SHERIDAN COUNTY GROUND-WATER MANAGEMENT PROGRAM: MANAGEMENT OF WATER RESOURCES FROM THE CLEAR LAKE AQUIFER

Montana Bureau of Mines and Geology Open-File Report 447

by

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ABSTRACT

The Sheridan County Conservation District (SCCD) has successfully managed water extracted from the Clear Lake aquifer since the ground-water reservation was established in 1995 and the initial permits to appropriate water were authorized in the spring of 1996. In addition to the 2,980 acre-feet of water developed under the reservation, the management process has monitored and evaluated impacts of 30 pre-reservation State-of-Montana water permits under which water is produced from the Clear Lake aquifer. Development of these systems started in the mid-1970's, and water-level declines observed during the 1980's were initially attributed to the increased irrigation extraction. The continued monitoring and evaluation of data sponsored by the SCCD through Department of Natural Resources and Conservation (DNRC) grants has produced evidence that climatic fluctuations from the relatively moist conditions of the late 1970's to the drought of the 1980's are the primary cause of significant water-level fluctuations in lakes, wetlands, and aquifers. Significant irrigation impacts to these resources are not discernable on the basis of the long-term water-level trends.

The scrutiny applied to permitting, monitoring and evaluating impacts of water extraction is much greater now than prior to development of the water reservation. A Technical Advisory Committee (TAC) made up of representatives from the SCCD, Montana Bureau of Mines and Geology (MBMG), DNRC, U.S. Fish and Wildlife Service (USFWS), Natural Resource Conservation Service (NRCS) and Sheridan County Planning Board, was developed to provide technical advice to the SCCD. Improved evaluation results in greater confidence that other water resources will not be significantly impacted by new appropriations. The SCCD has conducted or contracted test drilling, water-level monitoring, water-use monitoring, water-quality analyses, data compilation, mapping, and hydrogeologic interpretation required to support irrigation development from the Clear Lake aquifer. These activities have provided the hydrogeologic background used by the Technical Advisory Committee and SCCD to evaluate water permit applications. Maintaining and expanding hydrogeologic monitoring was the primary focus of this project. Twelve new wells were constructed to define hydrogeologic conditions in special areas of concern near Dominic Lake and south of Medicine Lake.

The Clear Lake aquifer can be divided into five management areas based on development patterns, general aquifer conditions, and proximity to locations of significant recharge and discharge. The management areas are named Clear Lake North, Dagmar, Medicine Lake East, Medicine Lake South, and Medicine Lake North. Monitoring has shown that the current level of irrigation development has not significantly impacted lakes or wetlands in any of these management areas. Additional irrigation development up to the 5809-acre-foot interim cap should not cause significant impacts. High-density development may create potential localized problems in the North Clear Lake area and to a lesser degree in the Dagmar area.

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INTRODUCTION

An extensive, aquifer system underlies the eastern portion of Sheridan County (Figure 1). This system is referred to as the Clear Lake aquifer and the Sheridan County Conservation District (SCCD) has been given control of a reserved water right for irrigation from this aquifer. The aquifer system is complex, and is composed of several buried glacial outwash channels and the buried ancestral Missouri River channel. Locally, these various aquifer units are hydraulically connected, but elsewhere, confining beds separate them. Precipitation recharges the aquifer, but the amount and distribution of recharge are poorly understood. Water losses from the aquifer are also not well defined. Water evaporates from the aquifer system where it reaches the surface, such as at sloughs and lakes. Ground water is consumed by some plants (phreatophytes) whose roots can tap the water table. The effect irrigation pumping has on aquifer levels also is not well understood.

All of these uncertainties make allocating water from the aquifer system difficult. Currently, the combined irrigation authorizations from the pre-reservation State permits and the Sheridan County Water Reservation total about 11,290 acre-feet of water per year. Local farmers are interested in constructing more irrigation wells and appropriating more ground water. However, there are concerns that additional pumping could affect existing water-right holders and water levels in area wetlands.

In 1989, the Sheridan County Conservation district applied to the Board of Natural Resources and Conservation to reserve much of the available water from the aquifer. The district's intent was to manage the remaining water to the best benefit for all uses. In 1994, the Board of Natural Resources and Conservation (Board) acted on the application, reserving 15,479 acre-feet of water for the district, with stipulations.

In the reservation the Board ordered that the SCCD could initially only permit the use of up to 5,809 acre-feet of the water. Once this cap was reached, the district must temporarily stop issuing permits. At that time a hearing would be held by the Board to determine whether the district should develop the remaining portion of the reservation. This requirement resulted because evidence presented before the Board indicated that the new sustainable development from the aquifer system was probably between about 5,800 and 15,500 acre-feet per year. Already, the SCCD has received applications approaching the cap of 5,809 acre-feet per year.

Work conducted since the early 1980's has provided data and interpretations to the SCCD for management of the ground-water resources in the Clear Lake aquifer. The SCCD's water management process includes (1) assessing the technical viability of applications; (2) monitoring aquifer conditions including water levels, aquifer inflows, water use, and water quality; and

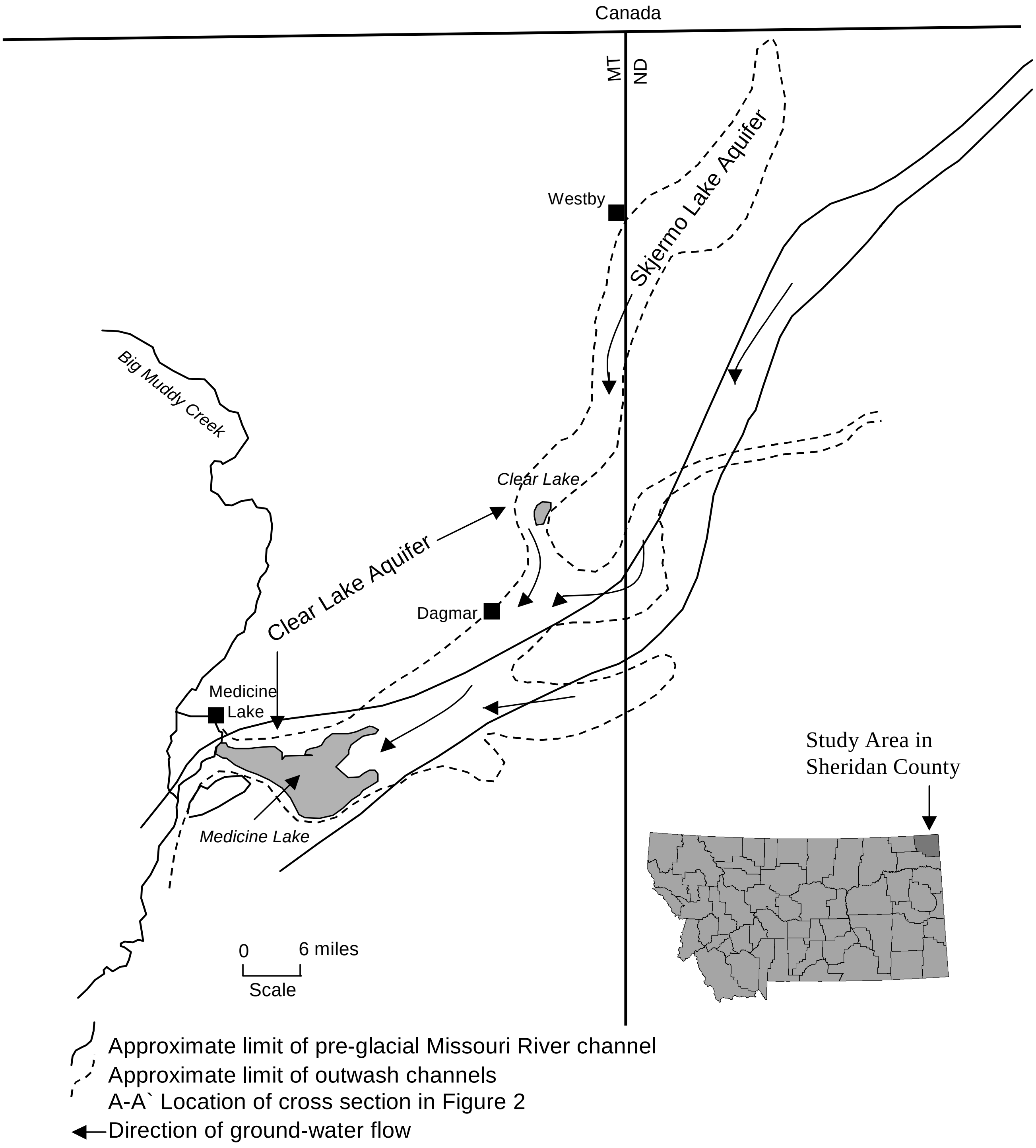

Figure 1. Buried pre-glacial channels of the Ancestral Missouri River and glacial outwash channels form the Clear Lake aquifer (MT). The Skjermo Lake aquifer is located within buried glacial outwash channels where they extend into North Dakota.

(3) determining how much pumping should ultimately be permitted from the aquifers.

Water management has successfully allowed moderate growth of irrigation development in eastern Sheridan County. The development has not interfered with prior water rights nor has it depleted surface water in the lakes and wetlands of the area. The SCCD has allowed only moderate growth of irrigation development so any evidence showing over-allocation of water resources can be evaluated before the development has an impact on other water resources. The controlled growth in water development was accomplished by setting rigorous data requirements to be submitted with each permit application. A technical advisory committee evaluates these data before approving permit applications. Each application has to demonstrate that water quantity, water quality, and soils are adequate for the proposed irrigation project and that the project is technically feasible. The applicant must show that water-level trends from nearby long-term monitoring are normal based on historical climatic observations. Evaluating water-level trends is important to demonstrate that the existing irrigation wells are not depleting the aquifer. Nearby wetlands are classified regarding their significance for habitat and the local environment. Potential impacts of the irrigation project on these wetlands are estimated based on the hydrogeology in respect of the wetland significance.

The primary benefit from irrigation development has been a boost to the local economy. Producers, government, and local businesses all benefit as a result of increased production and cropping variety possible under irrigation. Results of the ongoing hydrogeologic assessment have documented that these economic benefits do not occur at the expense of the environment. However, the SCCD must continue the monitoring and evaluation currently established to allow additional development of renewable water resources in the Clear Lake aquifer.

AQUIFER BACKGROUND

High-yield aquifers in eastern Sheridan County, Montana and western Divide County, North Dakota have been important sources of irrigation water for nearly 30 years. The aquifers occur in sand and gravel deposits formed by the preglacial Missouri River and meltwater streams draining from continental glaciers. Many deposits are coarse grained and can yield large supplies of water. Most recently, Donovan (1988) described these aquifers in Montana as part of a several-year field project conducted by the Montana Bureau of Mines and Geology. Earlier work was conducted by the USGS (Levings, 1986). A series of annual reports by Wanek (1983-95), in addition to a ground-water model (Wanek, 1984b) describe the aquifers and water use in the North Dakota section. Earlier geologic investigations concentrated on Late Tertiary and Quaternary deposits in the area

(Calhoun, 1906; Alden, 1924, 1932; Howard, 1958, 1960; Whitkind, 1959; Colton and others, 1961; Hansen, 1967; and Freers, 1970).

HYDROGEOLOGIC SETTING

As the ancestral Missouri River flowed towards Hudson Bay it cut several channels into the Fort Union Formation bedrock that were later filled with sand and gravel deposits. The buried channels commonly are reflected at the surface by broad topographic swales that trend southwest to northeast. Precise locations of the buried channels within the topographic swales are not clear, because as much as 300 feet of glacio-fluvial sediment masks their topographic expression. Where saturated with ground water, these sand and gravel deposits form moderate- to high-yield aquifers. Ground-water flow in the ancestral Missouri aquifer is from northeast to southwest towards the Big Muddy River valley.

Meltwater flowing from continental ice sheets deposited sand and gravel in glacial outwash channels in a northeast to southwest trending zone from north of Skjermo Lake in North Dakota to Medicine Lake in Montana. In places the outwash channels cut into the ancestral Missouri River sediments. These younger channels were often filled with highly permeable outwash sand and gravel. The glacial outwash and ancestral Missouri River alluvial deposits together form very thick permeable deposits resulting in a very high-yield aquifer. Figure 1, compiled largely from reports of Donovan (1988) and Wanek (1995), outlines the limits of buried channels. Locations within these limits have the greatest potential for constructing high yield wells. Figure 1 also shows the outlines of the Skjermo Lake aquifer in North Dakota and the Clear Lake aquifer in Montana. The Clear Lake aquifer directly overlies the ancestral Missouri aquifer over most of the southern third of the mapped area. Although the ancestral Missouri River deposits can be distinguished from overlying outwash deposits in some areas, these units are considered as one system for management purposes and are referred to as the Clear Lake aquifer.

Combined, the Clear Lake and Skjermo Lake aquifers extend approximately 40 miles. Twelve miles of the aquifer length are in North Dakota with the remaining 28 miles in Montana. The width of the aquifer ranges from 0.6 miles at its narrowest near the Clear Lake constriction to more than 3 miles wide east of Medicine Lake. Aquifer thickness is highly variable, ranging from 10 to 60 feet. Locally, areas of continuous sand and gravel greater than 100 feet thick have been identified (Figure 2). These areas, referred to as "central plugs" by Donovan (1988), are highly pervious and may yield very large volumes of water to wells. Thin aquifer zones hydraulically connected to these "plugs" typically show aquifer transmissivities much higher than would be expected on the basis of gravel thickness at the well. Flow in the Clear Lake aquifer system is from northeast to southwest towards Medicine Lake. Recharge to the aquifer is largely from direct infiltration of precipitation with additional recharge by lateral flow from side channels. Smaller amounts of recharge come from direct infiltration of streamflow. Water discharges from the Clear Lake aquifer into lakes and sloughs and is lost to evapotranspiration. Donovan (1988) estimated that between 70,000 and 90,000 acre-feet of water was removed by evaporation annually from water bodies located above or near the aquifer system. Other discharges from the aquifer are to wells, springs, and streams.

The land surface overlying the Clear Lake-Skjermo Lake aquifer system is dotted with many wetlands, sloughs, and small lakes. Many of these water bodies are located in kettles or depressions in the land surface that formed when stagnant glacial ice melted, leaving behind hills and depressions. The depressions later filled from ground-water inflow and surface runoff. The depressions and included water bodies display a wide range of hydraulic connection to the underlying aquifer system. Some are perched or separated from the aquifer by fine-grained materials, others are separated by thick sodium sulfate salt deposits (up to 70 ft thick in Miller lake near Westby--Murphy, 1996), and others are closely connected to the underlying aquifer. Donovan (1988) categorized many of the lakes as open, closed, or restricted-outflow type lakes. Closed or restricted-flow lakes have poor water quality because evaporation has increased the mineral concentration in the lake water. Many lakes and wetlands were sampled in 1984 (Donovan, 1988) and were resampled in 1990 (Reiten, 1992). Comparing the analytical results indicated many lakes had strong increases in dissolved solids over that 6 year time period. That time interval coincided with the end of significant drought in this region. In general, dissolved solids increased the most in the closed-outflow lakes and least in the open-outflow lakes.

The Clear Lake aquifer forms a very complicated aquifer system. The current base of knowledge does not adequately define the degree of hydraulic connection between the various components of the aquifer system. As a consequence, impacts to lakes, wetlands, and other irrigators are difficult to assess. The primary tools for monitoring irrigation impacts are climatic data, water-use data, and water-level data. There are many different ways to compare and display these data. Charts of water levels in wells versus time are effective methods to display and interpret water-level fluctuations. Precipitation also can be charted versus time and displayed as secondary data on hydrographs. Daily, monthly, or annual precipitation accumulations are commonly used frequencies to display precipitation totals. The accumulations can be related to the averages for whatever time period is desired. Cyclic wet periods interspersed with periods of drought can be observed using charts showing cumulative-monthly-departure-from-normal-precipitation. Climatic data are compiled from records of the National Oceanic and Atmospheric Administration (NOAA) climatic station established at the Medicine Lake Wildlife Refuge. The water-level monitoring program established by the MBMG for the SCCD provided the essential data to begin interpreting causes of the water-level fluctuations. Continued monitoring of water levels, precipitation, and irrigation water use are critical to develop a better understanding of the Clear Lake aquifer water balance. The data compilation and interpretation has recently become more efficient through use of the MBMG Groundwater Information Center (GWIC).

Aquifer models were developed by Donovan (1988) and Schuele (1998) to help identify major components of the aquifer system. Current models include a mass balance and indicate that limited development would not severely impact the resource (Donovan, 1988; Schuele, 1998). Careful monitoring and limited slow development appear to be the most reasonable management plans.

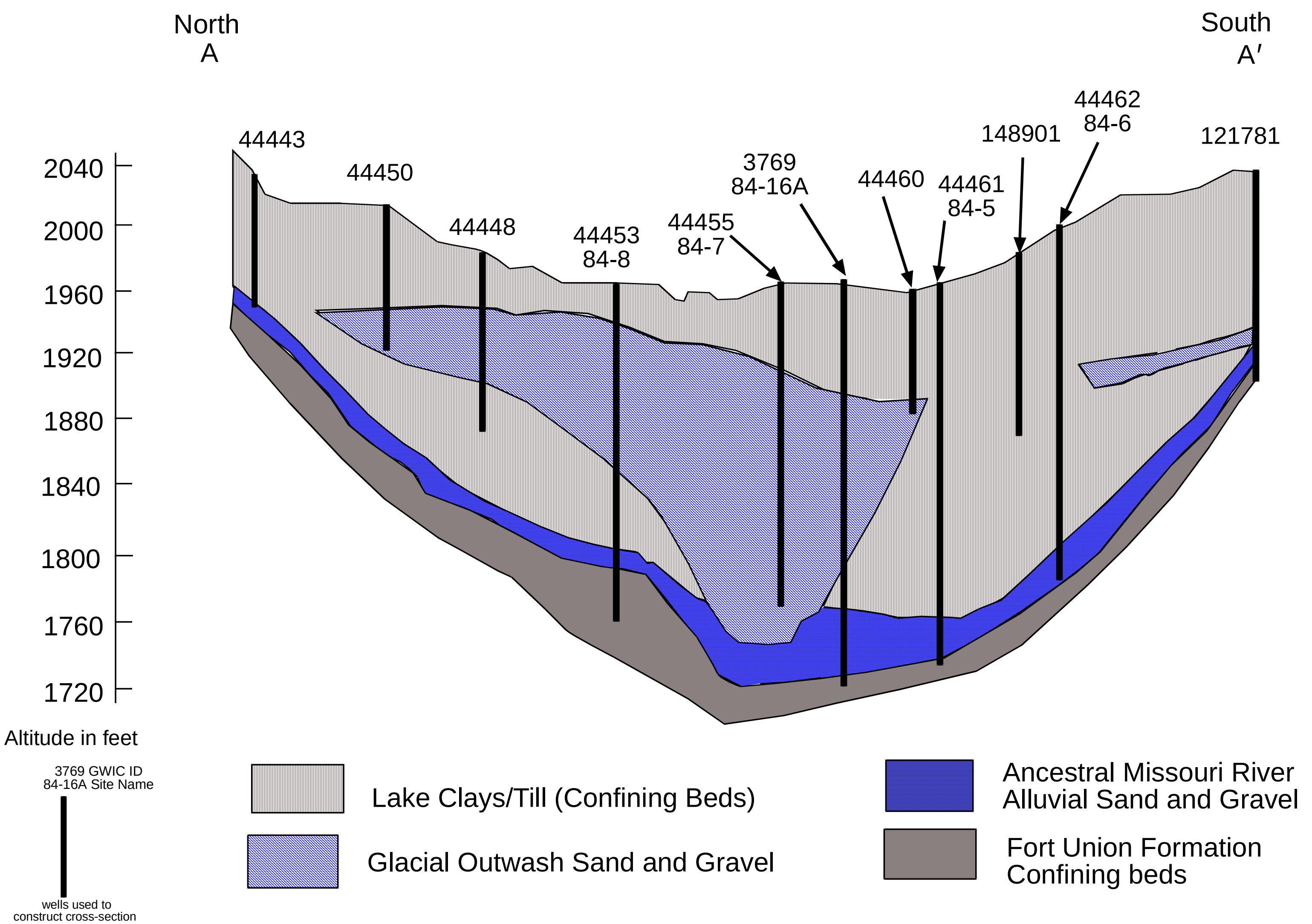

Figure 2. Geologic profile across the Clear Lake aquifer system east of Medicine Lake. See Figure 1 for location.
Blue-colored units make up the Clear Lake aquifer system. Grey-colored units are aquitards.

1 mile

VERTICAL EXAGGERATION X44

AQUIFER MANAGEMENT AREAS

The Clear Lake aquifer can be divided into five distinct areas based on development patterns, general aquifer conditions, and proximity to locations of significant recharge and discharge. These five areas make logical divisions for water management and are shown on Plate 1. The management areas from northeast to southwest (downgradient) are designated the Clear Lake North, Dagmar, Medicine Lake East, Medicine Lake South, and Medicine Lake North. A series of maps (Plates 2 to 6) provide detail for each of the five management areas.

CLEAR LAKE NORTH

The Clear Lake North area is underlain by a very high-yield segment of the Clear Lake aquifer (Plate 2). High yields are produced from glacial outwash and collapsed glacial outwash from wells ranging from 40 to 150 feet deep. No evidence of ancestral Missouri River sediments has been identified underlying this part of the aquifer. Water in the aquifer is under leaky confined conditions. Clear Lake, Goose Lake, Dominek Lake and several unnamed lakes and wetlands are all important habitat areas for migratory birds and other wildlife. Surface drainage is not well developed at current hydrologic conditions. The only named stream is Lake Creek, which is an intermittent stream draining the southern third of this area. Soils overlying the aquifer are very coarse grained and make the land surface overlying this part of the aquifer an important recharge area. Most recharge appears to be from snowmelt and occasional heavy summer rains. Typically plants use most growing-season precipitation.

Irrigation development began in the 1970's with wells located in Township 34N, Range 58E, section 14. Eleven state permits are developed and authorize use of about 3,590 acre-feet of water annually. One SCCD permit has been developed and authorizes use of up to 260 acre-feet of water annually in the Clear Lake North area. Current irrigation development is concentrated near the central part of the area, with nine irrigation systems located on adjacent quarter sections in Township 34N, Range 58E. Five additional applications have been submitted to the SCCD but have not yet been approved.

Aquifer water levels declined several feet in the Clear Lake North area between 1981 and 1993. Hydrographs from wells 45981, 46003, 3947, and 3944 demonstrating these declines are shown on Plate 2. These water-level declines were originally attributed to local irrigation development and development just to the east in North Dakota. Long-term monitoring of water levels and precipitation (plotted as cumulative change from monthly-normal precipitation) follow very similar trends. The charts imply that aquifer levels are closely tied to the cumulative change from monthly-normal precipitation. Compiling precipitation data on this basis appears to be a good proxy for estimating recharge to the aquifer. Aquifer water levels stabilized in the early 1990's and are currently rising, apparently in response to increased precipitation and therefore recharge.

