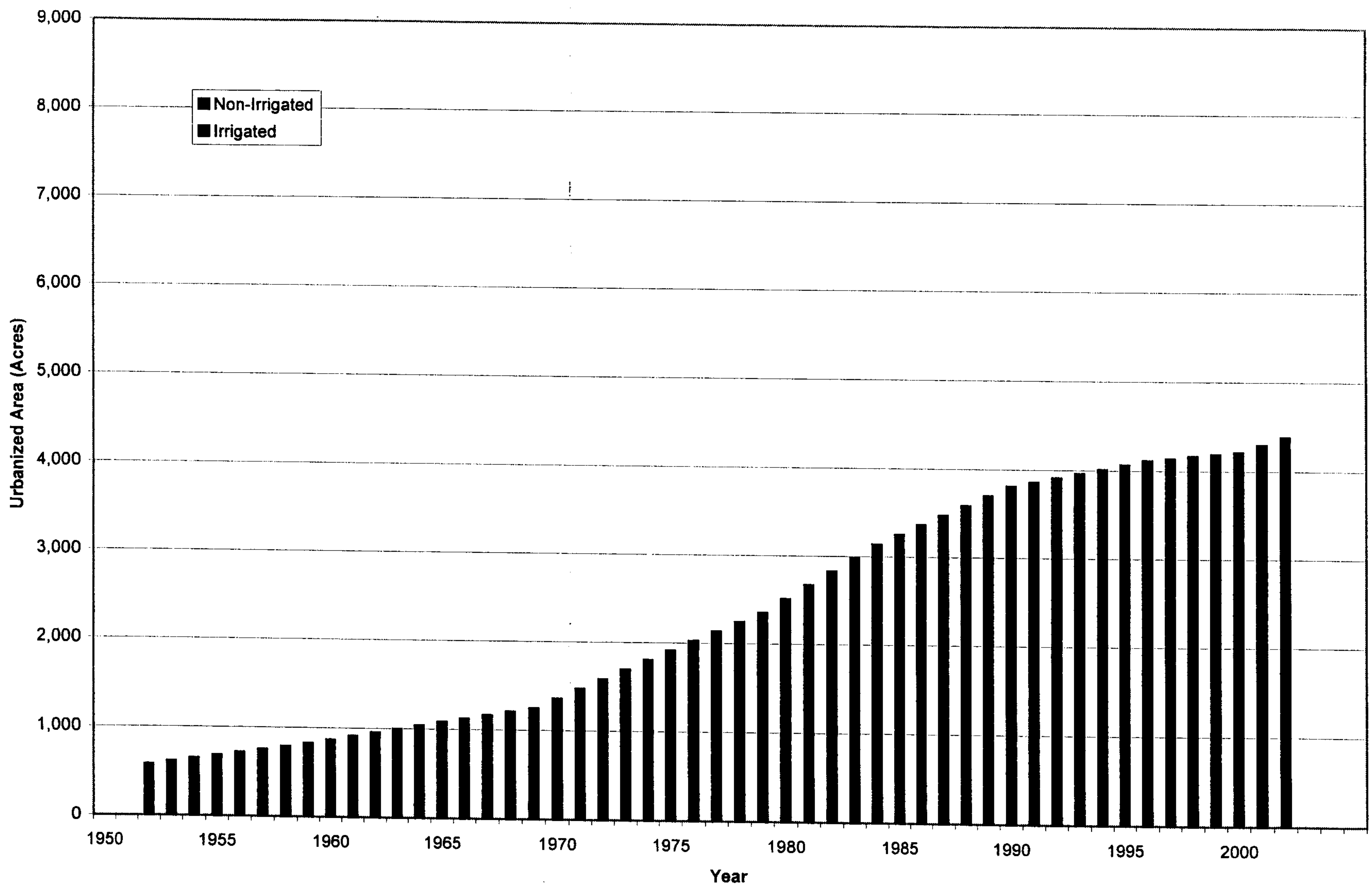

Figure 2.2b Urbanized and Landscaped Area within the Turlock Groundwater Basin, 1952-2002, for Ceres

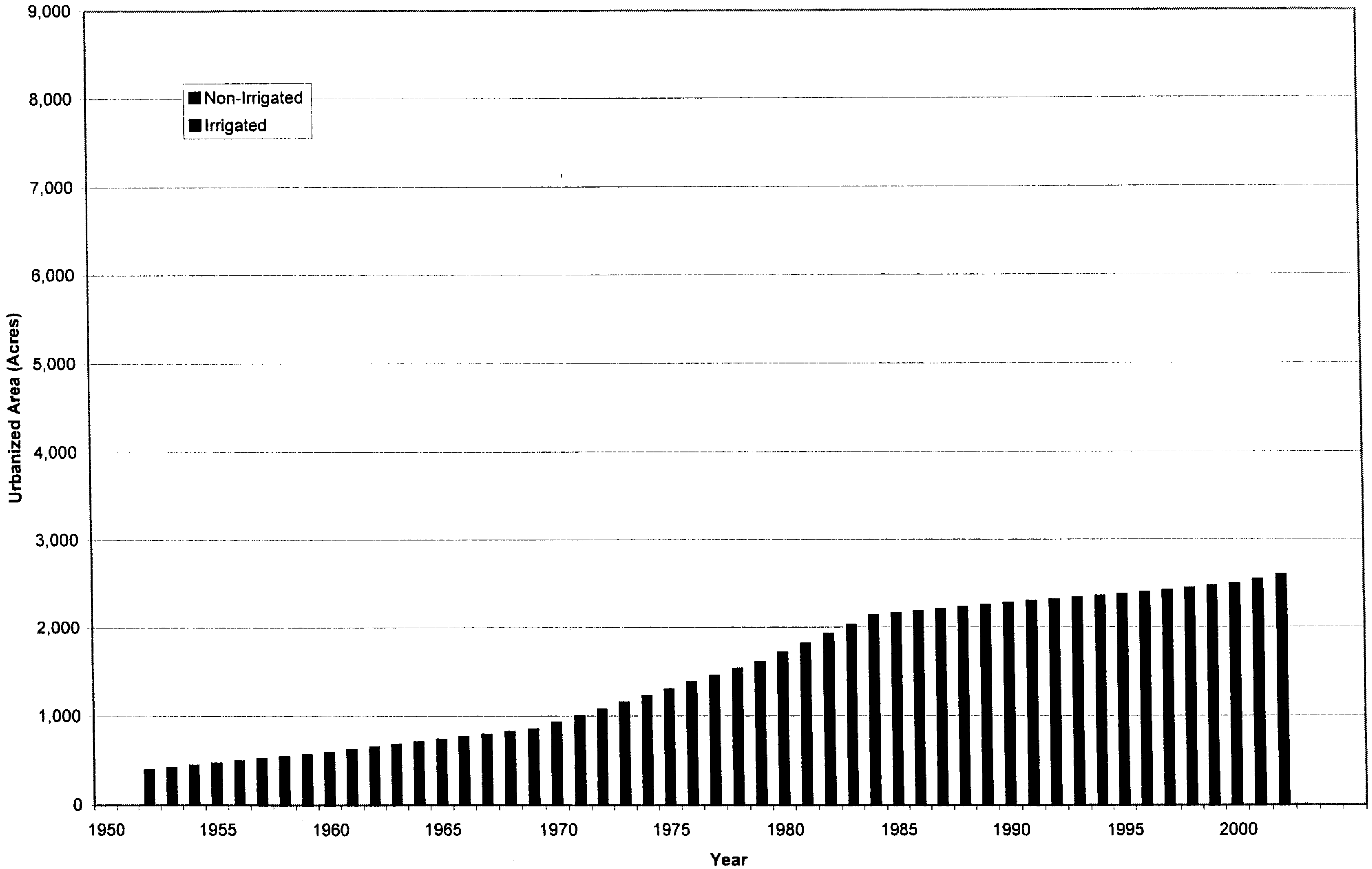

Figure 2.2c Urbanized and Landscaped Area within the Turlock Groundwater Basin, 1952-2002, for South Modesto