The Clear Lake North area does not yet appear to be over-appropriated. Aquifer water levels are recovering from the drought of the 1980's (see hydrographs on Plate 2). Several more years of above-normal precipitation will be required for water levels to recover to pre-drought conditions. Lakes that have been dry since the early 1980's such as Dominek Lake have been filling. Water levels in Clear Lake are about 1 foot higher in 2000 than they were in 1995. Monitoring of wetlands using staff gauges is charted on hydrographs 154483 and 154484. Water levels in these wetlands have also increased since 1995. The close proximity of nine high-yield wells in the central part of this management area is a major consideration for future development. The fact that both aquifer- and surface-water levels can rebound in areas of high-density development is encouraging. This strongly indicates that ground water is not being mined in this area. In addition, lakes and wetlands appear not directly impacted by the irrigation withdrawals. Levels of lakes and wetlands appear to be buffered by confining or semi-confining beds separating the lakes from the underlying high-yield intervals tapped by irrigation wells. Wider spacing of additional irrigation wells should be encouraged to optimize development without adverse impacts.

DAGMAR

The Dagmar area is underlain by a very high-yield segment of the Clear Lake aquifer. The extent of the glacial outwash and ancestral Missouri River alluvial components of the aquifer is shown on Plate 3. Twelve irrigation wells have been completed in the coarse-grained glacial outwash deposits between depths of 100 and 150 feet, but ancestral Missouri River alluvium has not been developed. Saturated sand and gravel ranges from 20 to more than 100 feet in thickness and the best wells appear to lie along the central axis of the aquifer. Lower yields along the edges appear to be associated with poorly sorted ice-contact deposits. Water in the aquifer is under unconfined to leaky confined conditions. Brush Lake, White Lake, Mallard Pond, Long Lake, Berger's Pond, Katy Lake and several unnamed lakes and wetlands are located in the Dagmar area; all are important habitat areas for migratory birds and other wildlife. Lake Creek is an intermittent stream that drains much of the area, connects many of the lakes and wetlands and is controlled for wetland management in the southwestern part of the Dagmar area. Cottonwood Creek is another intermittent stream that drains the southern part of the Dagmar area.

Irrigation development began in the early 1980's. Eight state permits are developed and authorize use of about 2,560 acre-feet of water annually. One state permit, located east of Brush Lake, authorizes use of 432 acre-feet of water and was abandoned after only a couple of years because of poor water quality. Four SCCD permits have been developed and authorize use of up to 804 acre-feet of water in the Dagmar area. Two other applications have been submitted, not been developed and are in the process of being revoked. Existing development is concentrated on a 2-mile-wide swath extending from about 3 miles southwest of Dagmar northeast to Brush Lake.

The 1980's drought caused noticeable water-level declines in the Dagmar area. However, the declines were about one-half of the magnitude of the declines observed in the Clear Lake North area. Reduced drought responses in comparison to the Clear Lake North area appear to be related to the more extensive aquifer in the Dagmar area. Water-level trends again closely resemble the departure-from-normal precipitation trends: falling in the 1980's and recovering in the 1990's. Seasonal responses caused by evapotranspiration from wetlands and lakes are shown on hydrographs for Brush Lake, Mallard Pond, and Marsh 1 (Plate 3). Hydrographs 3858 and 3773 show how the outwash part of the aquifer responds (Plate 3). Seasonal irrigation responses are shown on hydrographs of water levels in well 3862 (outwash aquifer) where rapid declines followed by rapid recovery occurred during the summer of 1984. These water-level changes were the result of irrigation from a nearby well that was abandoned in 1985 because of poor water quality. The 4- to 6-foot water-level fluctuations shown in the hydrograph of well 3779 are the result of irrigation withdrawals from the deep alluvial part of the aquifer in the Medicine Lake East area more than 2 miles southwest of well 3779. While these irrigation responses may be several feet or more annually, they typically recover totally before the next irrigation season.

The Dagmar area does not yet appear to be over appropriated. Aquifer water levels are recovering from the drought of the 1980's (see hydrographs on Plate 3). Water levels are approaching pre-drought levels and in some cases may have exceeded them. Brush Lake has recovered about 3 feet since 1990. Lakes that have been dry since the early 1980's such as White Lake are filling up. The density of development in the Dagmar area is not as serious as in the Clear Lake North area, but future management must continue to consider the density of irrigation development as a significant factor. Water-level recovery in the Dagmar area from the 1980's-1990's drought is even more encouraging than the recovery in the Clear Lake North area. In addition, lakes and wetlands are not directly impacted by the irrigation withdrawals. Levels of lakes and wetlands appear to be buffered by confining or semi-confining beds separating the lakes from the underlying high yield intervals tapped by irrigation wells. Wider spacing of additional irrigation wells should be encouraged to optimize development without adverse impacts.

MEDICINE LAKE EAST

Medicine Lake East is underlain by glacial outwash and ancestral Missouri River alluvial gravel of the Clear Lake aquifer. The extent of the glacial outwash and ancestral Missouri River alluvial components of the aquifer are shown on Plate 4. High-yield wells have been constructed in both parts of the aquifer.

Wells in the glacial outwash deposits range from 70 to 100 feet deep. Water in this part of the aquifer is under semi-confined to unconfined conditions. Very thick sand and gravel deposits form a highly transmissive plug along the axis of the buried valley. This highly transmissive plug formed when the fine-grained lake deposits were eroded by glacial meltwater and glacial outwash was deposited in direct hydraulic contact with the ancestral Missouri River alluvial deposits. Aquifer tests and monitoring of response to irrigation pumping from the glacial outwash show expansion of drawdown cones to be limited to less than 3,000 to 4,000 feet.

Wells in the ancestral Missouri River alluvial deposits range from 250 to 270 feet deep. Water in this part of the aquifer is under confined conditions. Fine-grained lake deposits form the confining layer overlying the alluvial gravels. Aquifer tests and monitoring of responses to high yield irrigation pumping in the confined part of the aquifer show a very broad cone-of-depression extending five to six miles. Drawdown is reduced as the cone-of-depression reaches the highly transmissive plug that forms a recharge boundary.

Medicine Lake, Gaffeney Lake, and several unnamed wetlands and lakes are located in this area. Lake Creek, Sand Creek, and Cottonwood Creek drain the Medicine Lake East area. Sand Creek and Cottonwood Creek are intermittent streams. Several dikes, dams, and other control structures control flow and levels of Lake Creek. As a result the creek is backed up over most of this area and flow is directed to different wetlands to enhance water resources in the Refuge.

Irrigation development began in the late 1980's with development of both the ancestral Missouri River alluvial and the glacial outwash parts of the aquifer. Four state permits have also been developed and authorize use of up to 951 acre-feet of water annually. Four SCCD permits have been developed and authorize use of as much as 1500 acre-feet of water annually in the Medicine Lake East area. Two additional permits have been submitted to the SCCD Reservation and have been approved pending completion of an aquifer test.

Hydrographs of the irrigation wells and monitor wells in this area display responses caused by climatic factors (precipitation, temperature, wind), natural biologic-induced responses caused by transpiration of plants, and man-induced responses caused by irrigation discharges and surface water diversions (Plate 4). Precipitation and the timing of precipitation events largely determine ground-water recharge. Ground-water discharges are dominated by evapotranspiration with a minor but an increasing amount attributable to irrigation usage.

Continuous water-level recorders have operated on well 3769 (84-16A), screened in the deep alluvial gravels, since 1995 and well 3770 (84-16B), screened in the glacial outwash deposits, since 1984. Data from these recorders along with periodic measurements allow construction of hydrographs to compare pre-development (before 1987) water-level fluctuations to those including impacts of 5 nearby high-yield irrigation wells. In addition to showing the difference in water-level fluctuations as the result of development, varying responses in the deep (ancestral Missouri River alluvium) and shallow (glacial outwash) parts of the aquifer to irrigation stresses are clearly demonstrated. Maximum seasonal fluctuations in the deep alluvial part of the aquifer at well 3769 were about 1 foot prior to development. These seasonal fluctuations increased to between 7 and 13 feet as additional wells were constructed closer to this monitoring well. Maximum seasonal fluctuations in the glacial outwash part of the aquifer at well 3770 prior to development were about 2 feet. In contrast, since development the seasonal fluctuations ranged from about 2.5 to 3 feet. The most obvious change in water-level fluctuations since the development of irrigation is the magnitude of the seasonal change. Water-level fluctuations are greatest close to irrigation wells. Although no serious problems have been reported, well interference is a significant concern in the ancestral Missouri River alluvial part of the Clear Lake aquifer. Post-irrigation-season water levels typically return to near static levels by the following spring. Recovery appears to be slower and somewhat subdued near aquifer boundaries such as at well 3678 and well 3679. At several locations, water levels appear to have stabilized at slightly lower levels than the initial head prior to development.

Impacts to the shallow glacial outwash aquifer caused by pumping of the deep alluvial aquifer are not evident. Water levels in this part of the aquifer respond to nearby pumping, but these responses are typically limited to distances of several hundred feet to as much as ½ miles from a pumping well. Well 157817 (Marsh 2) was constructed to a depth of 8 feet and is monitored to document water-level responses in a wetland. This well is located over 1 mile from the closest irrigation well. Water-level fluctuations in this wetland appear to respond to evapotranspiration and diversions from Lake Creek. Water-level declines caused by evapotranspiration and irrigation withdrawals both occur during the growing season and are difficult to discern on long-term hydrographs. The causes of fluctuations are much easier to identify on monthly or seasonal hydrographs. Irrigation responses can be identified by noncyclic water-level declines corresponding to nearby pumping. Evapotranspiration responses are expressed as cyclic diurnal fluctuations with water levels declining during daylight hours and recovering at night. None of the pumping-induced fluctuations have been documented in shallow parts of the outwash aquifer associated with wetlands. Therefore, it is doubtful if this pumping directly impacts nearby surface water resources.

The Medicine Lake East area of the Clear Lake aquifer does not yet appear over-appropriated for irrigation withdrawals. Water-level fluctuations remain relatively stable from one year to the next and no direct impacts to wetlands have been identified. The relatively moist conditions of the past few years have probably allowed for normal to above-normal recharge and produced less demand for irrigation withdrawals. Recent modeling (Schuele, 1998) supports these observations for this part of the Clear Lake aquifer. Schuele's results for the 1981-1996 period indicate very small differences between simulated water-level changes (caused entirely by climate) to changes caused by both climate and irrigation withdrawals. However, the limited areal extent and finite recharge make over-appropriation a potential possibility in the future. Continued monitoring of water levels is critical in this area to verify the timing of recharge in different parts of the aquifer and to provide data to guide future development.

MEDICINE LAKE SOUTH

The Medicine Lake South area is underlain by alluvial gravels deposited by the ancestral Missouri River. The extent of this aquifer is mapped on Plate 5. Moderately high yields of water can be produced from irrigation wells completed in this aquifer. Depths of existing irrigation wells range from 150 to 250 feet. Aquifer thickness ranges from 10 to 30 feet. A very narrow and deeply buried channel crosses the area from southwest to northeast. This channel was encountered while drilling well 3677 where it is less than ¼ mile wide and is incised into bedrock about 350 feet below land surface. More than 100 feet of cemented sand and gravel was penetrated at the bottom of well 3677. This was overlain by more than 200 feet of fine-grained lake sediments and glacial till. Water levels in well 3677 do not appear to respond directly to the pumping of a nearby irrigation well (152254). Therefore, this buried channel does not appear to be in direct hydraulic connection to parts of the aquifer tapped by irrigation well 152254. Ground water in the aquifer is under confined conditions in the parts of the aquifer currently developed. Test drilling conducted in 1999 helped to define the extent of this aquifer and provided several additional monitoring points.

Medicine Lake and Homestead Lake are located in this area. Several small intermittent streams drain into the south side of Medicine Lake. Lake Creek and Big Muddy Creek provide the major surface water drainage in this area.

Irrigation development began in the Medicine Lake South area in the late 1980's. Two state permits are developed and authorize use of up to 663 acre-feet of water annually. Two SCCD permits are currently developed and authorize use of up to 580 acre-feet annually. Two new permit applications have recently been proposed in this area.

The only monitoring well in the current area of development with more than 10 years of water-level history is well 3677(Plate 5). Water levels in this well have declined about 8-10 feet since 1984. Water-level fluctuations at well 3677 have been difficult to monitor with a continuous recorder because of deep (124-130 foot) static water levels and a very large barometric response. Seasonal fluctuations coincide with irrigation development in the Medicine Lake South area, which started in 1990. Long-term declining water-level trends may be related to irrigation withdrawals or delayed effects of recharge. A possible explanation of the observed water-level fluctuations is that recharge takes 8-10 years to affect water levels. Hydrographs of several other wells in the Medicine Lake South Area are shown on Plate 5. Most of the wells tapping the deep alluvial aquifer show significant seasonal declines caused by irrigation. These water levels typically recover to conditions prior to irrigation by the next season. A slight trend towards incomplete recovery is apparent near irrigation well 152254. Several wells located between existing development and Medicine Lake show very minor fluctuations (169212, 169213, 169214) but none of these responses appear to be related to irrigation. Based on these observations irrigation in the South Medicine Lake area does not impact water levels in Medicine Lake. Coincidental timing of evapotranspiration and irrigation during the growing season causes similar responses between lake levels and aquifer levels.

The Medicine Lake South area of the Clear Lake aquifer does not yet appear to be over-appropriated for irrigation withdrawals. The magnitude and timing of water-level fluctuations remain relatively similar each year. The poor understanding of recharge is a significant concern for future water management. Continued monitoring of water levels is critical to verify the timing of recharge in different parts of the aquifer and to provide data to allow future development. Incomplete recovery of water levels needs to be closely monitored to prevent over-pumping the aquifer.

MEDICINE LAKE NORTH

Medicine Lake North is underlain by alluvial gravels deposited by the ancestral Missouri River. In addition, glacial outwash gravels overlie the alluvial deposits and the combination forms a very thick aquifer system. The extent of the aquifer is mapped on Plate 6. High yields of water can be produced from irrigation wells completed in this aquifer. One irrigation well has been constructed and was completed at a depth of 200 feet. It encountered 128 feet of sand and gravel. Ground water is under unconfined to semi-confined conditions in the part of the aquifer currently developed.

Big Muddy Creek is the major surface water drainage in this area. This stream can be diverted to freshen Medicine Lake during periods of high flow. The outlet of Medicine Lake is controlled by a structure called Dam 4. Surface water draining out of the Lake is carried by Big Muddy Creek to the Missouri River.

Irrigation development began in the Medicine Lake North area in the early 1990’s. One state permit is developed and authorizes use of up to

250 acre-feet of water annually. There are no SCCD applications or approved permits in this area.

The only monitoring well in the current area of development with over 10 years of history is well 3766 (Plate 6). Water levels at this well declined from 1987 to 1993 but have since risen several feet. Currently water levels are higher than when monitoring started. Diurnal fluctuations at this well have been used to calculate evapotranspiration from Medicine Lake. The historic water-level trends closely follow levels in Medicine Lake. Water levels in well 3763 show significant seasonal declines caused by irrigation. These water levels typically recover to conditions prior to irrigation by the next season. The overall trend in this area is towards increasing water levels, from historic lows in the winter of 1992-93.

The Medicine Lake North area of the Clear Lake aquifer does not yet appear to be over-appropriated for irrigation withdrawals. The poorly defined extent of the aquifer and poor understanding of recharge are significant concerns for future water management. Additional test drilling will be required to provide data for future development.

DISCUSSION AND RESULTS

The primary goal of this project is to develop a ground-water management plan that is based on sound scientific data. Developing management plans includes:

1) Reviewing water permit applications.
2) Monitoring aquifer and surface water conditions.
3) Aquifer modeling review and assessment of using existing models as part of the management process.

Data for these three components of the project have been compiled into an annual report format that will be used to periodically update, summarize, and report on the status of development in the Clear Lake aquifer. An expanded version of this report follows.

APPLICATION REVIEW

Early in the development of the Sheridan County Water Reservation, guidelines were established to review water-permit applications. These guidelines were followed for every project reviewed. A technical advisory committee (TAC) was established to advise the SCCD consisting of representatives from the SCCD, U.S. Department of Natural Resource Conservation Service (NRCS), Montana Department of Natural Resources and Conservation (DNRC), United States Fish and Wildlife Service (USFWS), Sheridan County Planning Board, and Montana Bureau of Mines and Geology (MBMG). Under guidance of the technical advisory committee rules were established to evaluate applications to divert and use ground water for irrigation projects. After the committee established these rules, the committee’s focus changed to applying them to applications to use the water reservation. The MBMG has been authorized to provide technical hydrogeologic support to the SCCD regarding the appropriation of ground water. Funding for hydrogeologic assessment and monitoring has come from the USFWS, DNRC administrative grants, and DNRC Renewable Resource grants. The MBMG and SCCD have provided matching funds.

The TAC made minor modifications to the guidelines, but all applications were reviewed based on data provided by the applicant and historic data collected by the MBMG and SCCD. These data provide the necessary background both in terms of potential aquifer productivity and long-term water-level trends to make decisions. The applicant must show that an adequate volume of water is available by constructing a high yield well and conducting an aquifer test. The results of a water analysis must be submitted to demonstrate acceptable water quality. Soils must be shown to be irrigable. Potential impacts to other water resources including lakes, wetlands, and senior water rights must be assessed. If the assessment indicates significant impacts to other resources the application will be denied. Access must be provided to monitor water levels and collect water-quality data. The primary goals of these requirements are to provide the best chance for developing successful irrigation systems without impacting other water resources.

A total of 29 applications for irrigation water have been submitted to the SCCD. These are summarized on Table 1. Currently 11 applications have been permitted, developed, and authorize use of as much as 2,980 acre-feet of water to irrigate 1,661 acres. Seven of the permit applications were revoked in some cases because of poor water quality and in other cases because the applicant did not pursue timely development. Eleven permit applications are pending and are scheduled for review by the Technical Advisory Committee. Location and status of the permits are shown on Plates 1-7. These maps are developed in GIS format and will be updated as necessary.

MONITORING

The primary tools for water management are long-term monitoring of aquifer water levels, wetland and lake water levels, climate, water use, and water quality. Water levels in a network of 104 wells and 22 lakes and wetlands are periodically measured. Frequencies of measurements range from continuous to semiannual. Continuous recorders monitor water levels at 18 sites. Monthly to biweekly measurements are collected at 68 sites. Semiannual measurements are collected at 38 sites. Hydrographs displaying water-level fluctuations at selected wells, lakes, and wetlands are plotted on Plates 2 through 6.

Climatic conditions are measured at a NOAA station established at the Medicine Lake Refuge Headquarters. The principal climatic variable evaluated is monthly precipitation. Precipitation is plotted along with water levels at selected wells on Plates 2 through 6.

All well data including well logs, water-level measurements, and water-quality data are stored on the Montana Bureau of Mines and Geology Ground-Water Information Center database (GWIC). The data are easily accessible through the website at http//mbmggwic.mtech.edu. All data are stored under the project named Sheridan County Water Reservation. New water-level data, driller's logs, and water-quality reports are input into GWIC shortly after they are received. An interactive system has been developed to construct updated hydrographs on demand. Data are inspected frequently to resolve inconsistencies and to monitor fluctuations. Water-use data and climatic data are compiled annually and summarized graphically. These data are stored on the MBMG Billings computer system. Other data such as interim reports, aquifer tests, drawdown projections, permit applications, and USFWS historic lake-level measurements are on file in the MBMG Billings office.