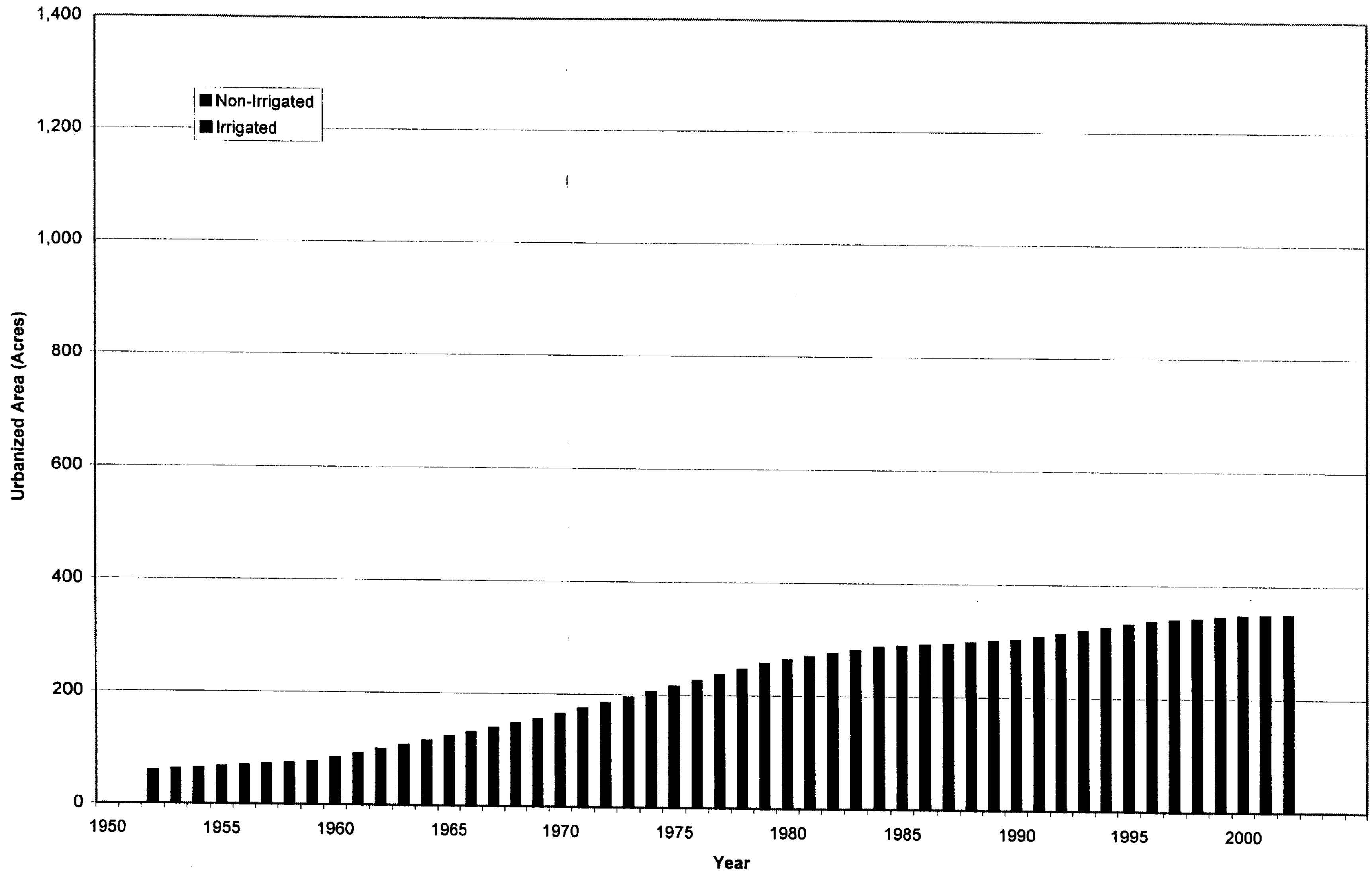

Figure 2.2d Urbanized and Landscaped Area within the Turlock Groundwater Basin, 1952-2002, for Keyes

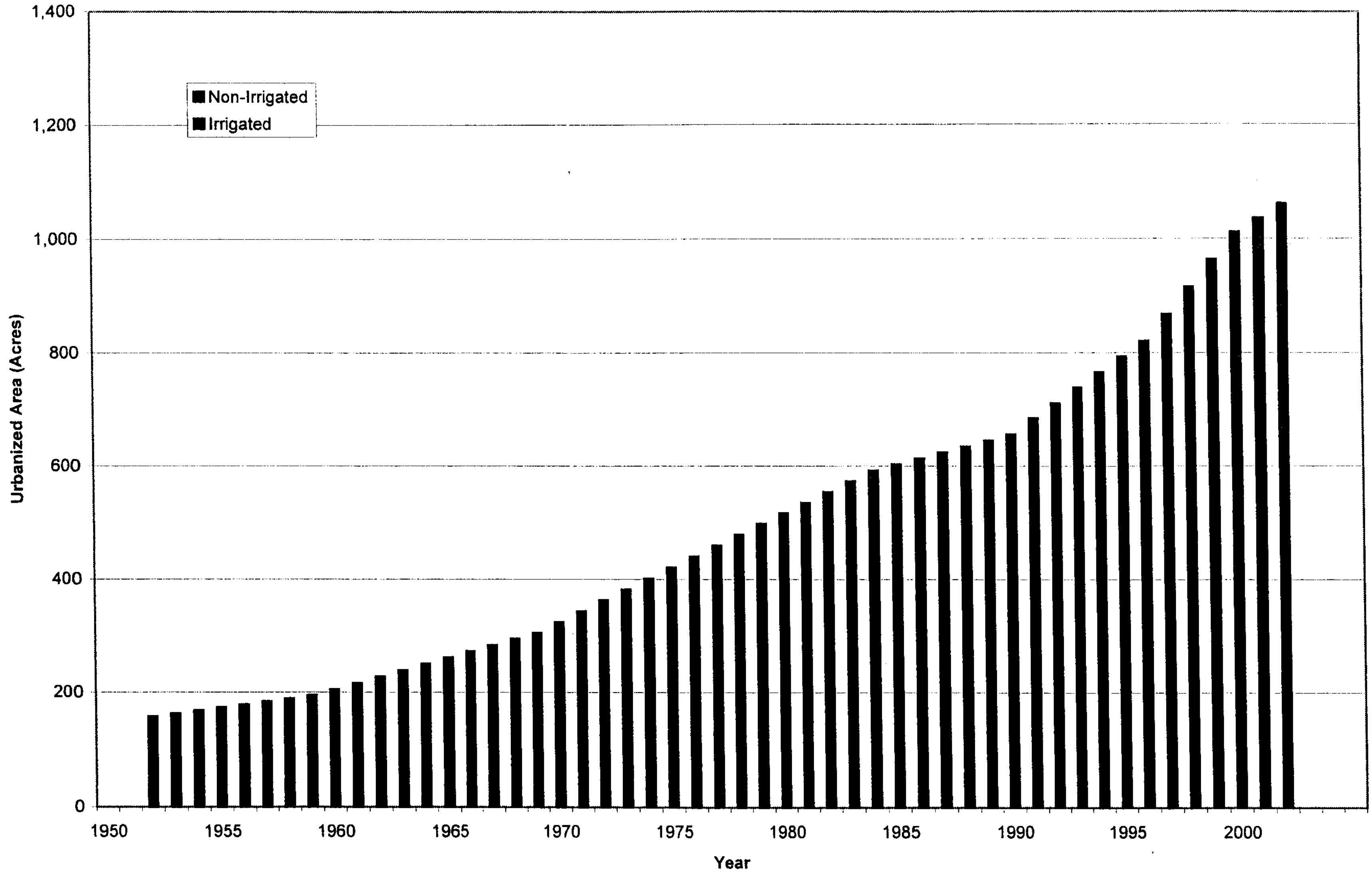

Figure 2.2e Urbanized and Landscaped Area within the Turlock Groundwater Basin, 1952-2002, for Delhi