Table 1. **RESERVED WATER APPLICANTS**

application #	applicant name	date	Time	legal description	acres	ac-ft	Cum. total
SC-001 permitted	Neil & Janice Andersen	3/5/96	8:06	nw4 S30 T33N R58E	134	268	268
SC-002 permitted	Richard E. Sampson	3/5/96	8:07	se4 S25 T33N R57E	67		
				nw4 S36 T33N R57E	67	268	536
SC-003 pending	Richard E. Sampsen	3/5/96	8:08	nw4 S5 T32N R58E	134	268	804
SC-004 permitted	Smith Farms, Inc.	3/5/96	8:10	S35 T32N R57E	405	536	1340
SC-005 permitted	Loren Henke	3/5/96	8:11	se4 S34 T32N R57E	134	268	1608
SC-006 permitted	James Bolstad	3/5/96	8:16	ne4 S28 T31N R56E	134	200	1808
SC-007 revoked	DH Hansen Ranch	3/5/96	8:17	sw4 S10 T32N R58E	41.2	82	1808
SC-008 permitted	Orvis Nelson	3/5/96	8:18	se4 S26 T31N R56 ne4 se4,nw4 se4, ne4nw4, se4 nw4	190	380	2188
SC-009 revoked	Jeppe Sorensen	3/7/96	14:40	se4 S9 T32N R58E	132	264	2188
SC-010 revoked	Ken & Jean Nyby	3/13/96	16:13	sw4 S35 T33N R57E	225	450	2188
SC-011 permitted	Loren Henke	7/1/96	14:57	nw4 S2 T31N R57E	134	268	2456
SC-012 pending	Aasheim & Clark	8/7/96	21:10		258	387	2843
SC-013 pending	Marlowe Onstad	9/3/96	9:54	ne4 S15 T34N R58E	130	260	3103
SC-014 permitted	Marlowe Onstad	9/3/96	9:55	se4 S15 T34N R58E	130	260	3363
SC-015 permitted	Roger&Juanita Schmitz	10/11/96	11:05	ne4 S9 T31N R57E	132	264	3627
SC-016 pending	Roger&Juanita Schmitz	10/11/96	11:06	sw4 S34 T32N R57E ne4 S3 T31N R57E	264	528	4155
SC-017 revoked	Marlowe Onstad	2/18/97	10:45	se4 S36 T35N R58E lots 6-12	134	268	4155
SC-018 revoked	Marlowe Onstad	2/18/97	10:53	sw4 S25 T35N R58E lots 2-11	134	268	4155
SC-019 revoked	Marlowe Onstad	2/18/97	10:59	ne4 S25 T35N R58E lots 2-11	134	268	4155
SC-020 revoked	Richard E. Sampsen	3/17/97	10:17	w2 nw4 S31 T33N R58E	65	97.5	4155
SC-021 permitted	Richard E. Sampsen	10/20/97	14:12	ne4 S35 T33N R57E	134	268	4423
SC-022 pending	Marlowe Onstad	11/3/97	13:33	se4 S36 T35N R58E lots 6-12	134	268	4691
SC-023 pending	Marlowe Onstad	11/3/97	13:34	sw4 S25 T35N R58E lots 2-11	134	268	4959
SC-024 pending	Marlowe Onstad	11/3/97	13:35	ne4 S25 T35N R58E lots 2-11	134	268	4959
SC-025 pending	Marlowe Onstad	6/29/98	9:36	nw4 S12 T34N R58E	134	268	5227
SC-026 pending	Roger&Juanita Schmitz	10/19/98	11:31	e2 sw4 S9 T31N R57E w2 se4 S9 T31N R57E	130	260	5487
SC-027 permitted	Richard E. Sampsen	2/16/99	10:28	ne4 S35 T33N R57E			
				s2s4 S25 T33N R57E	flow increase only		
				n2 S36 T33N R57E			5487
SC-028 pending	Orvis & Dale Nelson	2/17/00	15:15	sw4 S26 T31N R57E	135	203	5690
SC-029 pending	David Skillingberg	2/24/00	14:50	se4 S24 R31N R55E	135	270	5960
	Total Reserved(Immediate use) 5809 ac-ft						
	Total permitted 2980 ac-ft						
	Total pending 3248 ac-ft						
	Total revoked 1697.5 ac/ft						

TABLE 2. WATER RIGHTS DEVELOPED FROM THE SHERIDAN COUNTY CONSERVATION DISTRICT WATER RESERVATION							
NUMBER	NAME	LOCATION	PRIORITY DATE	FLOW RATE GPM	ACRES IRRIGATED	VOLUME ACRE FEET	REMARKS
SC001	N&J FARMS	NW1/4 SEC 30 T33N R58E	3/4/96	700	134	268	DEVELOPED IN 1997
SC002	SAMPSEN& MONTANA	N1/2 NE1/4 SEC36 S1/2 SE1/4SEC25 T33N R57E	3/4/96		134	268	DEVELOPED IN 1995, POOR WELL YIELD CHANGED POD(SC021)
SC004	SMITH FARMS	SEC 35 T32N R57E	3/4/96	1400	405	536	DEVELOPED IN 1996 STATE PERMITS CHANGED FOR ADDITIONAL WATER
SC005	HENKE	SE1/4 SEC 34 T32N R57E	3/4/96	750	134	268	DEVELOPED IN 1995
SC006	BOLSTAD	NE1/4 SEC 28 T31N R56E	3/4/96	650	134	200	DEVELOPED IN 1996 SAME POD AS STATE PERMIT
SC008	NELSON	140 ACRES NE1/4 PARTS OF NW1/4 AND SE1/4SEC26 T31N R56E	3/4/96	950	190	380	DEVELOPED IN 1996 EXPERIMENTAL SINGLE PHASE PUMP
SC011	HENKE	NW1/4 SEC 2 T31N R57E	7/1/96	750	134	268	DEVELOPED IN 1998 SAME POD AS(SC005)
SC021	SAMPSEN	NE1/4 SEC35 T33NR57E	10/20/97	750	134	268	DEVELOPED IN 1999
SC015	SCHMITZ	NE1/4 SEC9 T31N R57E	10/11/96	750	132	264	DEVELOPED IN 1998
SC014	ONSTAD	SE1/4 SEC15 T34N R58E	9/3/96	750	130	260	DEVELOPED IN 1999
SC027	SAMPSEN	SEE SC002 AND SC0021	2/16/99	400	0	0	FLOW INCREASE ONLY 1999
			TOTAL	7850	1661	2980	

Water-use permits currently allocate about 11,290 acre-feet of water for irrigation from the Clear Lake aquifer. The majority (about 8,300 acre-feet) comes from State DNRC water permits granted before the SCCD's water reservation (1995). The total volume allocated has not yet been used in a single year. The greatest volume of water used in a single year was in 1998 when nearly 5,900 acre-feet of water were pumped. Interest in further development by local farmers remains strong and applications for new irrigation permits are expected to increase.

Water use authorized by the SCCD and State DNRC permits are monitored to evaluate the volume of water extracted annually. The SCCD is in the process of reviewing several new permit applications as part of their water reservation. The SCCD has been authorized to permit up to 5,809 acre-feet annually of the 15,479 acre-feet of water in the reservation. By the spring of 2000, applications for water permits had nearly exhausted the initial authorization. Figure 3 documents the volume of water used for irrigation from 1980 to 1999. These volumes are determined by reported and calculated water use. Water use at irrigation systems powered by electricity is calculated based on power usage reports from the Sheridan Rural Electric Cooperative and the pumping rate at each well. Water use at diesel-powered pumps is based on the number of hours pumping and the discharge rate. Comparison of calculated records with measurements by totalizing flow meters provides a check on water use. Unfortunately not all of the totalizing flow meters are reliable.

The history of water use logically follows irrigation development history. Most of the water extracted was from the Clear Lake North and Dagmar areas where the aquifer was first developed. The high-density irrigation in these areas was largely permitted by the State. Because of this high density, the TAC has only allowed a few additional permits from the reservation in these areas.

The quality of ground water is a critical component of successful irrigation and water management. The compatibility of soil and water must be established prior to development, or serious soil damage can occur. Soil damage did occur at an irrigation system near Brush Lake early in the development of irrigation in this region, so the potential for incompatible soil/water chemistry is a known risk. Therefore, producers clearly understand the importance of water-quality data and soil-water compatibility. Because of these concerns, water samples have been collected, analyzed, and interpreted with respect to irrigation suitability for several years. Initial samples were collected in the 1980's. Fifteen additional samples were collected in 1995 as part of a cost-share program with irrigators and the USFWS. Irrigators provide additional water-quality data as part of the permit application requirements for the water reservation. Fourteen samples were collected under the current renewable resource grant in the fall of 1999. Ten samples were collected as part of the MBMG statewide ground water

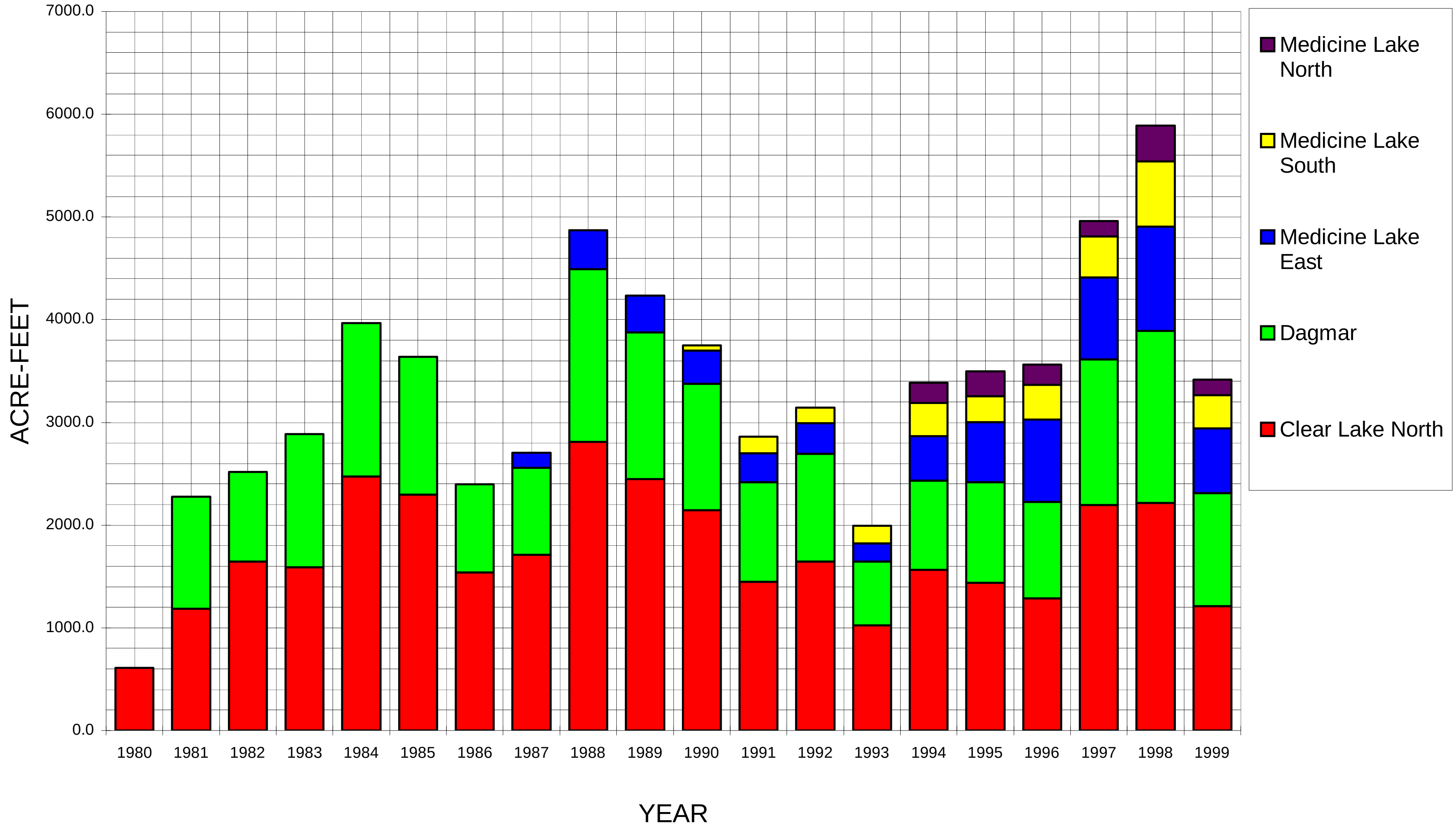

Figure 3. Historical water use from the Clear Lake aquifer.

monitoring program during the summer of 2000. All of these sample data are on file with the MBMG and can be reviewed on the GWIC website.

General indicators of the quality of water used for irrigation are Specific Conductance (SC) and Sodium Adsorption Ratio (SAR). The distributions of lab conductivity values are shown on Plate 7 and SAR values are mapped on Plate 8. These maps were designed to help the Technical Advisory Committee evaluate locations where water-quality problems are possible. High SAR values indicate several potential problem areas, highlighted on Plate 8. Special scrutiny of water quality and soil compatibility must be given in these highlighted areas.

A final map to assess overall aquifer conditions shows the change in water levels from the spring of 1995 to the spring of 2000 (Plate 9). Water levels were compared during seasonal highs if possible. Several wells were either not installed or measured in 1995, and show changes over a later interval. Most of the aquifer shows significant increases in water levels. This appears to be primarily caused by relatively wet years providing recharge. The areas showing declines are all associated with the deep alluvial aquifer, which does not respond to recharge as rapidly as other parts of the aquifer. There may be a several-year delay in the response to high precipitation and consequently high recharge rates. Additional years of monitoring will be needed to understand the temporal relationship of aquifer response to recharge in the deeper parts of the aquifer.

The monitoring data provide the background for approving or denying permit applications. As more information is collected, a better understanding of the hydrogeologic conditions of the aquifer is possible and water management will improve. Plates 1-9 are designed to assist the Technical Advisory Committee visualize the setting and monitoring information needed to approve or deny permit applications. These maps are working drafts and will be updated on demand. Additional maps of ground-water flow, depth to bedrock, aquifer thickness, and water-quality distribution also are being developed.

Aquifer monitoring has attained the goals set by the Legislature and agreed to in the contract agreement. Data have been collected and compiled in a timely manner so that interpretations could be used to make aquifer management decisions. In addition, the value of data collected for the SCCD played a significant role in a legal water rights issue. These data provided background information and were the basis for expert witness testimony in a challenge to Smith Farms and DNRC water management policies by the U.S. Fish and Wildlife Service. The hearing ruled in favor of Smith Farms, upholding the application to transfer salvage water because of increased efficiency. The Montana First Judicial Court upheld this decision by the DNRC hearing officer. The Court concluded that DNRC correctly determined that substantial and competent evidence exists that the water rights of the Medicine Lake Wildlife Refuge would not be adversely affected by the proposed change in appropriation. According to Nancy Andersen, Chief of DNRC's Water Rights Bureau, "A decision in favor of the Medicine Lake Refuge would have had far-reaching implications and repercussions in our water permitting practices" (Western States Water, 1999). The data collected and compiled for the SCCD were used by both parties in the proceedings and provided the substantial and competent evidence needed for this decision.

AQUIFER MODELLING

Donovan (1988) and Schuele (1998) developed ground-water models of the Clear Lake aquifer. The model by Donovan was restricted to the Clear Lake aquifer in Montana. Schuele's model covered the entire internally drained basin that includes the Clear Lake aquifer in Montana and the Skjermo Lake aquifer in North Dakota. Donovan's model was designed to estimate aquifer mass balance and yield for agricultural ground-water management. Both a steady-state model and a transient model were developed. The steady-state model was calibrated to long-term average climatic conditions and late winter water levels. The mass balance of the steady-state model indicated that evapotranspiration accounted for 87% of the total discharge, with the remainder attributed to surface- and ground-water outflow from the basin. The transient modeling investigated the aquifer response to 1987 irrigation extractions and hypothetical extractions at levels twice the 1987 volume. Simulated irrigation development decreased aquifer evapotranspiration losses by lowering the water table and reduced surface-water outflow from Medicine Lake.

Schuele's model indicated that aquifer storage changes are induced principally by climate and to a lesser extent by irrigation withdrawals. Ground water is removed primarily by evapotranspiration from lakes and wetlands. Recharge is added to the aquifer primarily by infiltrated precipitation, through soils developed in glacial outwash. Relatively little recharge occurs through soils in glacial till. Actual recharge during a given year depends on the geographic and temporal distribution of precipitation. This modeling indicates that under 1996 development conditions, recapture of evapotranspiration, or evapotranspiration salvage, is the principal source of irrigation water. By comparison of simulated stage changes in Clear Lake, Brush Lake and Medicine Lake the model indicates minor stage declines as the result of irrigation.

Donovan's and Schuele's models are useful tools for estimating the water balance and developing an understanding of the major components of the hydrogeologic system. However, they depend on estimates of recharge and discharge that may not be representative of actual conditions. In addition, as new drilling data become available the conceptual model of the hydrogeology will improve. Therefore, data are not adequate to develop a reliable management model where different scenarios of water development can be tested, and this may not be a reasonable expectation. Numeric and conceptual models will continue to be evaluated and improved as management tools, but currently evaluation of the monitoring data is the primary tool for water management.

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Clear Lake Aquifer Management Areas
Plate 1 of 9

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Open File MBMG 447
Clear Lake North
Plate 2 of 9

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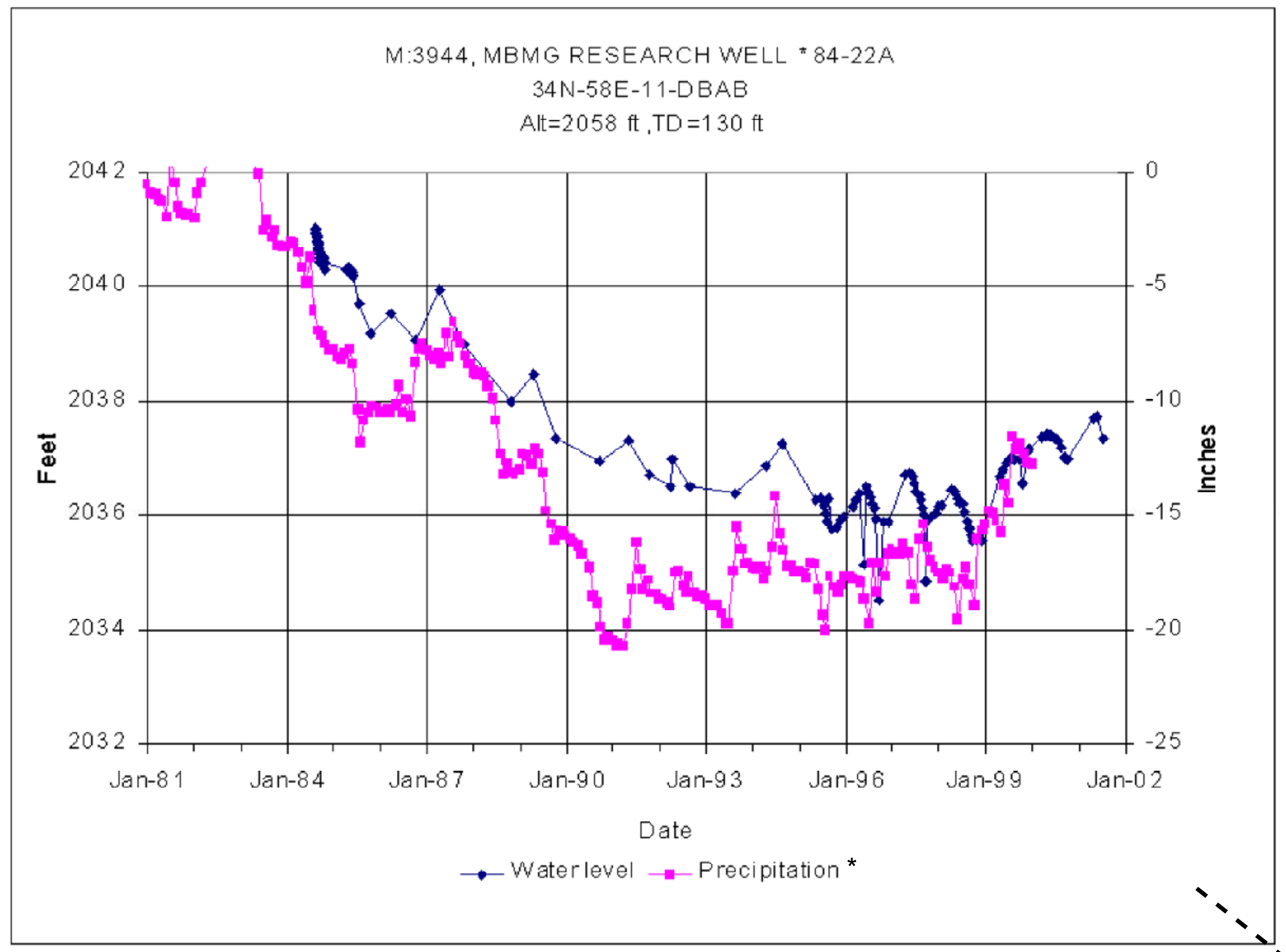
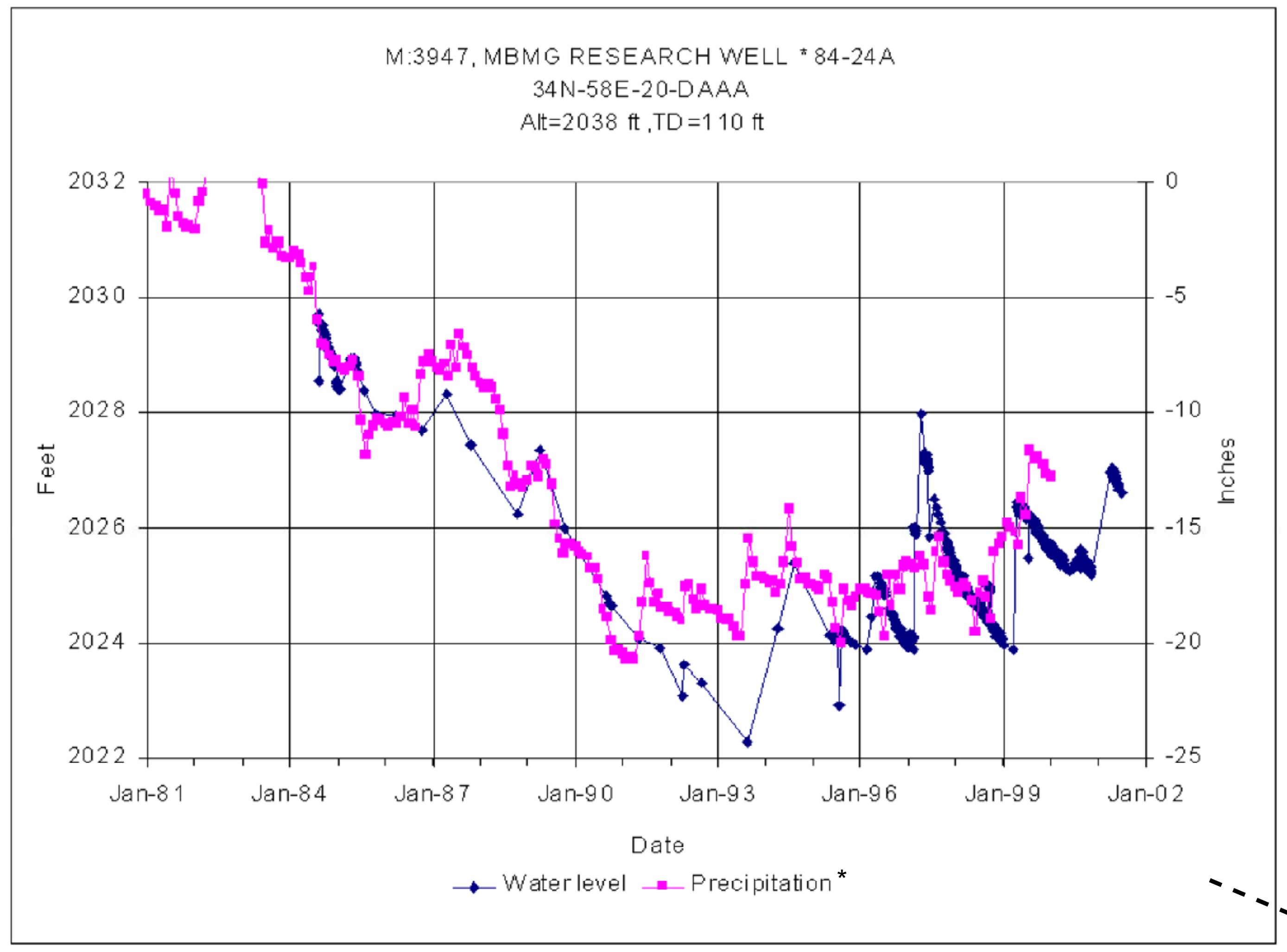
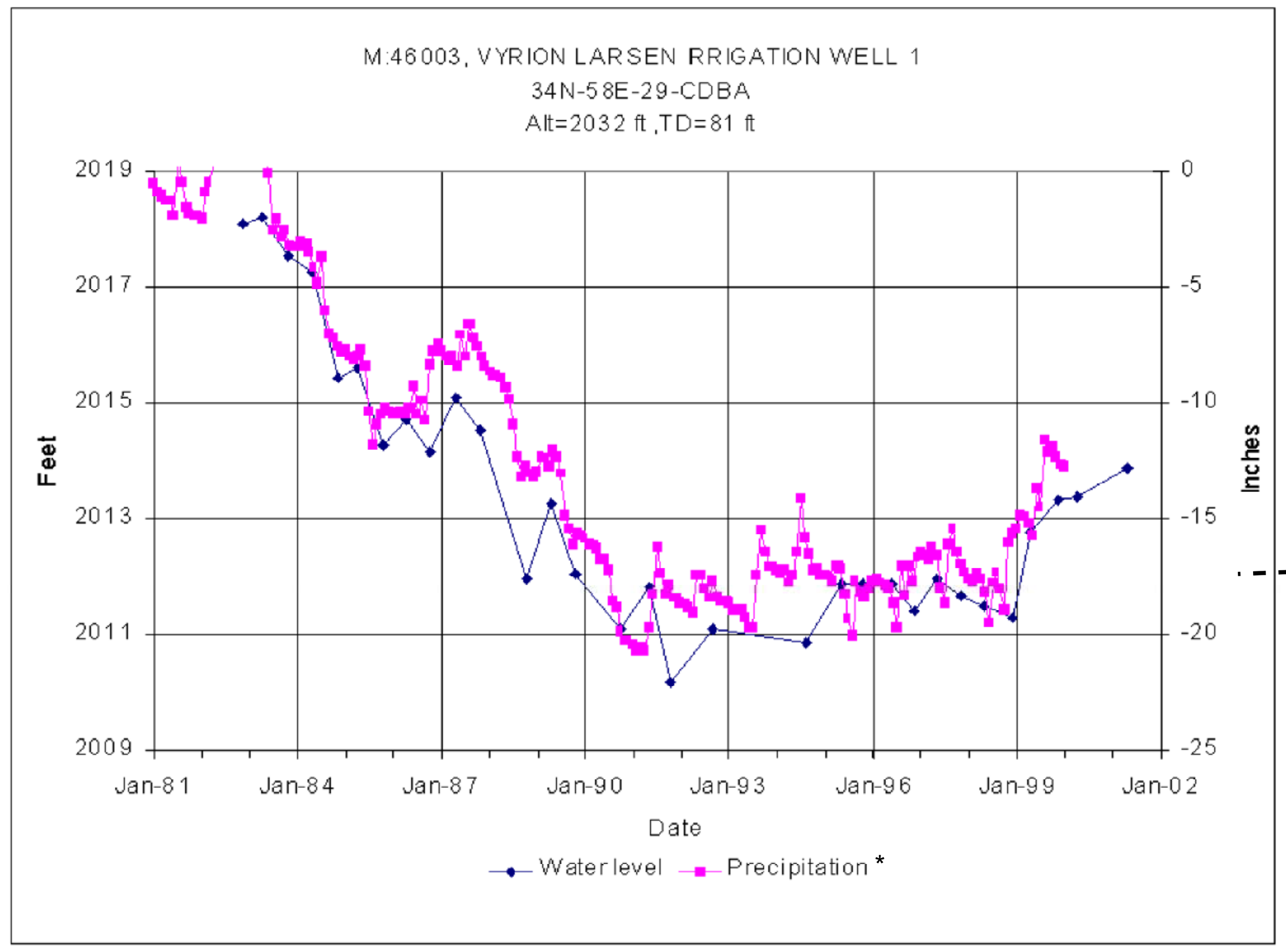
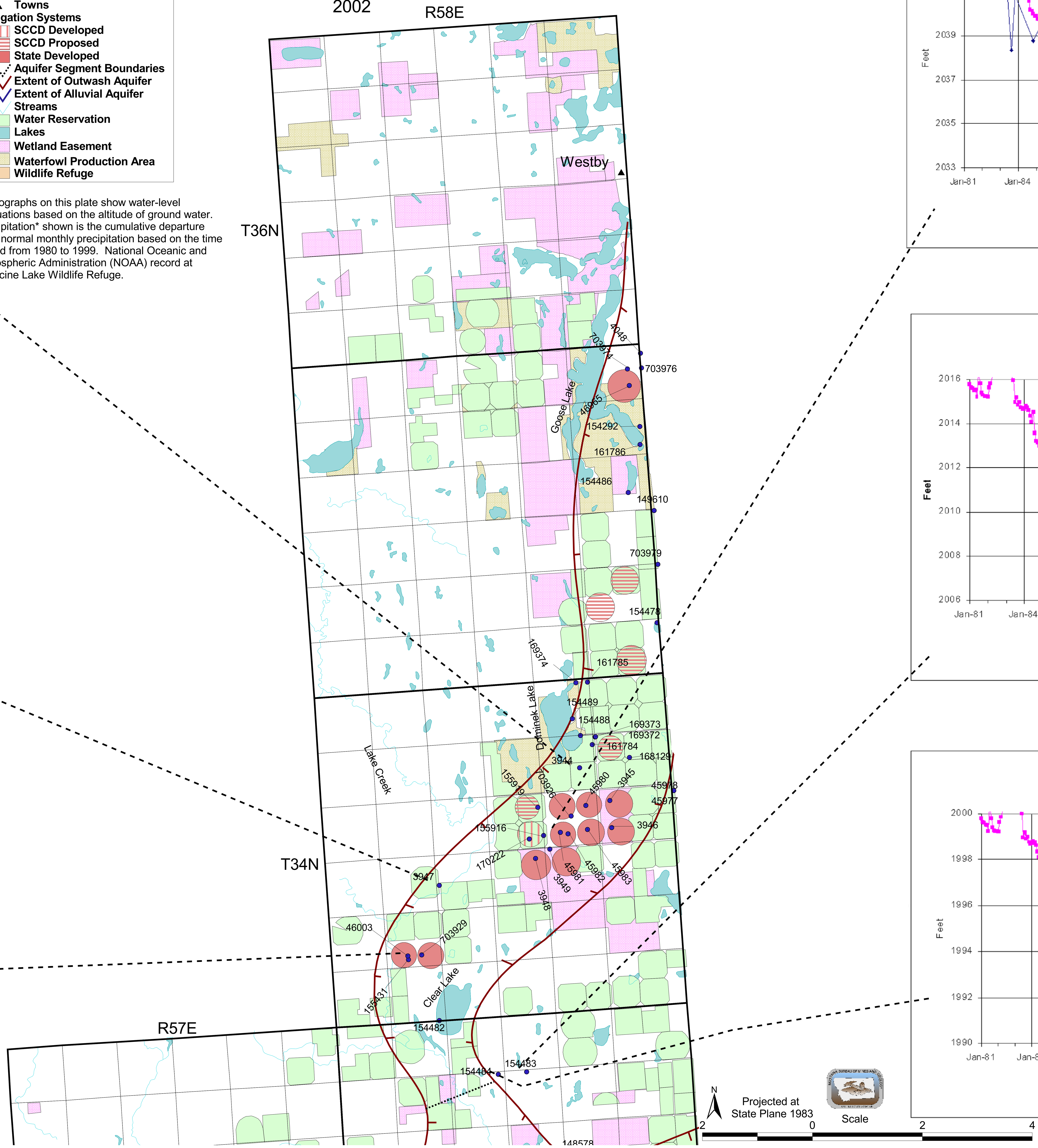