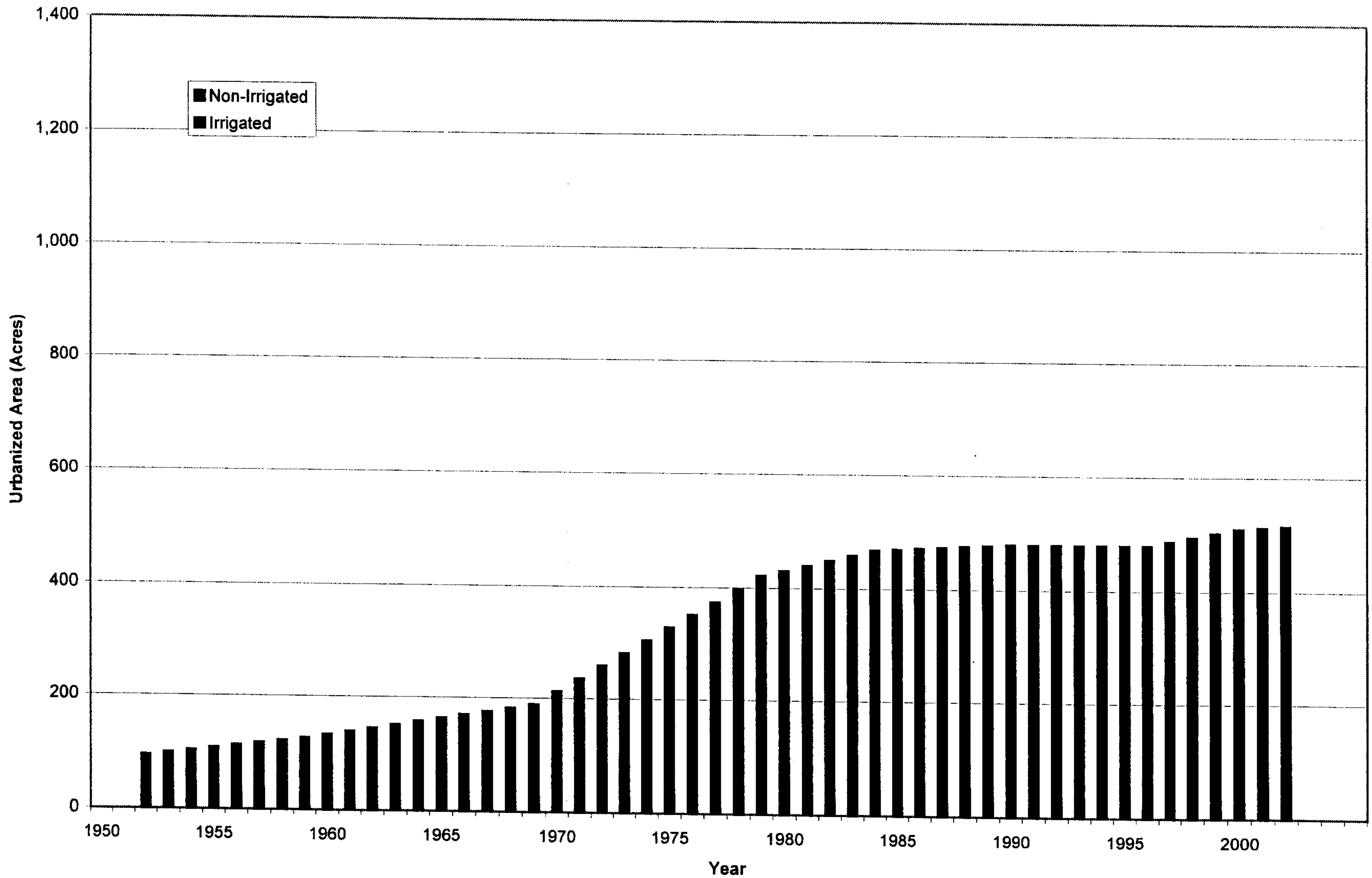

Figure 2.2f Urbanized and Landscaped Area within the Turlock Groundwater Basin, 1952-2002, for Denair