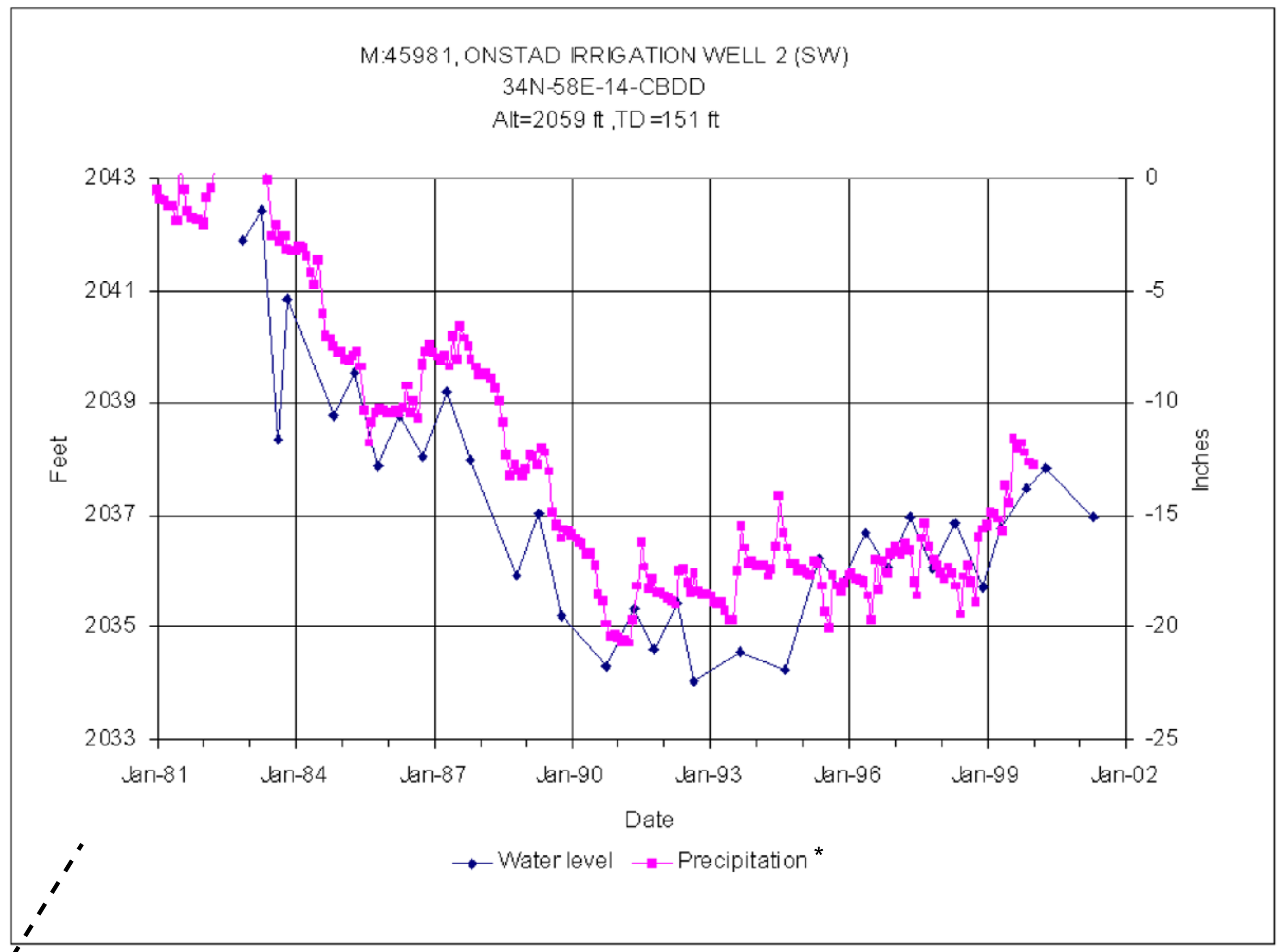


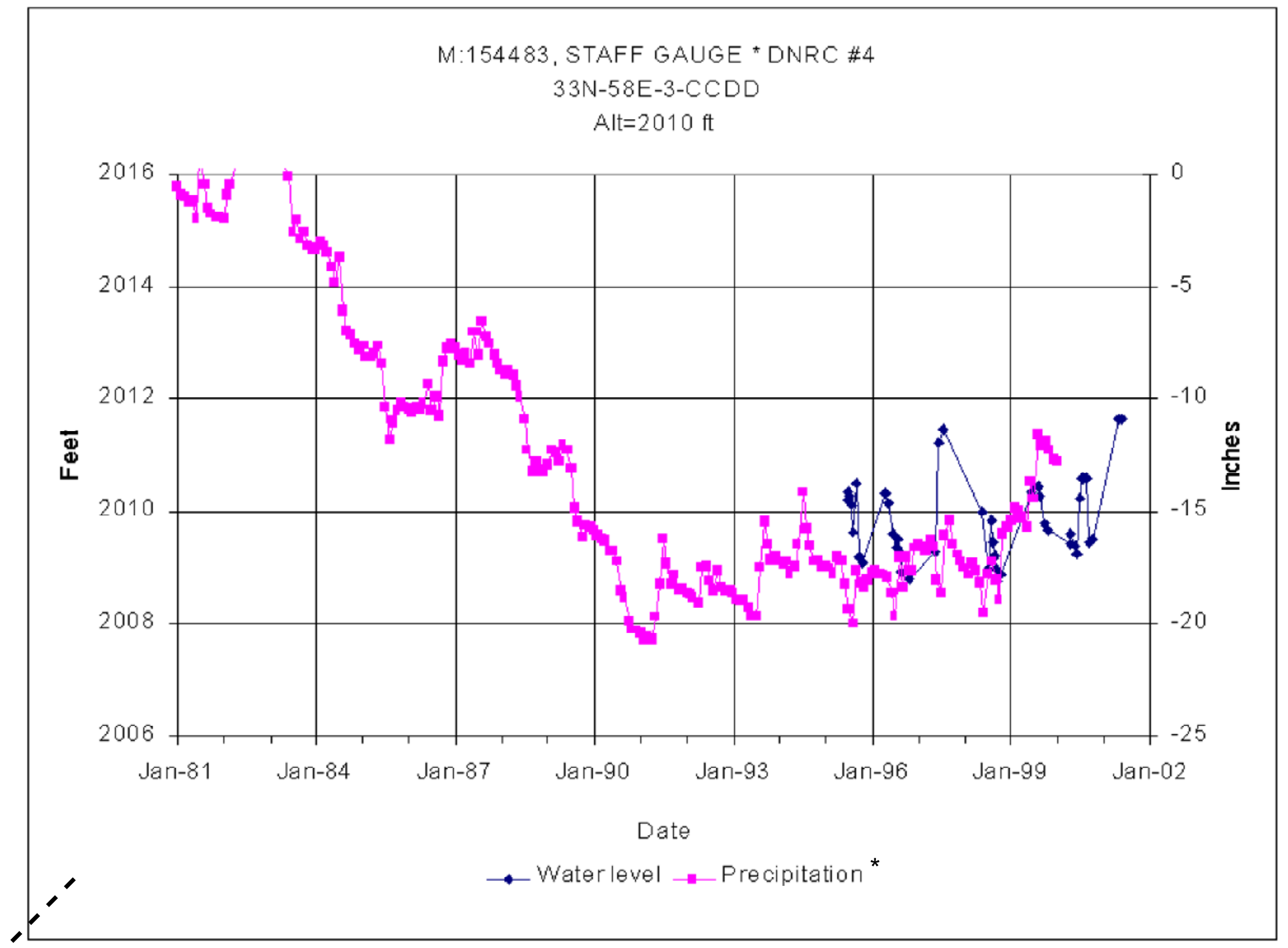


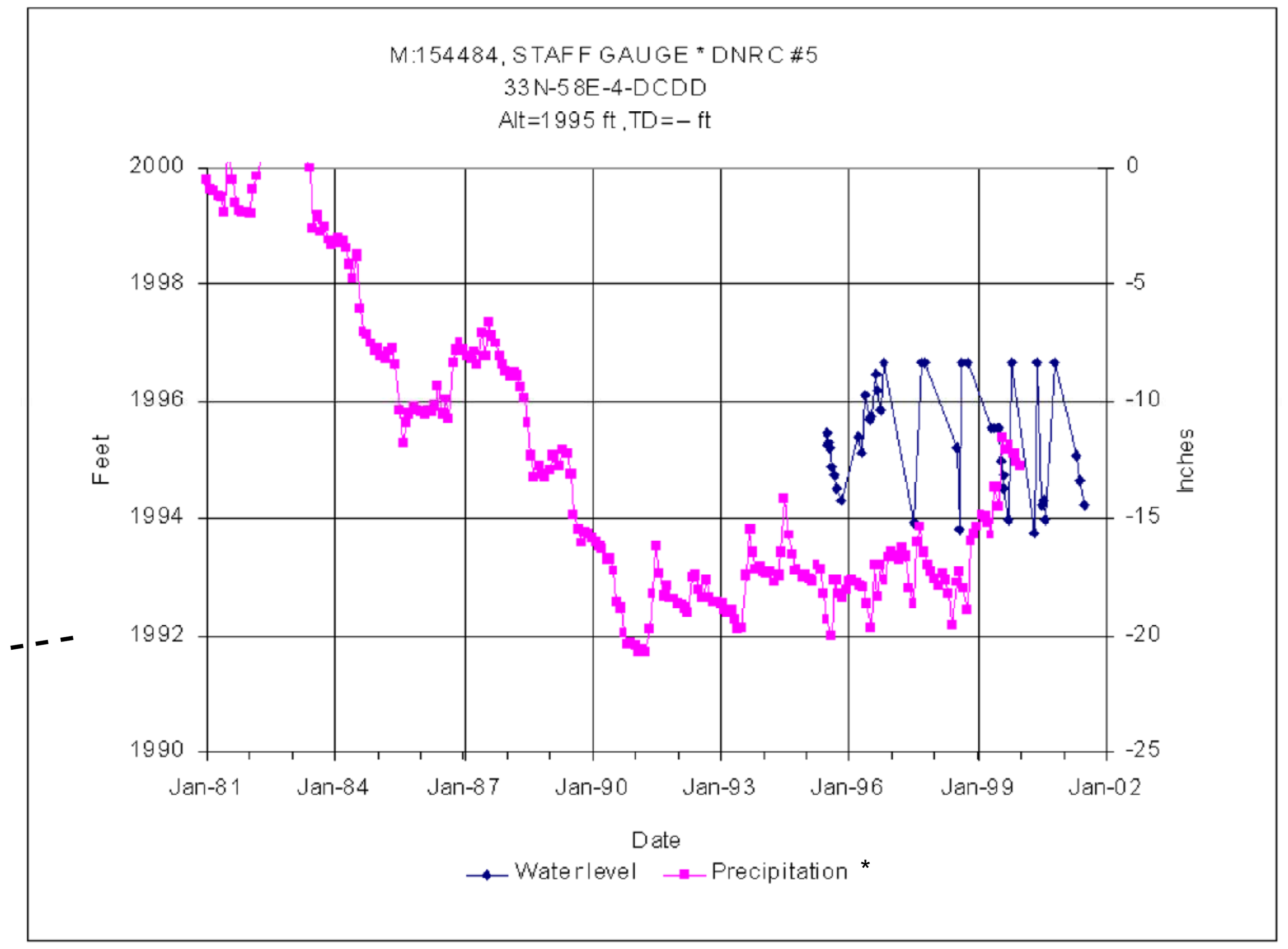
Legend
- Monitor Wells
- Towns
- Irrigation Systems
- SCCD Developed
- SCCD Proposed
- State Developed
- Aquifer Segment Boundaries
- Extent of Outwash Aquifer
- Extent of Alluvial Aquifer
- Streams
- Water Reservation
- Lakes
- Wetland Easement
- Waterfowl Production Area
- Wildlife Refuge

Hydrographs on this plate show water-level fluctuations based on the altitude of ground water. Precipitation* shown is the cumulative departure from normal monthly precipitation based on the time period from 1980 to 1999. National Oceanic and Atmospheric Administration (NOAA) record at Medicine Lake Wildlife Refuge.









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Dagmar
Plate 3 of 9

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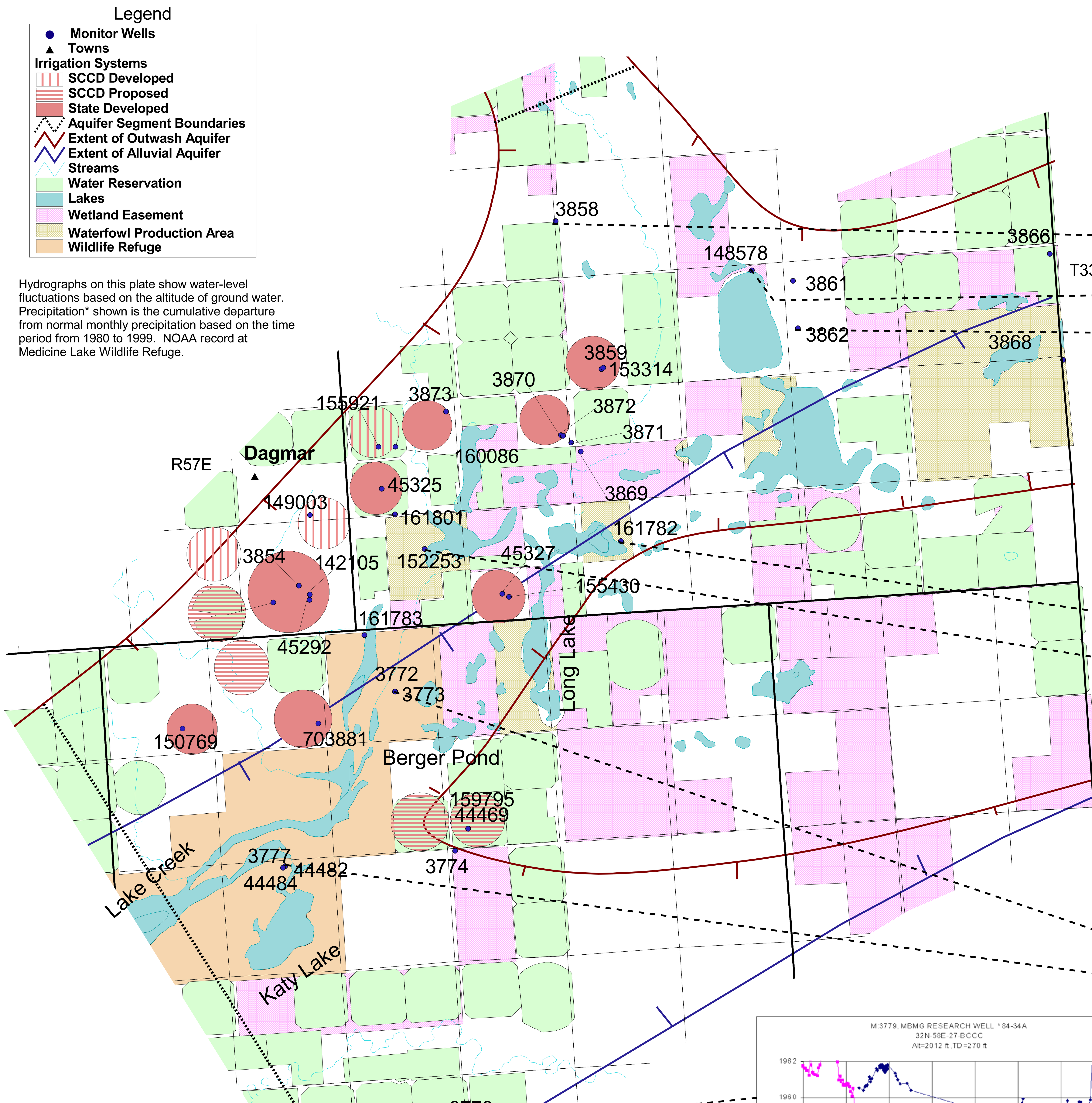
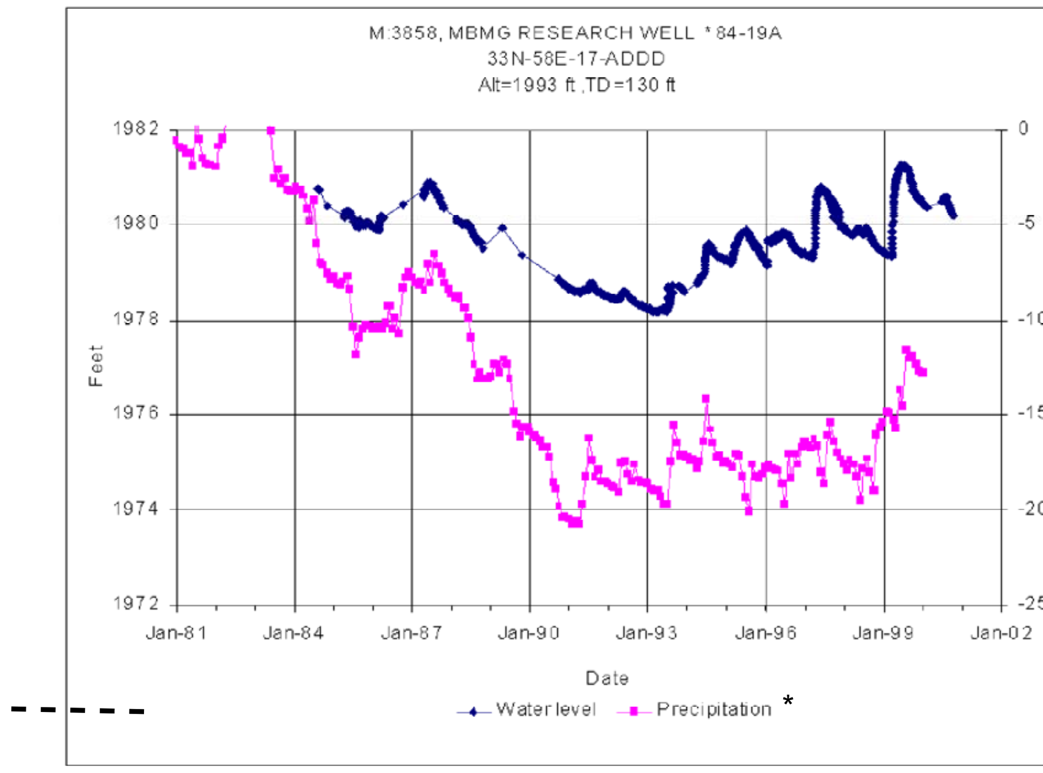
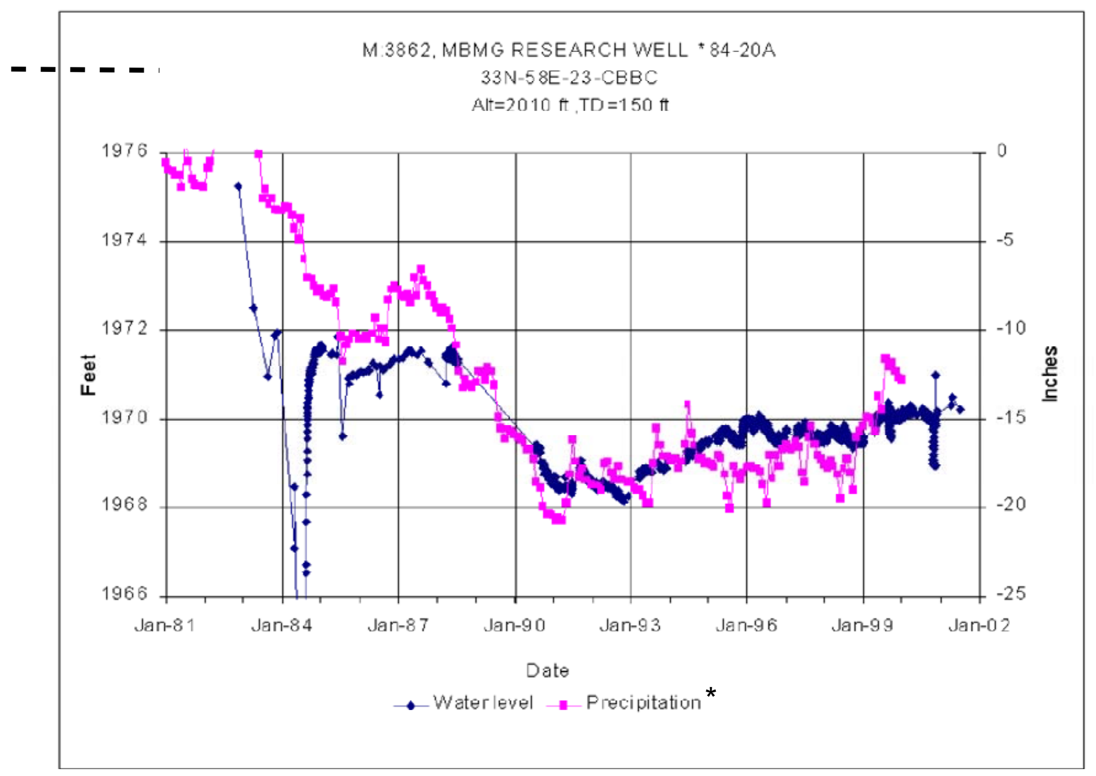
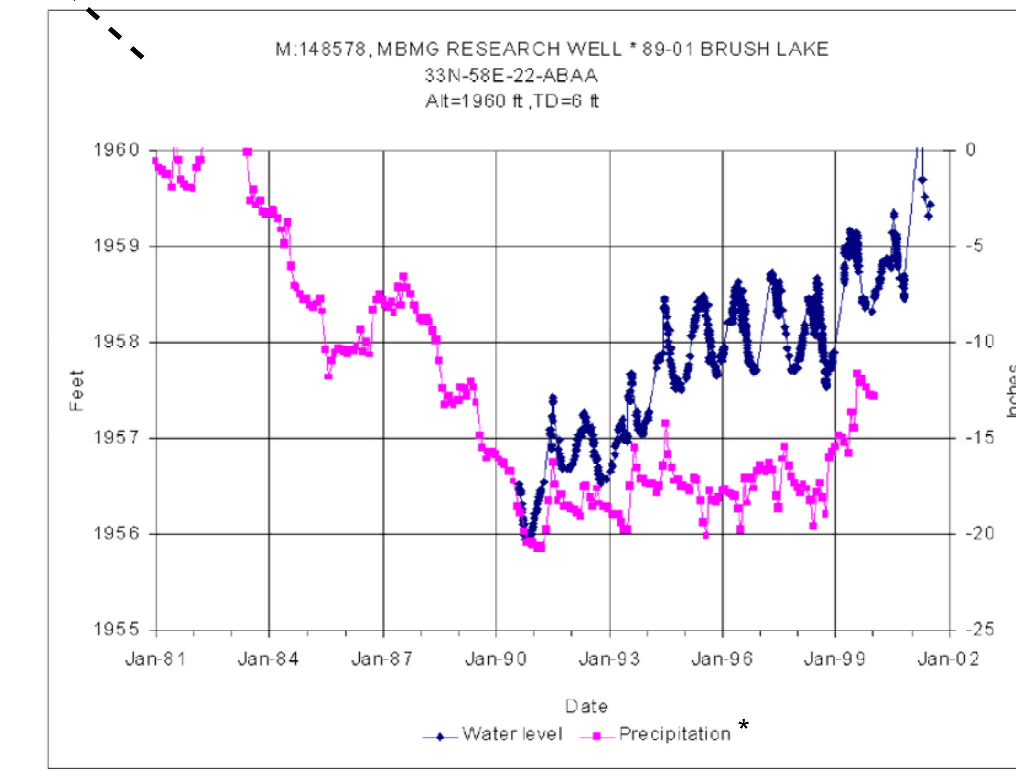
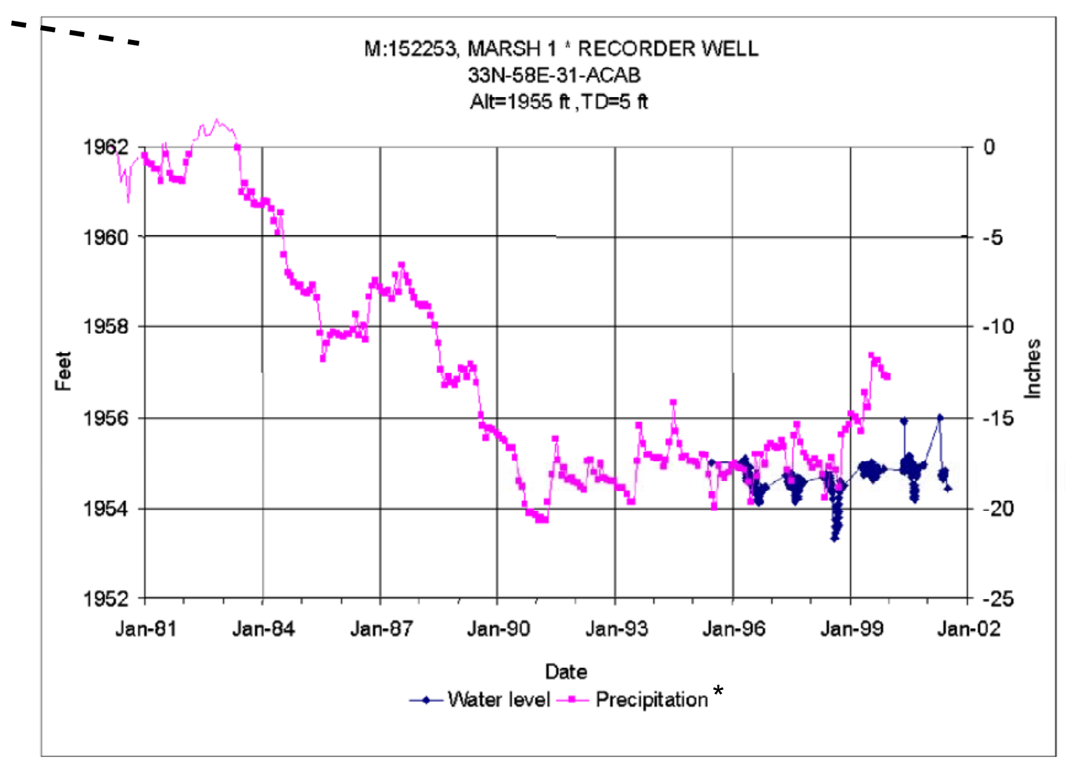
Hydrographs on this plate show water-level fluctuations based on the altitude of ground water. Precipitation* shown is the cumulative departure from normal monthly precipitation based on the time period from 1980 to 1999. NOAA record at Medicine Lake Wildlife Refuge.

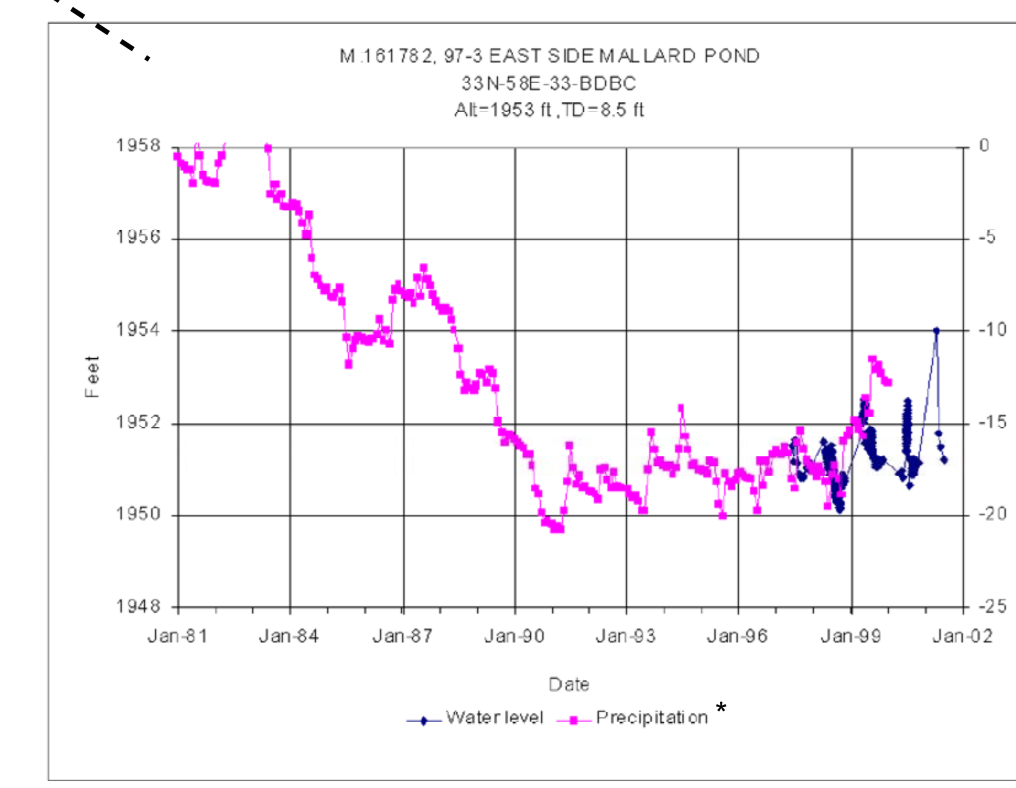


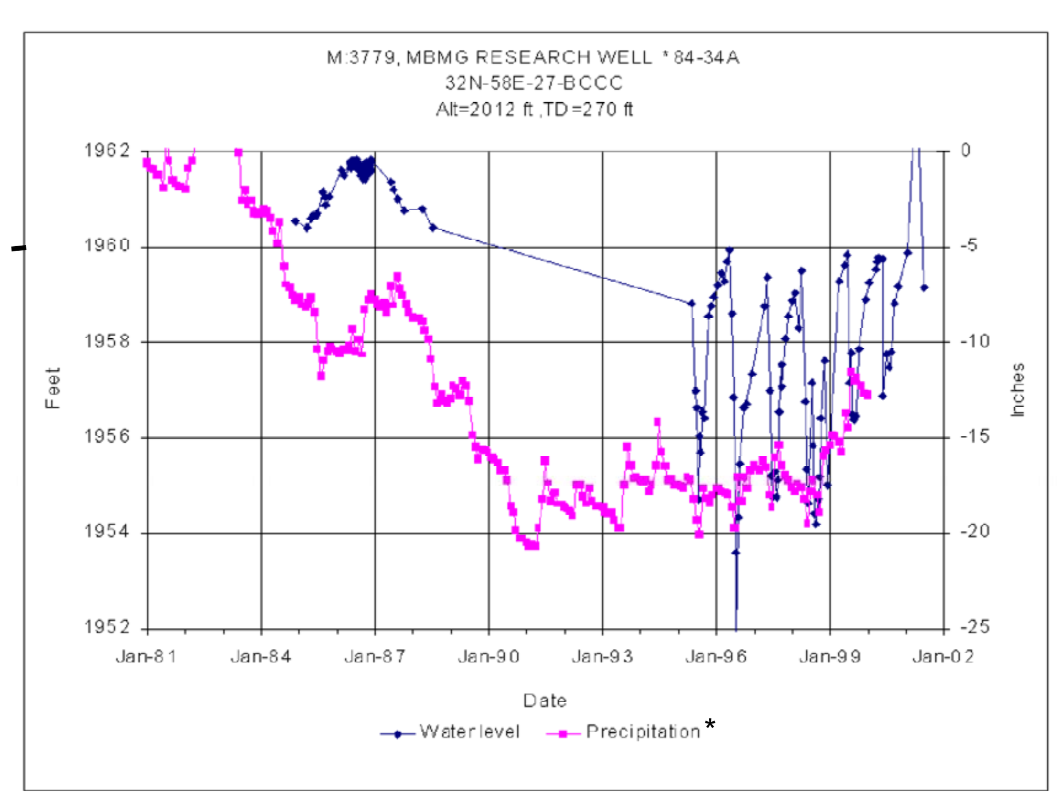


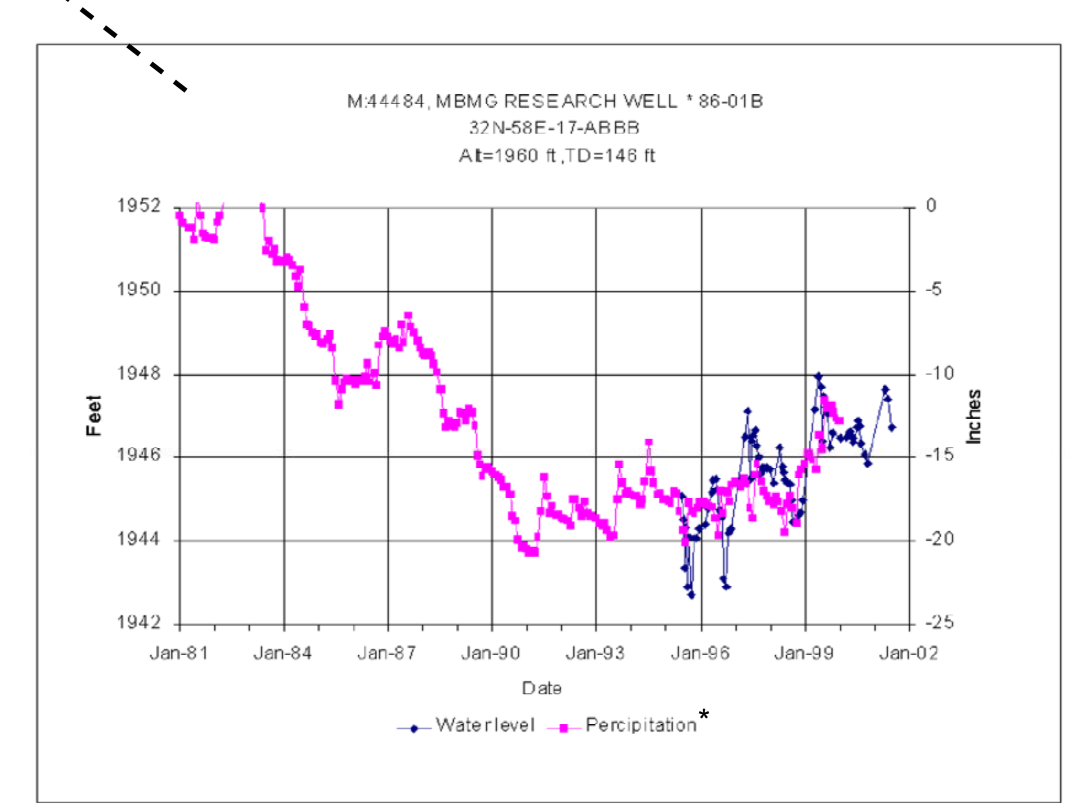


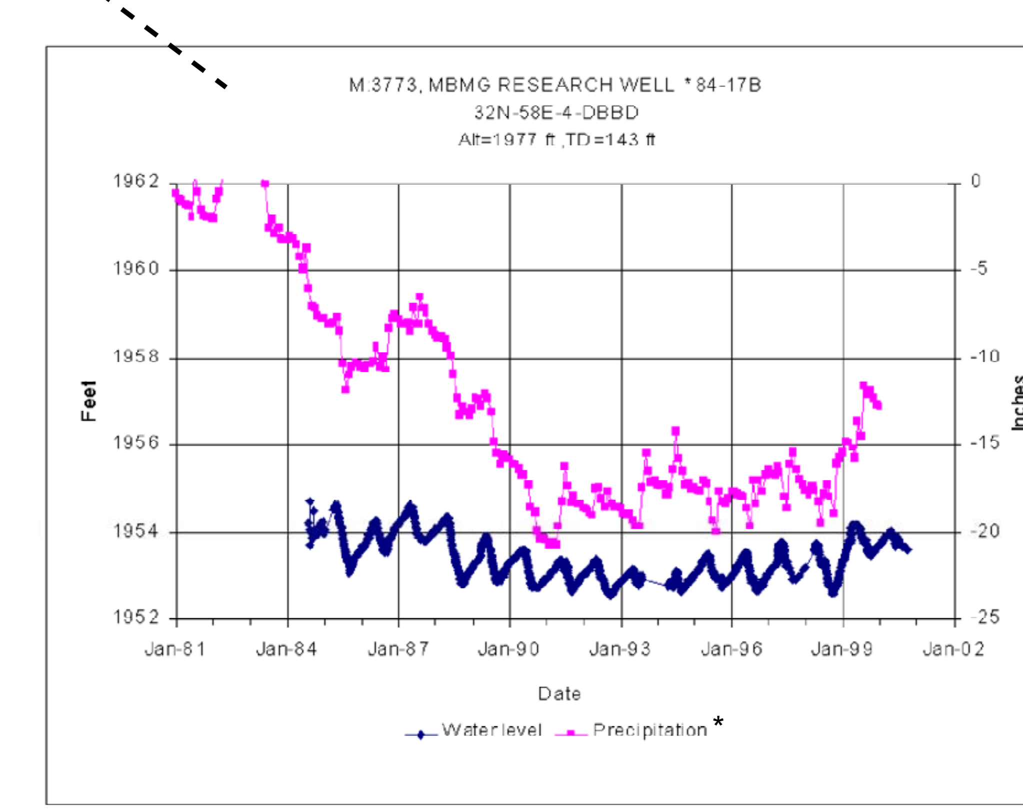












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Medicine Lake East
Plate 4 of 9