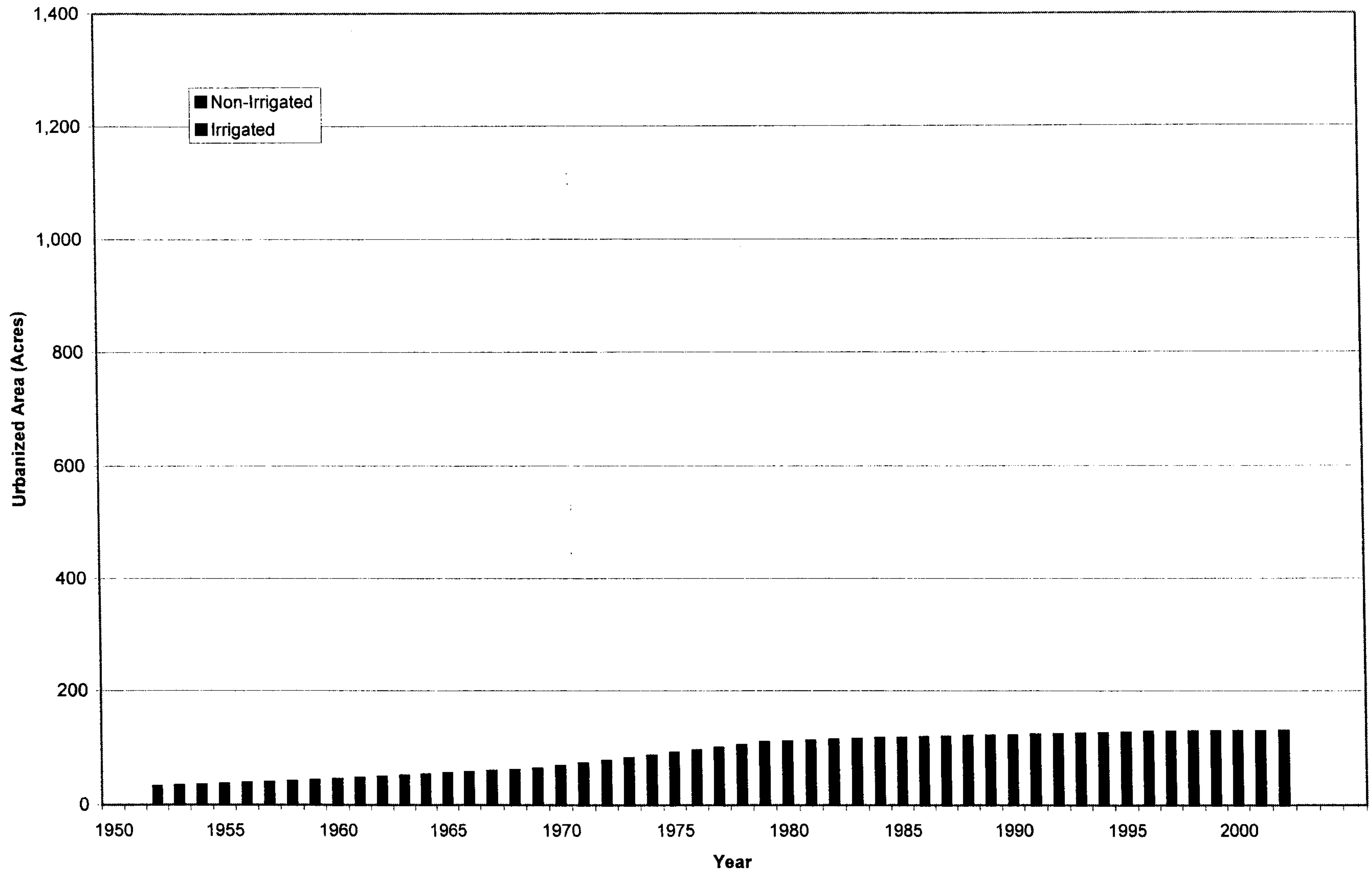

Figure 2.2g Urbanized and Landscaped Area within the Turlock Groundwater Basin, 1952-2002, for Hickman