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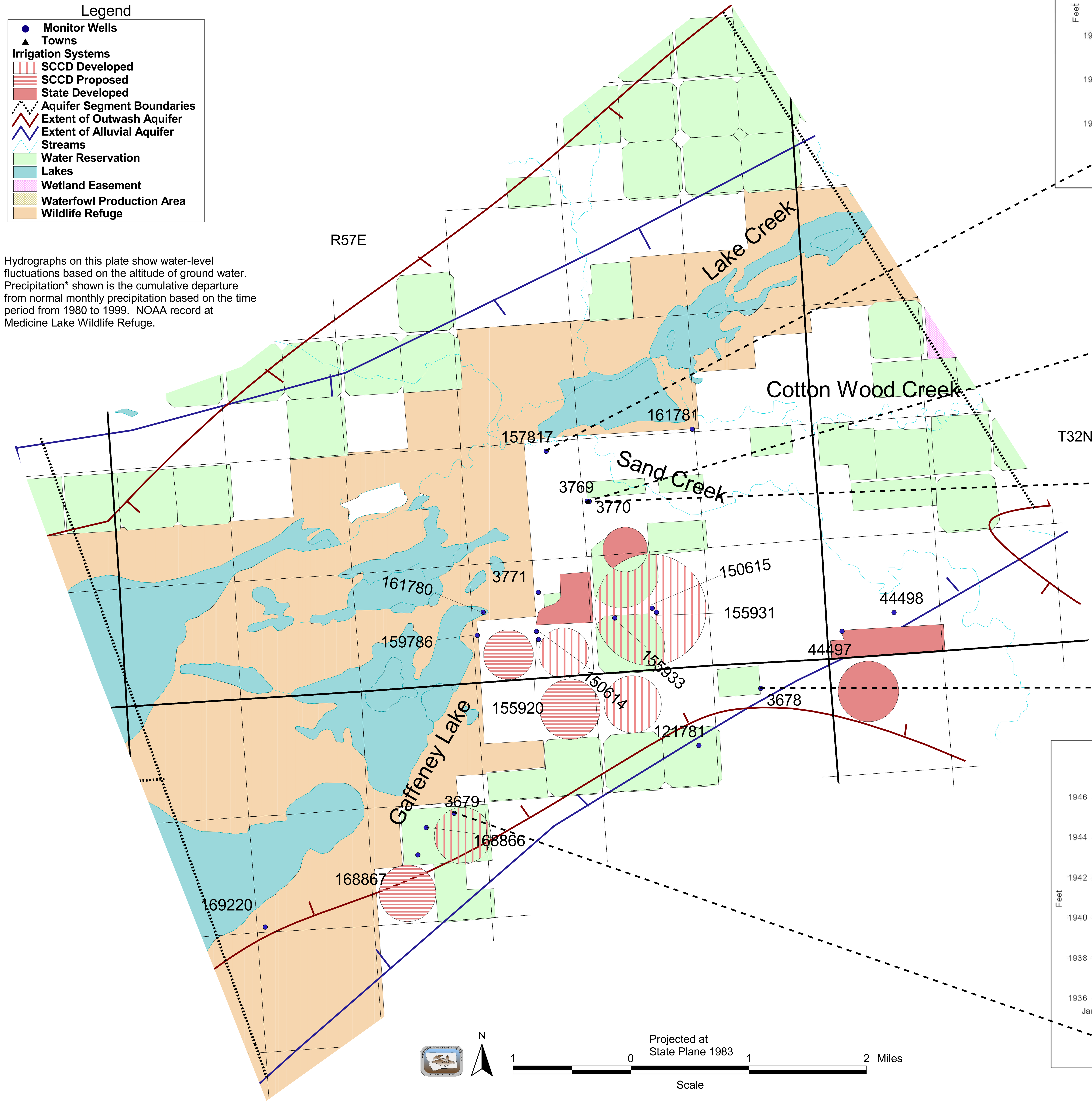
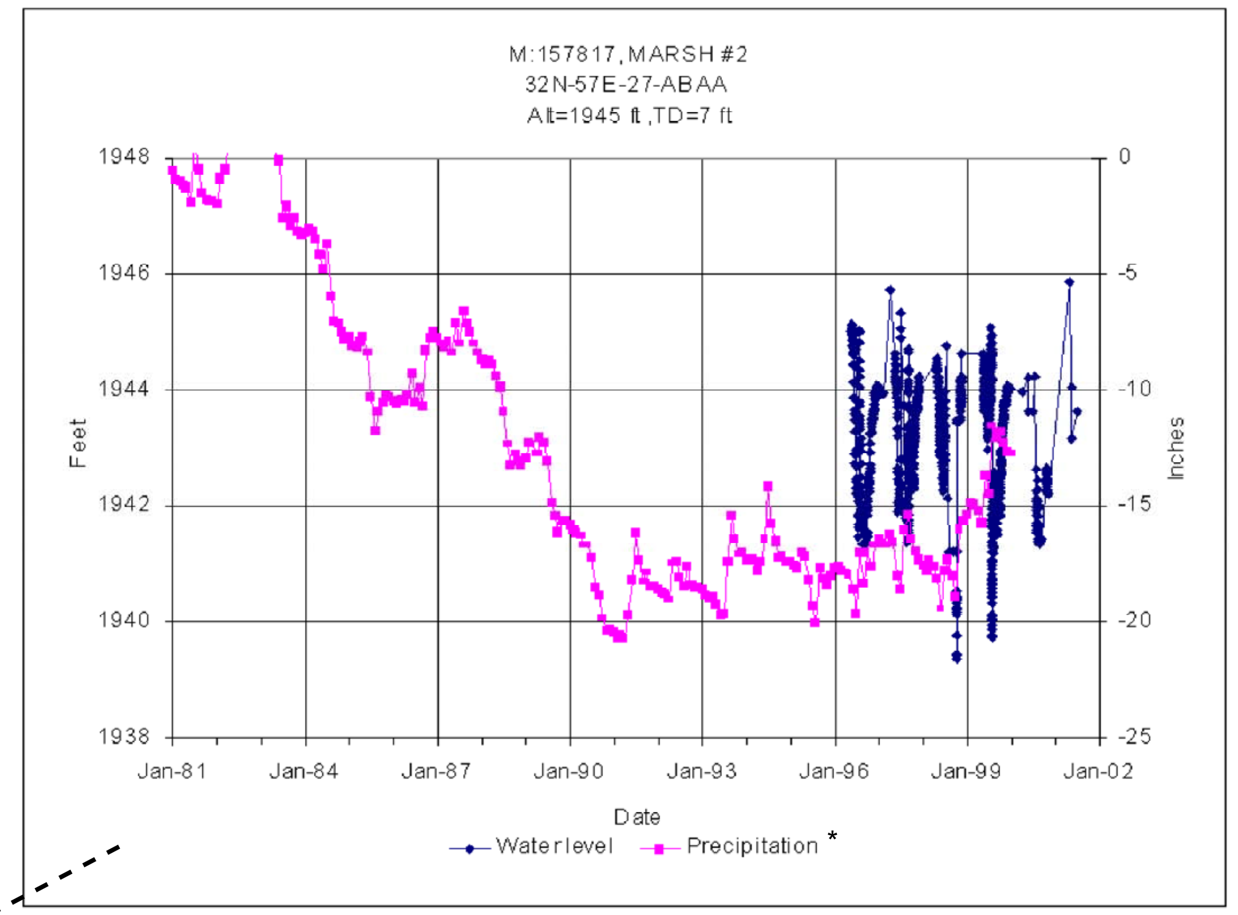
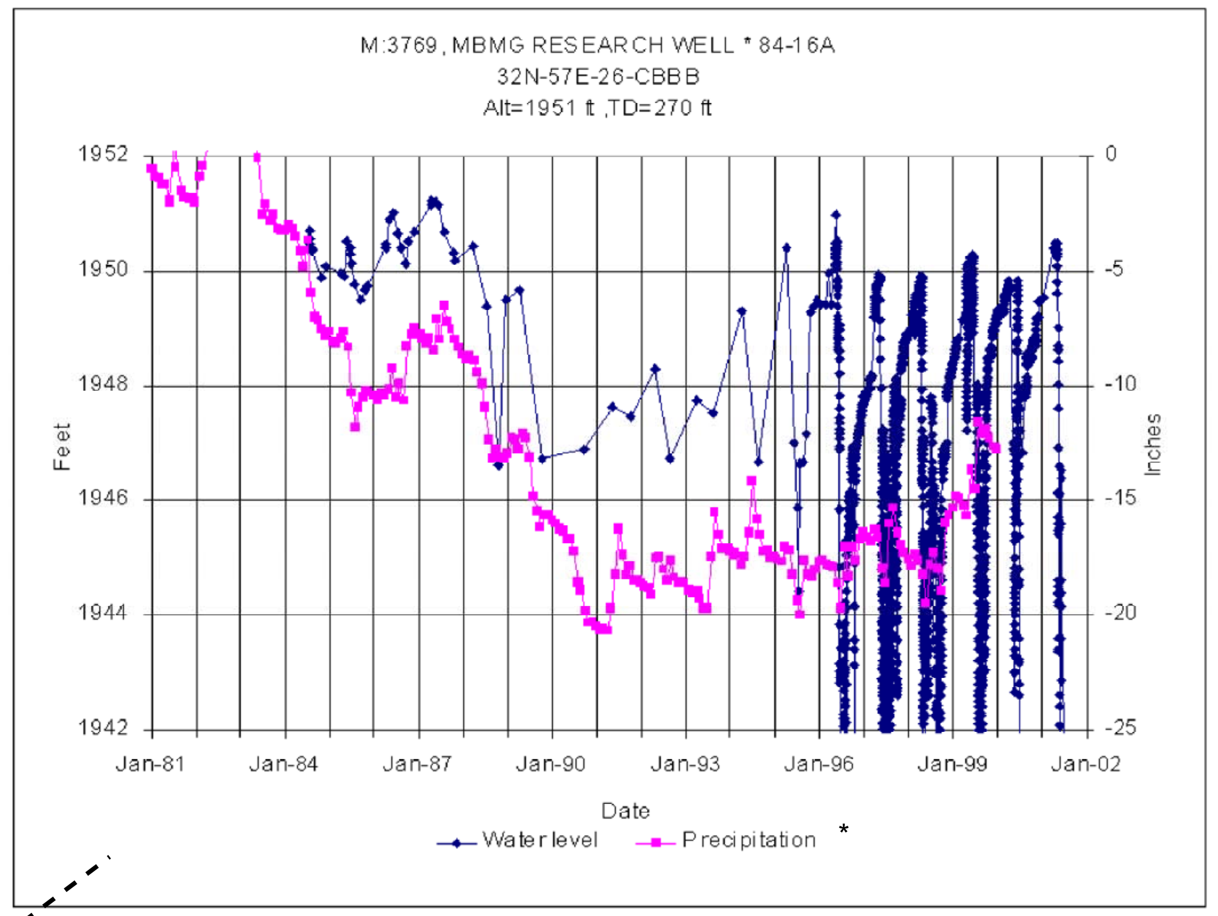
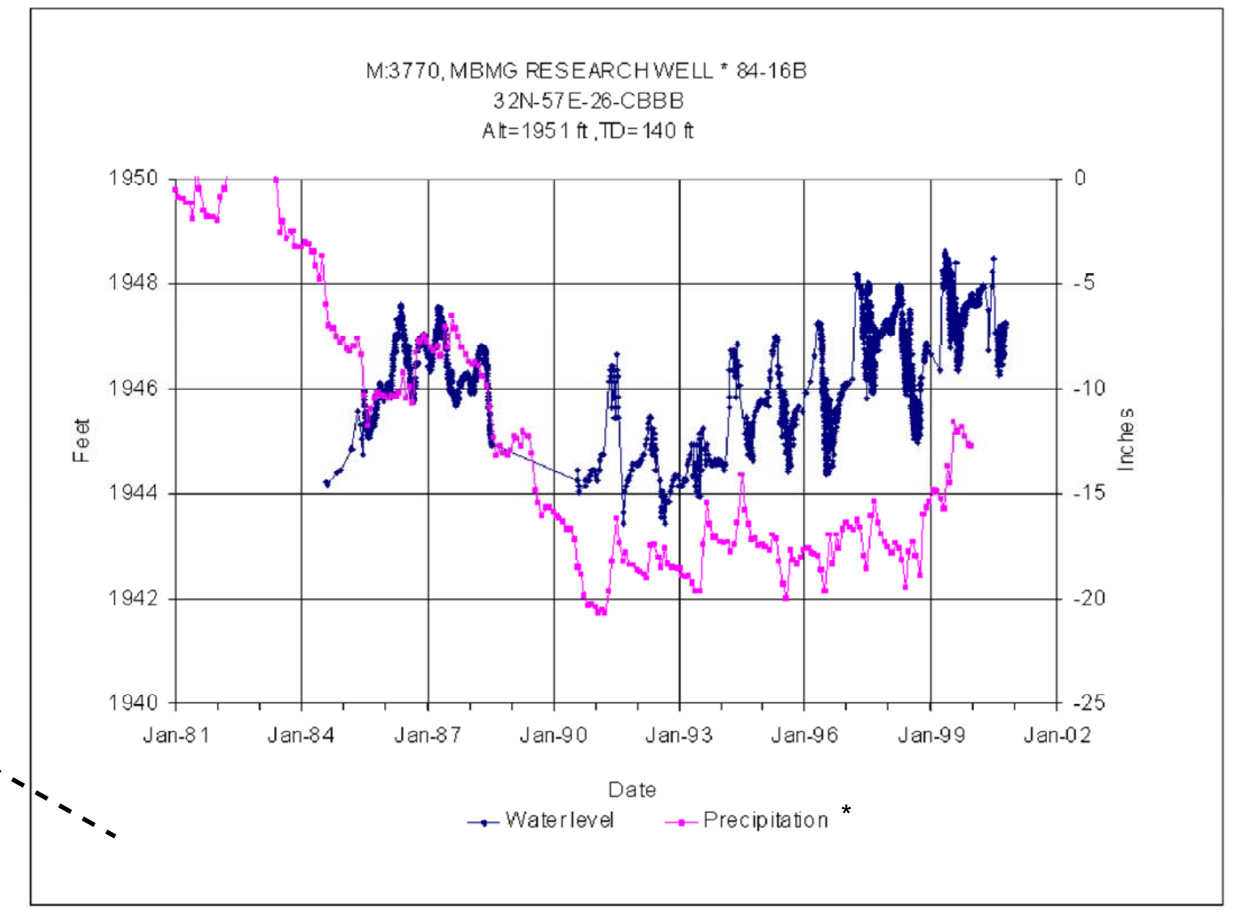
2002

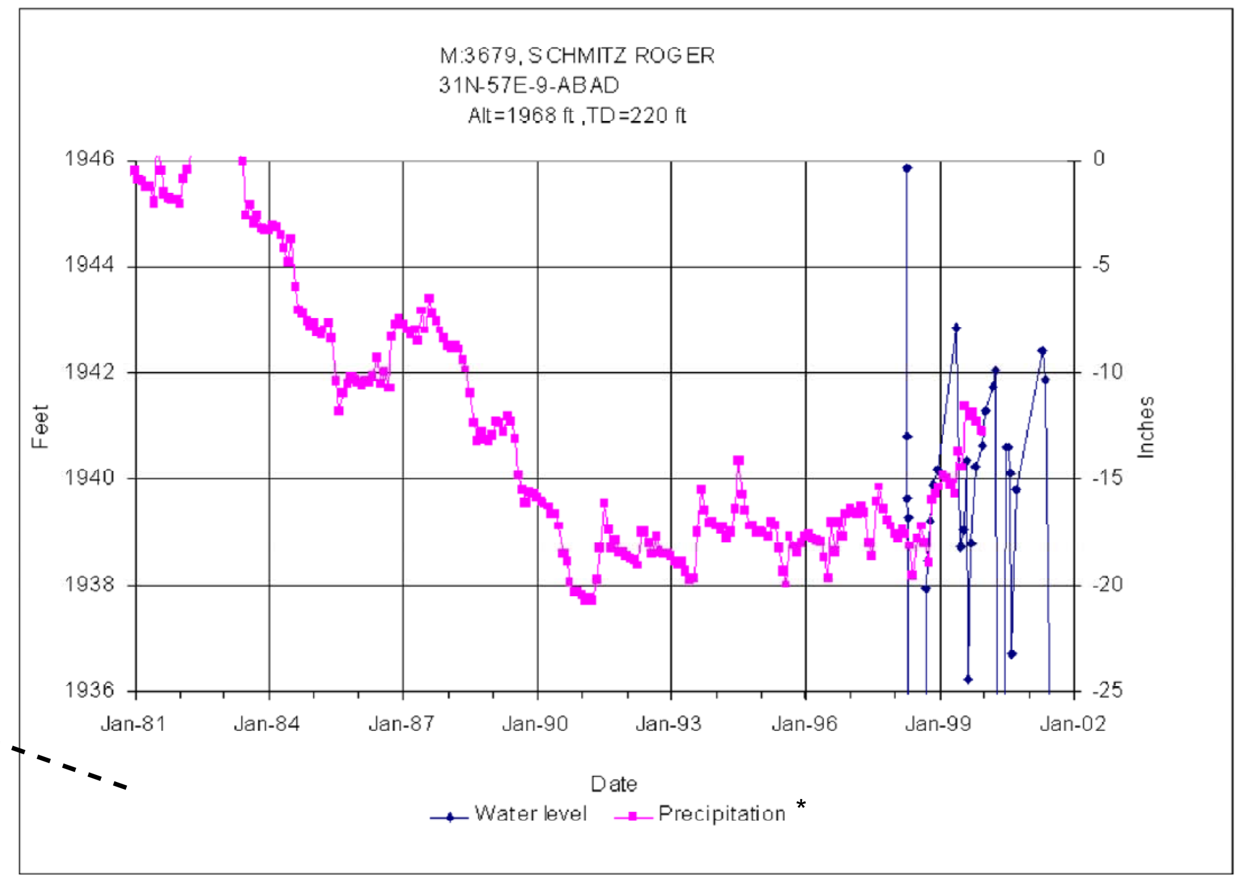


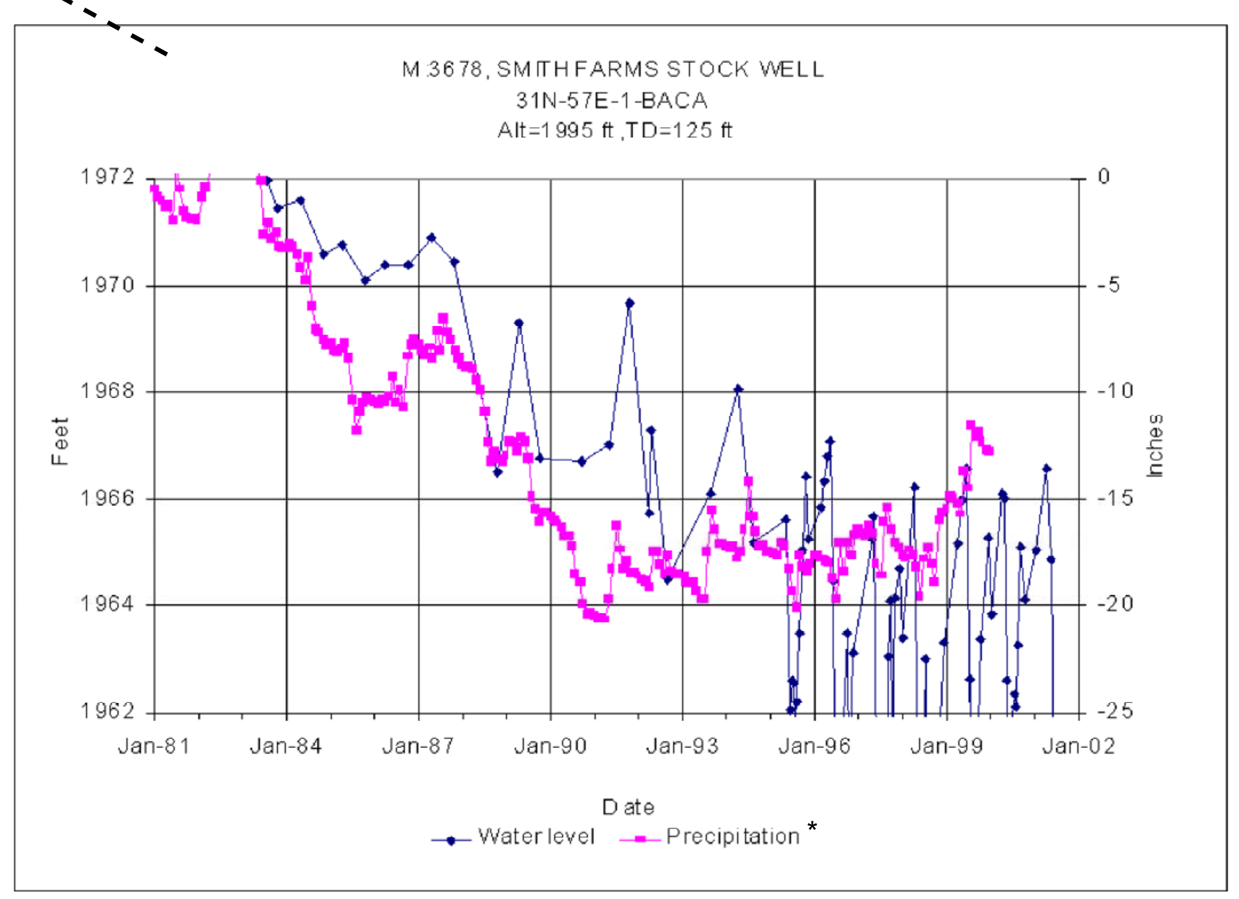
Hydrographs on this plate show water-level fluctuations based on the altitude of ground water. Precipitation* shown is the cumulative departure from normal monthly precipitation based on the time period from 1980 to 1999. NOAA record at Medicine Lake Wildlife Refuge.











Open File MBMG 447
Medicine Lake South
Plate 5 of 9

by Jon Reiten

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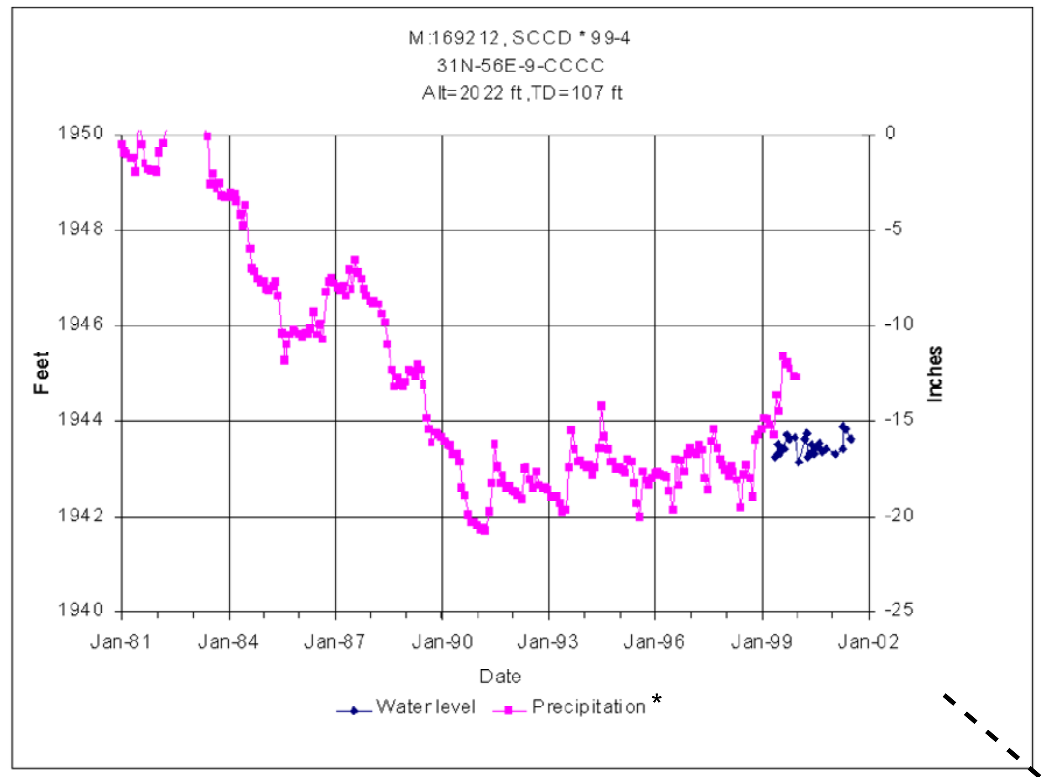
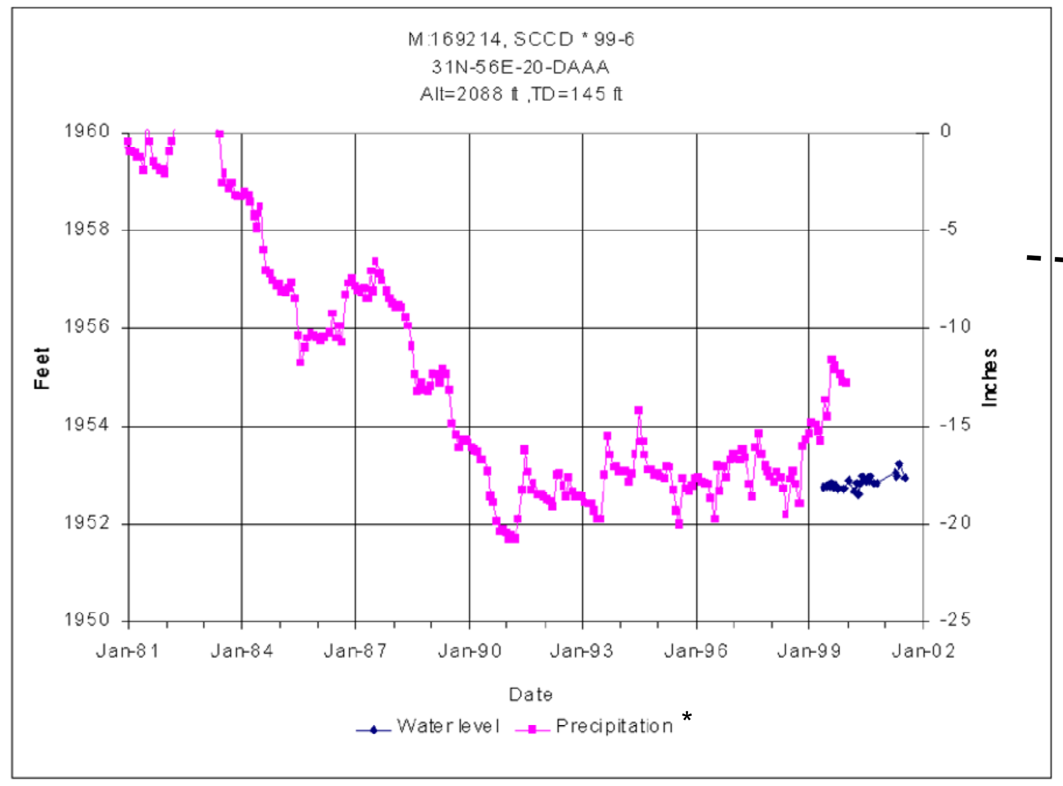
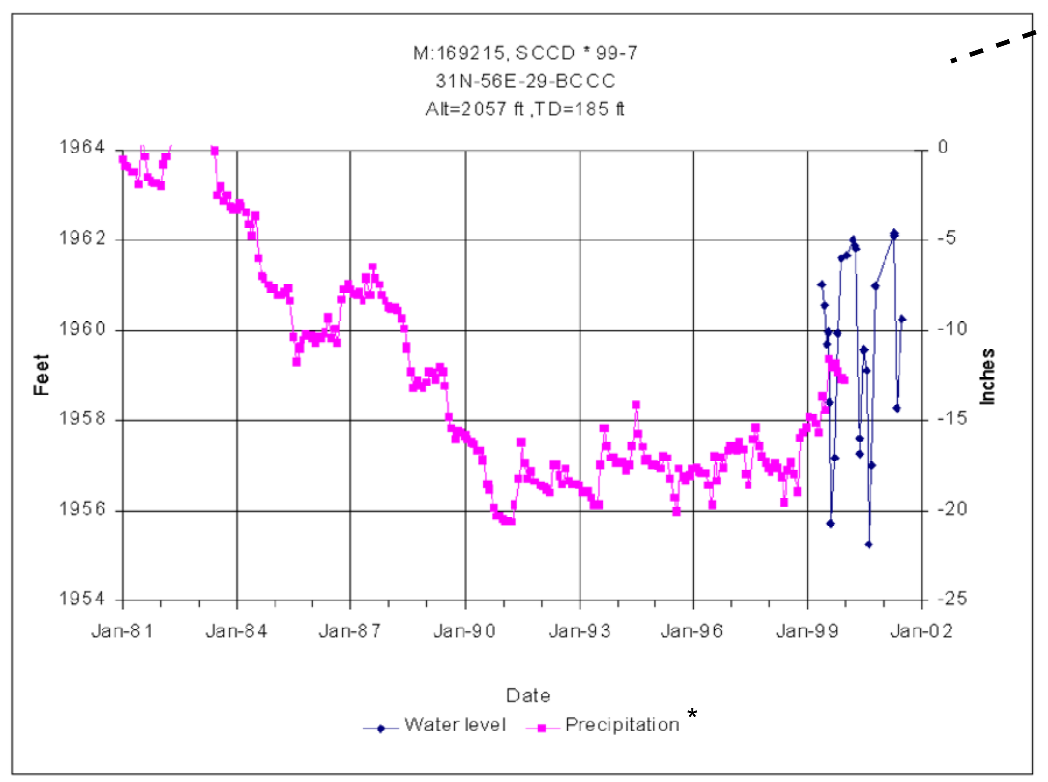
Hydrographs on this plate show water-level fluctuations based on the altitude of ground water. Precipitation* shown is the cumulative departure from normal monthly precipitation based on the time period from 1980 to 1999. NOAA record at Medicine Lake Wildlife Refuge.

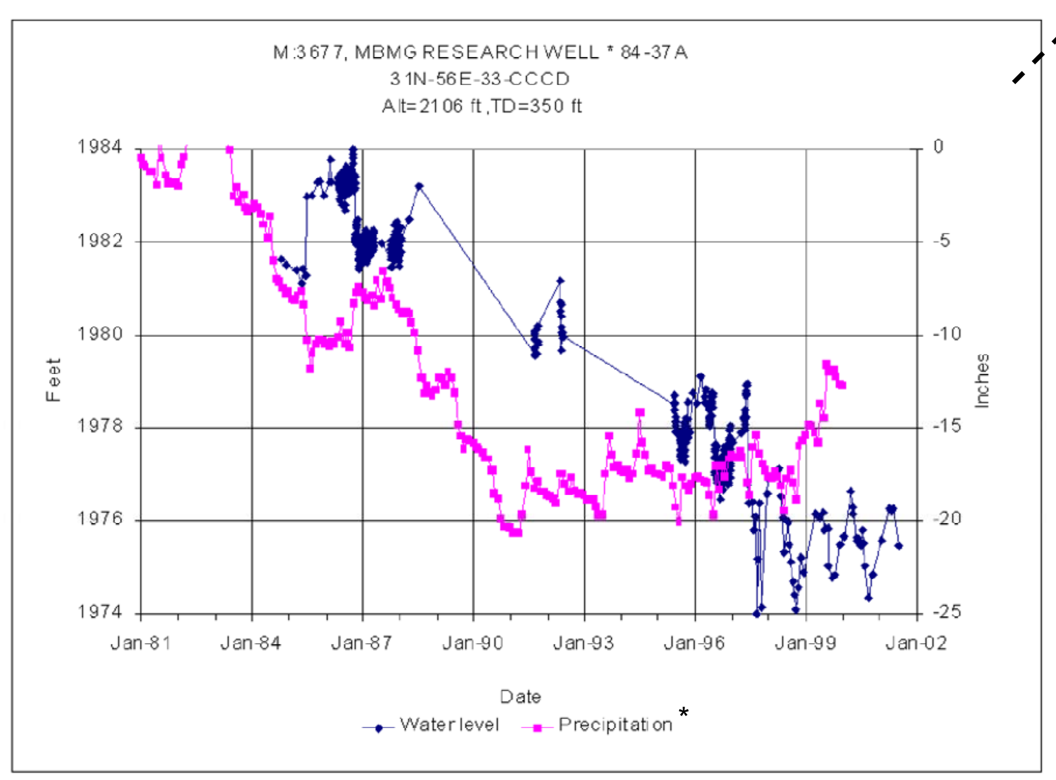
Legend

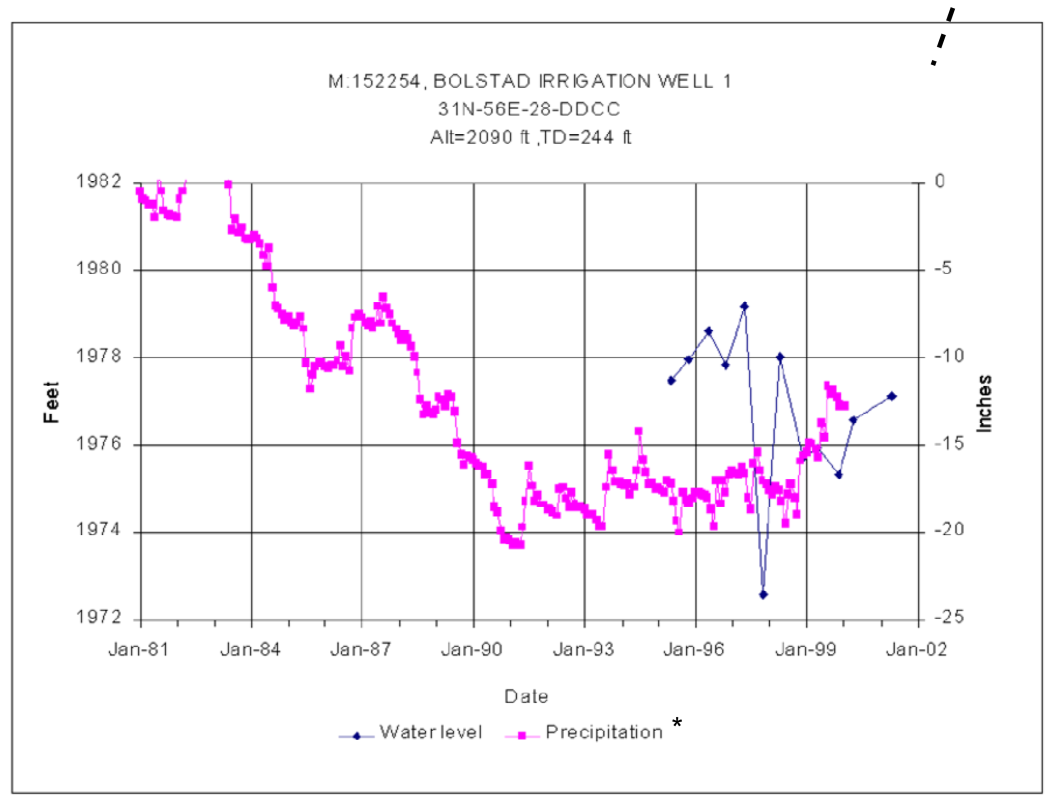
- Monitor Wells
- Towns
- Irrigation Systems
  - SCCD Developed
  - SCCD Proposed
  - State Developed
- Aquifer Segment Boundaries
- Extent of Outwash Aquifer
- Extent of Alluvial Aquifer
- Streams
- Water Reservation
- Lakes
- Wetland Easement
- Waterfowl Production Area
- Wildlife Refuge