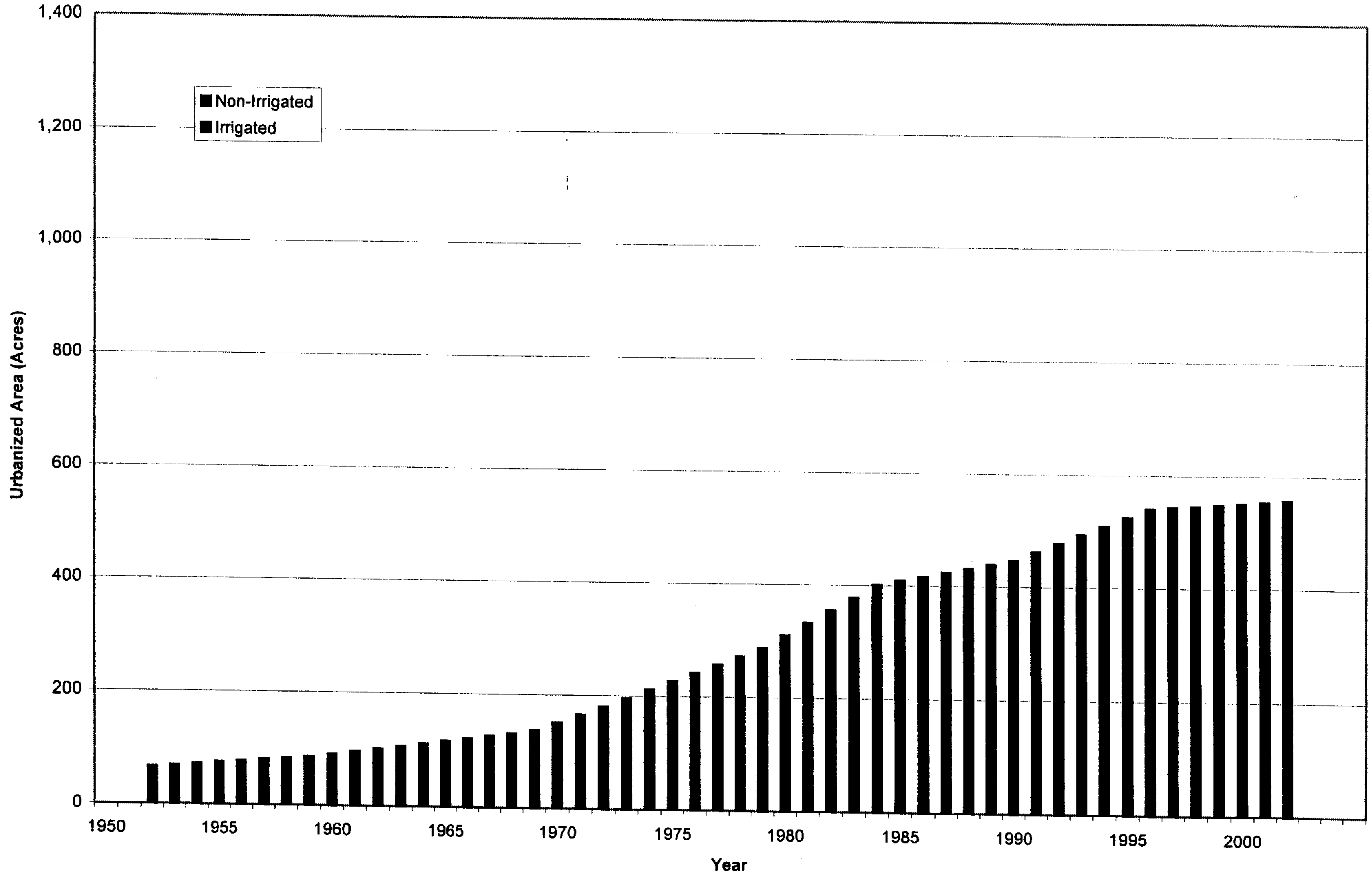

Figure 2.2h Urbanized and Landscaped Area within the Turlock Groundwater Basin, 1952-2002, for Hilmar