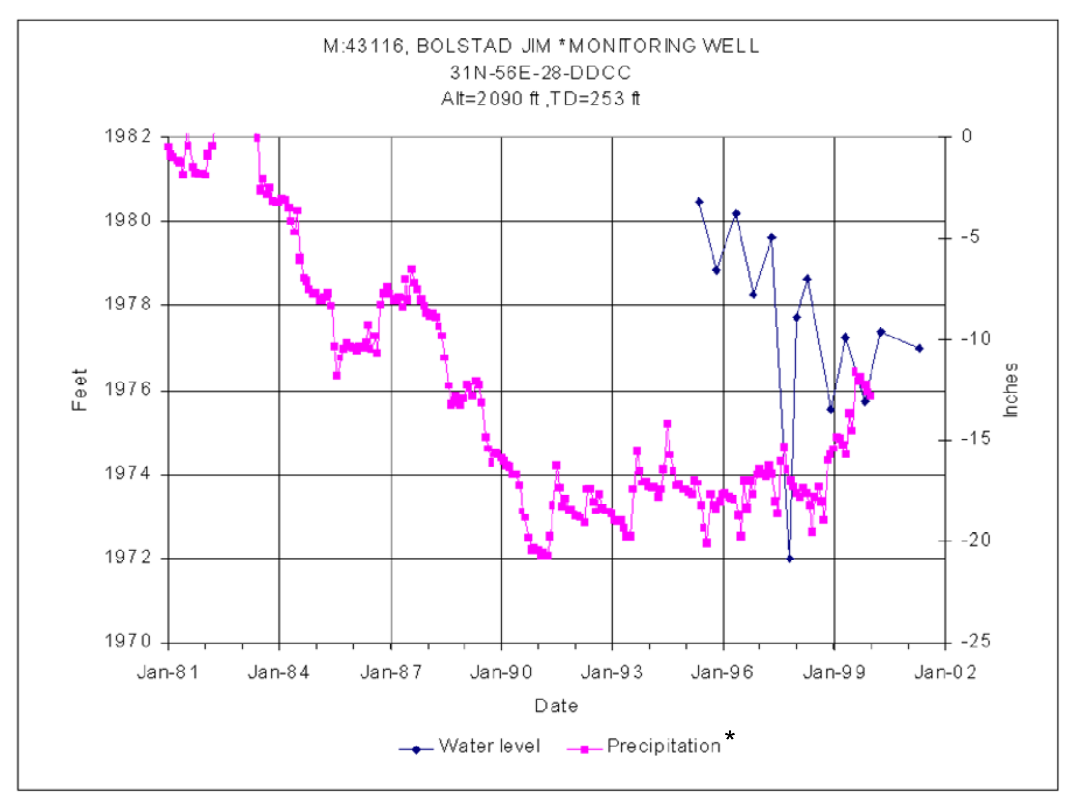


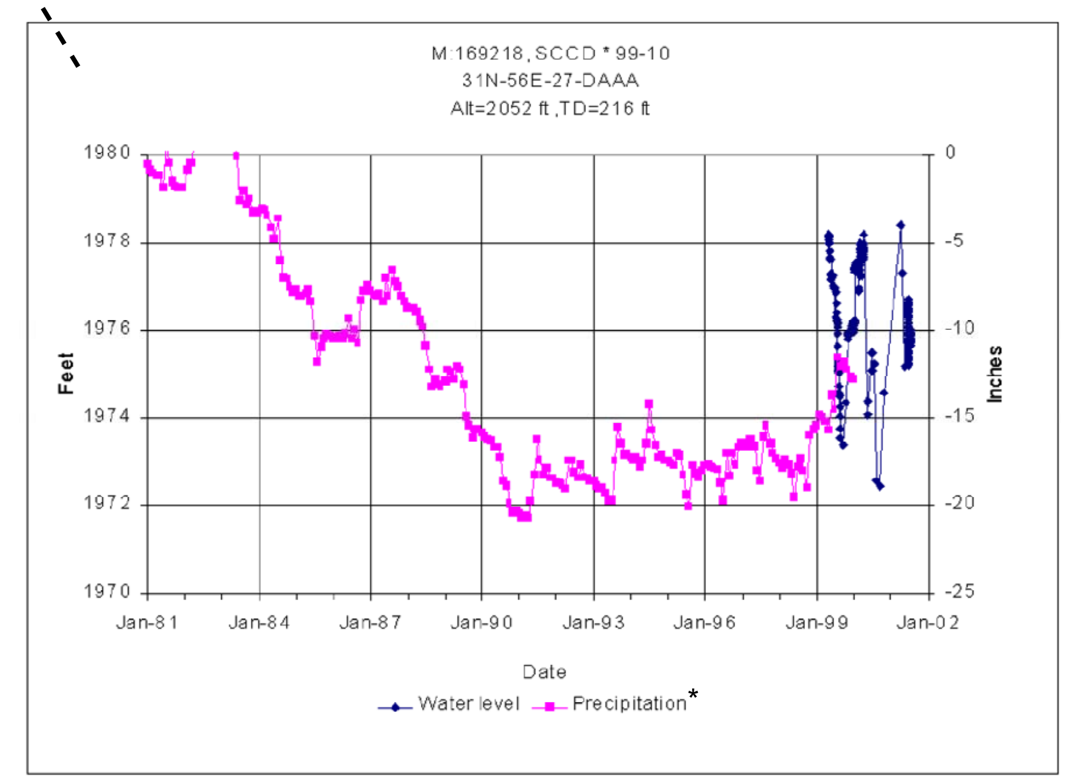


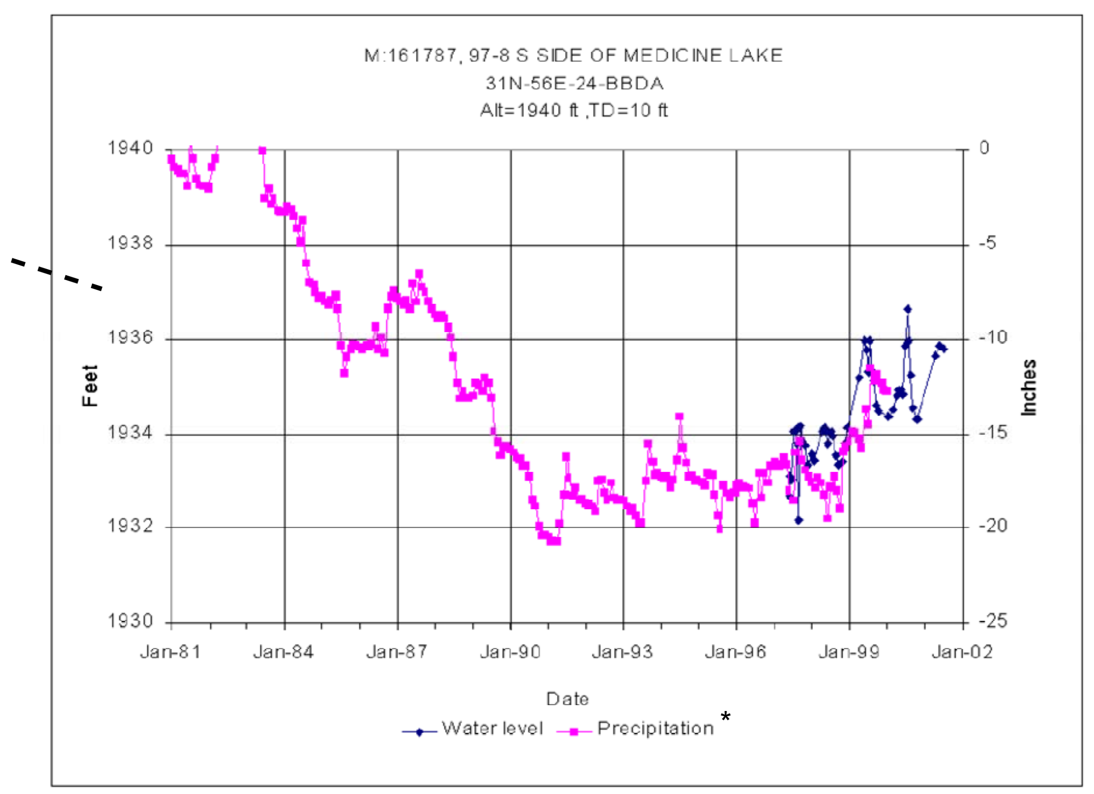


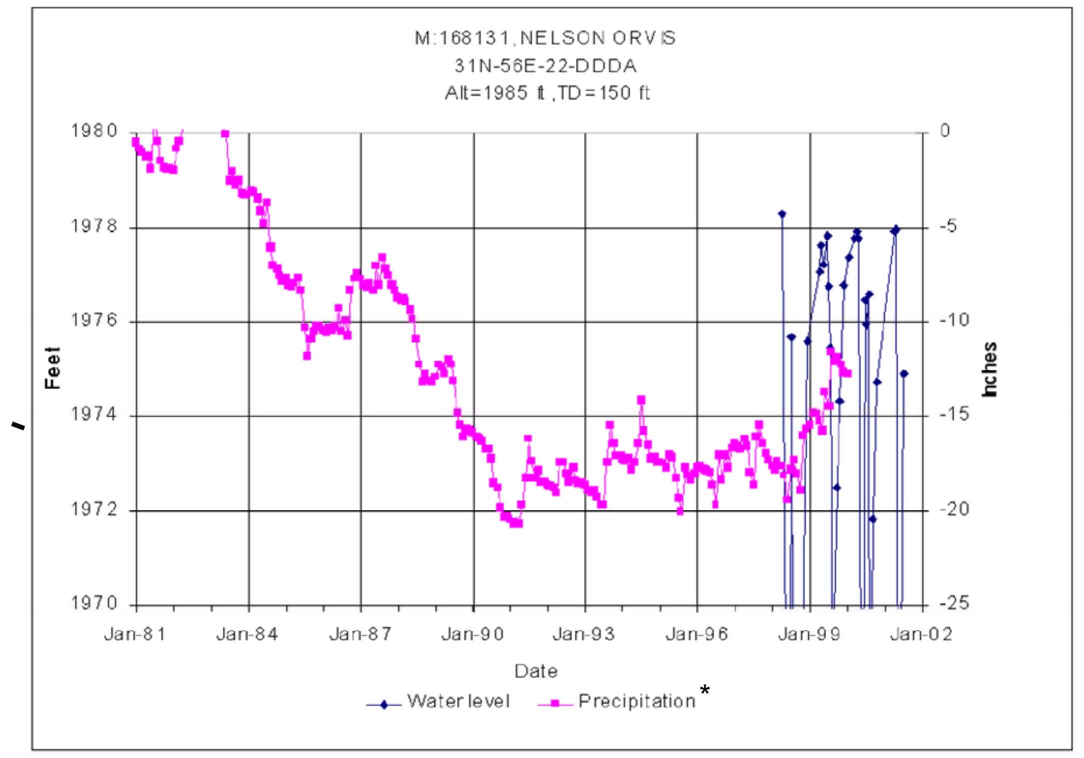


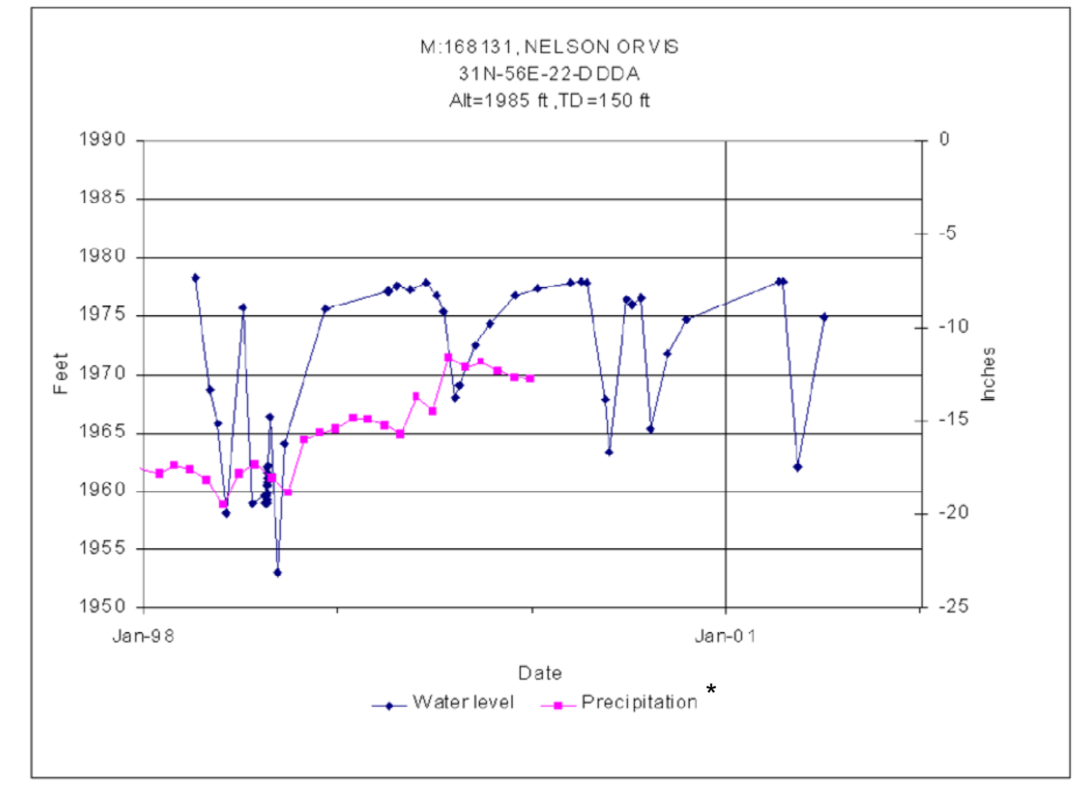


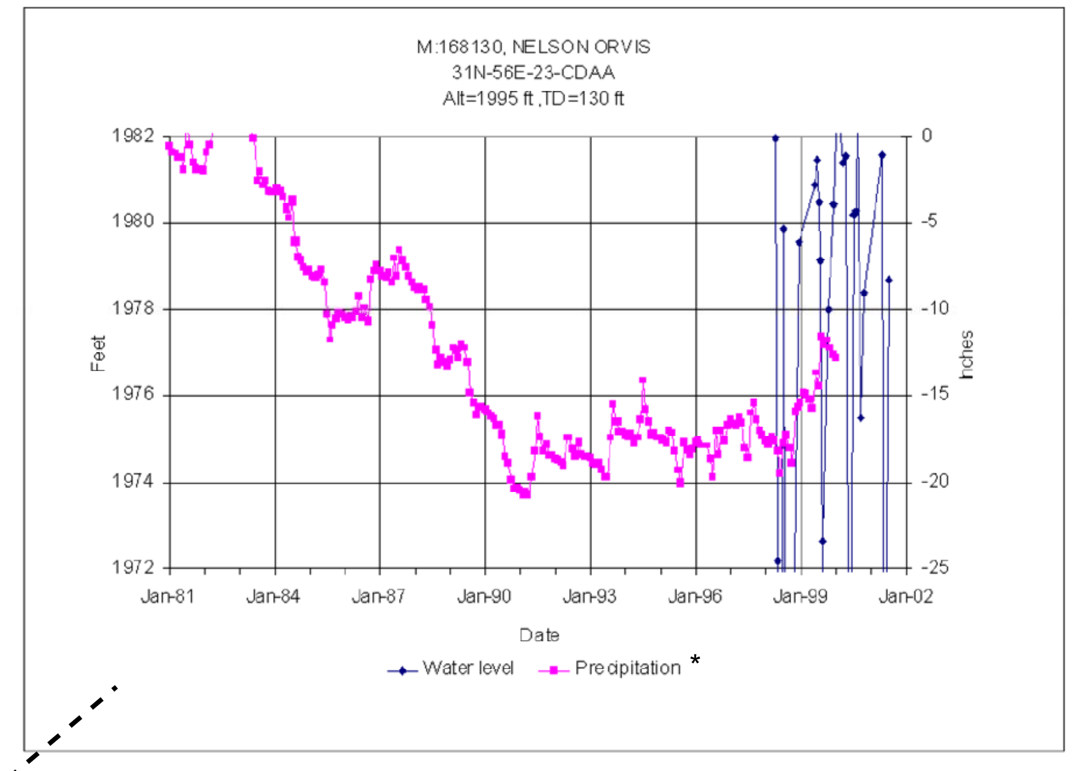


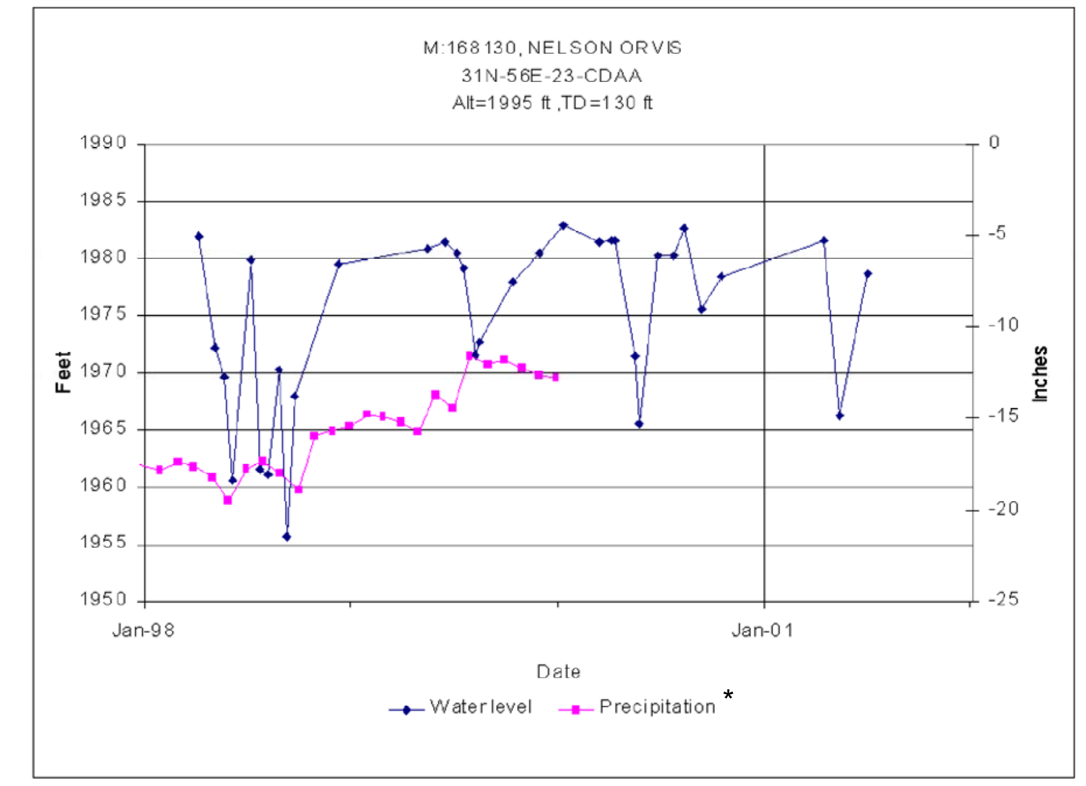


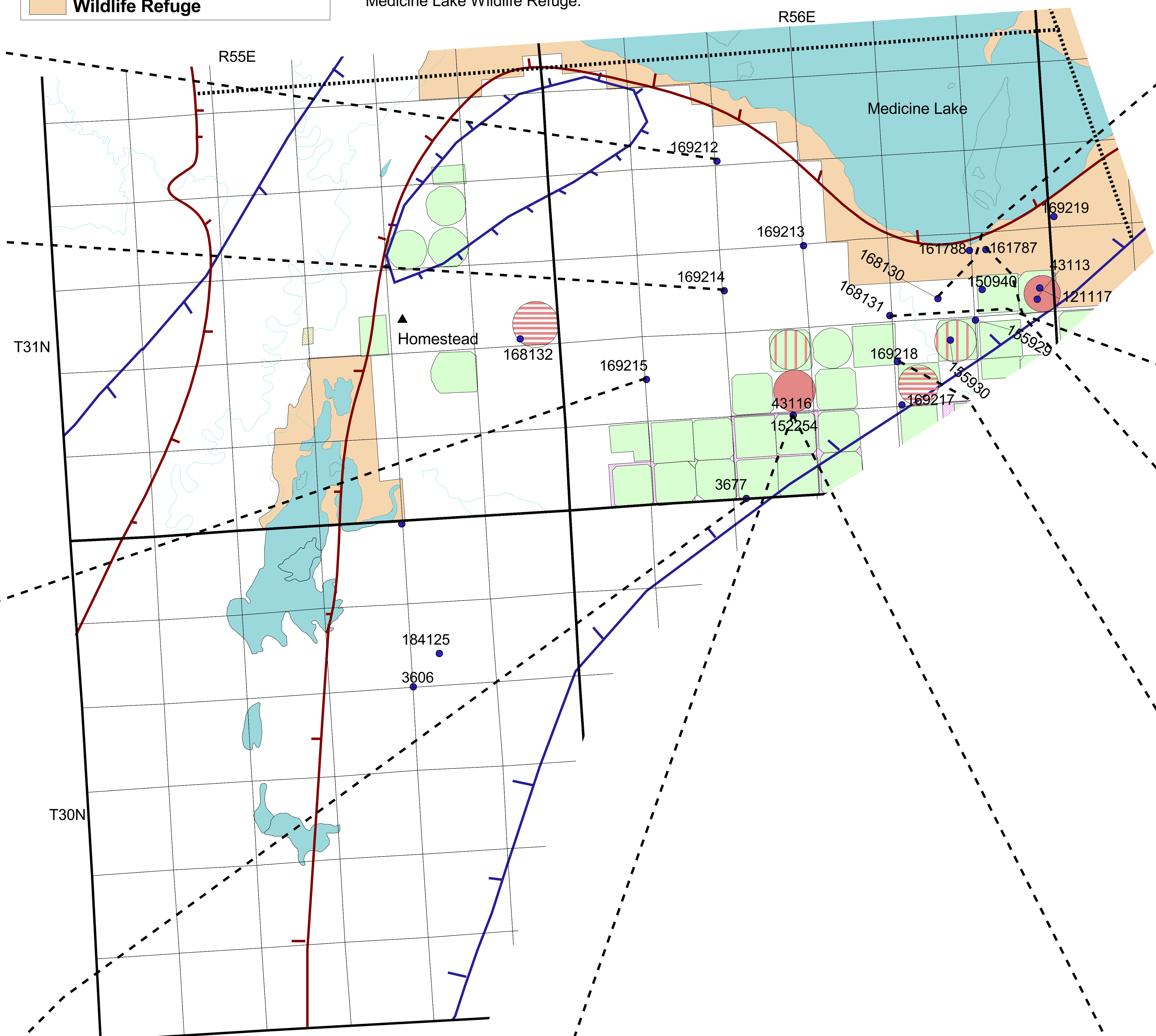












Projected at State Plane 1983

1 0 1 2 Miles

Scale

Open File MBMG 447
Medicine Lake North
Plate 6 of 9

by Jon Reiten
2002

Legend

- Monitor Wells
- Towns

Irrigation Systems

- SCCD Developed
- SCCD Proposed
- State Developed
- Aquifer Segment Boundaries
- Extent of Outwash Aquifer
- Extent of Alluvial Aquifer
- Streams
- Water Reservation
- Lakes
- Wetland Easement
- Waterfowl Production Area
- Wildlife Refuge

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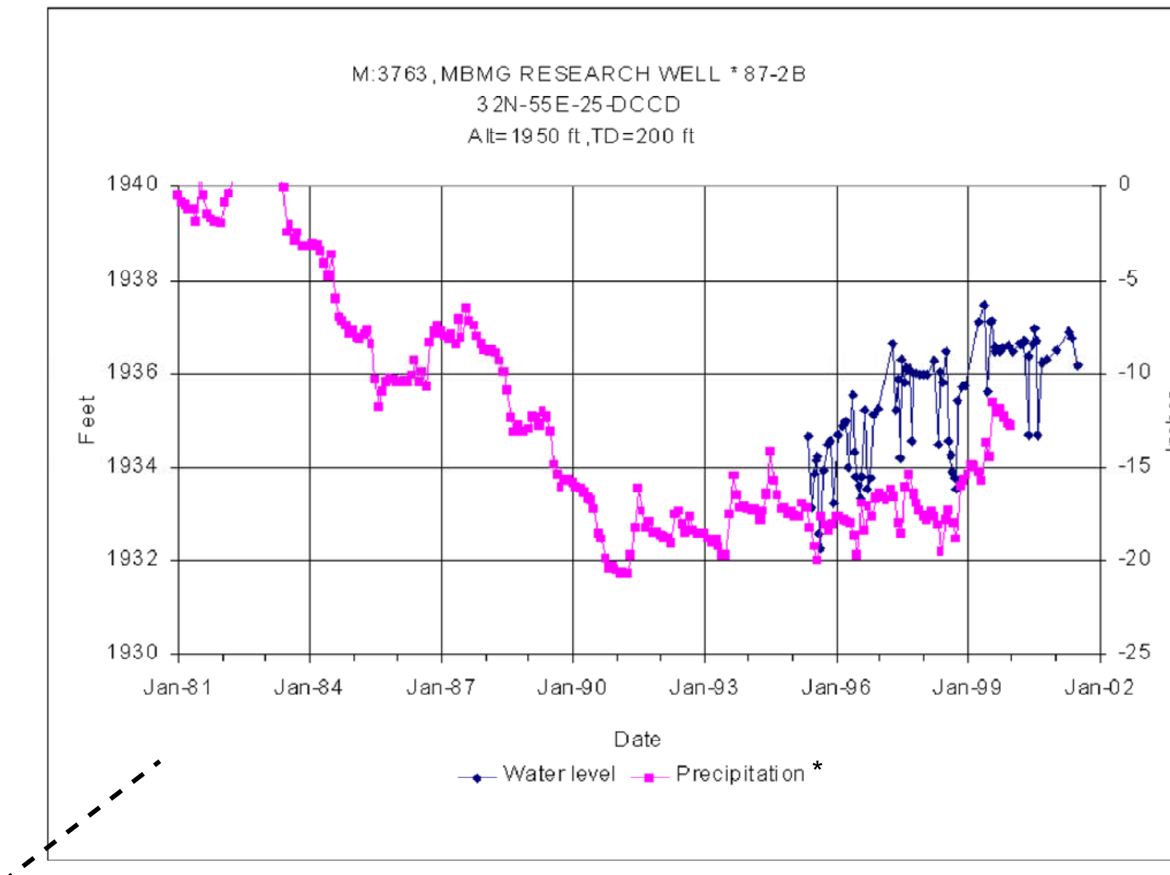

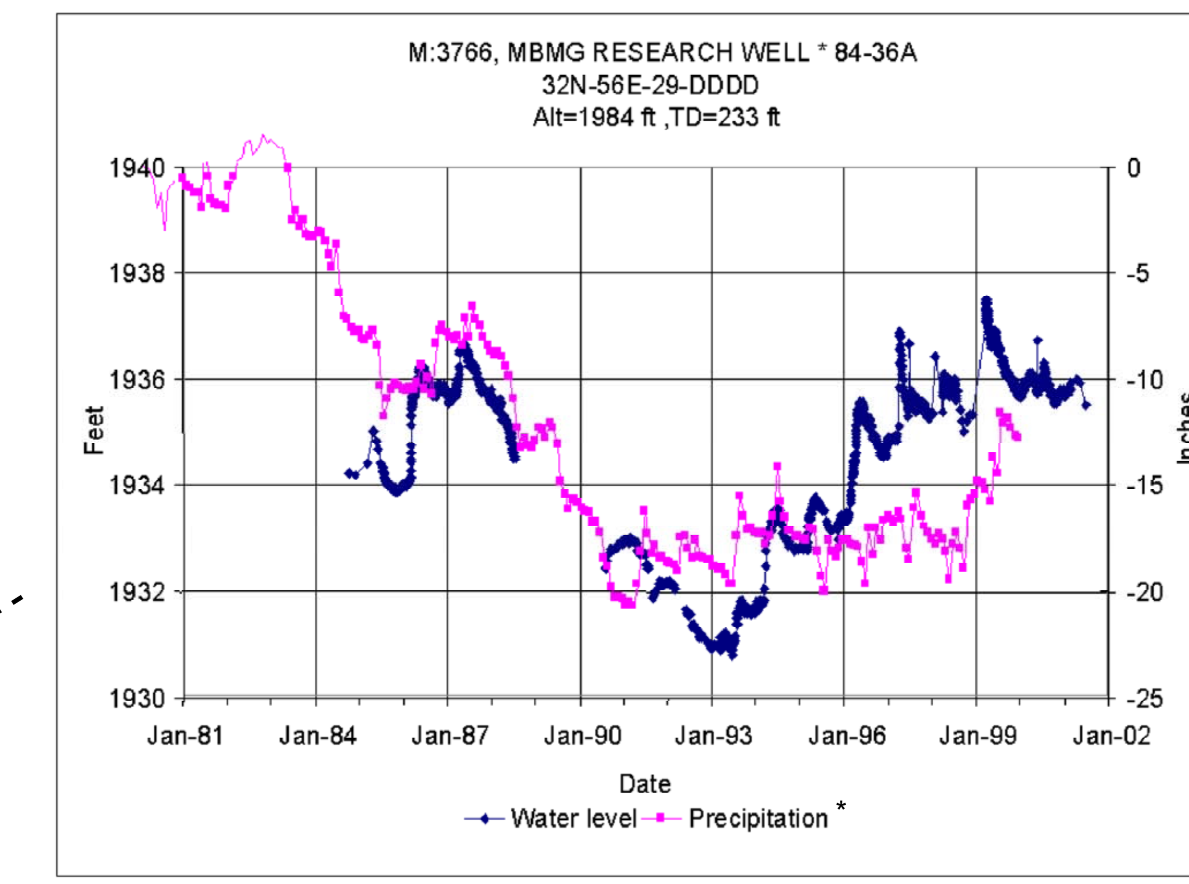

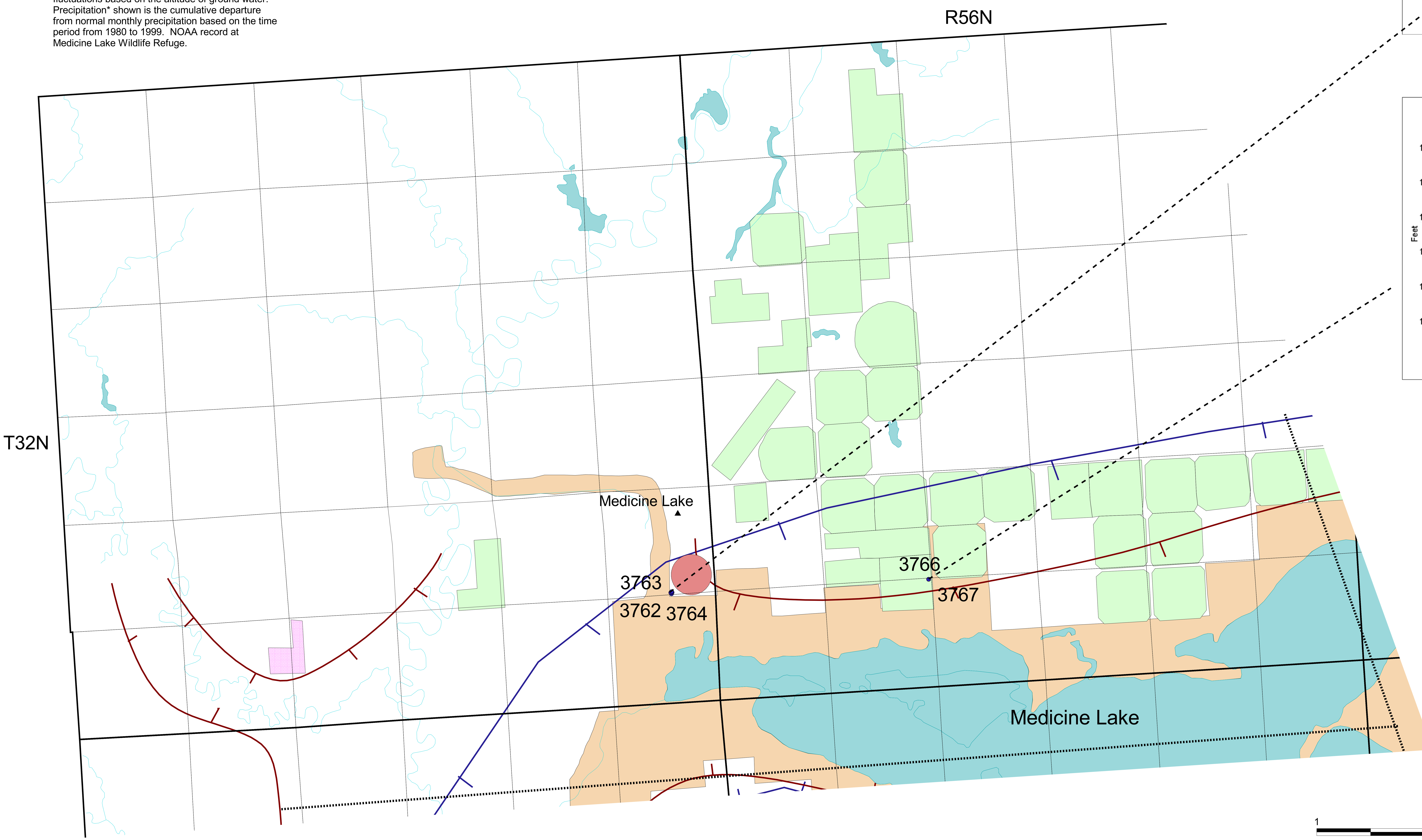

Projected at
State Plane 1983

1 0 1 2 Miles

Scale

N

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Clear Lake Aquifer
Lab Conductivity
Plate 7 of 9

by Jon Reiten
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Open File MBMG 447
Clear Lake Aquifer
Sodium Adsorption Ratio
Plate 8 of 9

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Open File MBMG 447
Clear Lake Aquifer
Change in Water Levels
Plate 9 of 9

by Jon Reiten
2002

Legend

Clear Lake Aquifer
- **Well in Alluvial Aquifer**
- **Well in Outwash Aquifer**
- **Well in Fort Union Formation**
- **Towns**
- **Wells**
- **Extent of Alluvial Aquifer**
- **Extent of Outwash Aquifer**
- **Streams**
- **Lakes**

Water Level Changes
- **0-1ft increase**
- **1-2ft increase**
- **2-3ft increase**
- **0-3ft decrease**
- **+2 to -3 ft variable**

(Water-level change (feet) is estimated from the spring/summer high in 1995 to the spring/summer high in 2000)