POTENTIAL LAND SURFACE SUBSIDENCE AT THE ARIZONA SUPERCONDUCTING SUPER COLLIDER (SSC) SITE; CONSIDERING PAST, CURRENT AND POSSIBLE FUTURE GROUND-WATER WITHDRAWAL

by

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Introduction

The Superconducting Super Collider (SSC) is a 53-mile in circumference, race-track-shaped particle accelerator proposed to be built by the U.S. Department of Energy (DOE). Because of its 4 to 6 billion dollar cost, 270 million dollar annual operating budget, and the assumption that wherever it is located will become a mecca for other high-tech industries, 25 states submitted 43 proposals to the DOE expounding the virtues of their sites. This list was trimmed to seven, including the Arizona-Maricopa Site, after review of the proposals by the National Academy of Engineers, the National Academy of Science, and DOE. Reasons for eliminating certain sites included site instability from seismic hazards and complicated geology. Confidence and safety in the construction and operation of the facility is paramount in the siting process. Included in these concerns is stability of the underlying rock or alluvium.

Arizona-Maricopa Site.

Among the technical advantages that the Arizona site (Figure 1) possesses is it's placement in easily constructable, yet highly competent alluvium or basin-fill material. This material, called fanglomerate by the Arizona technical team, is characterized by the ease with which it can be excavated but at the same time hold vertical cuts or even unsupported tunnels for long periods of time without failure. However, with siting the SSC in basin-fill material, land surface subsidence from ground-water withdrawal becomes a concern.

Because particle beam stability is required for successful collider experimentation the structural stability of the underlying material is vital. Approximately 36 miles of the proposed alignment in Arizona is through alluvium with about 25

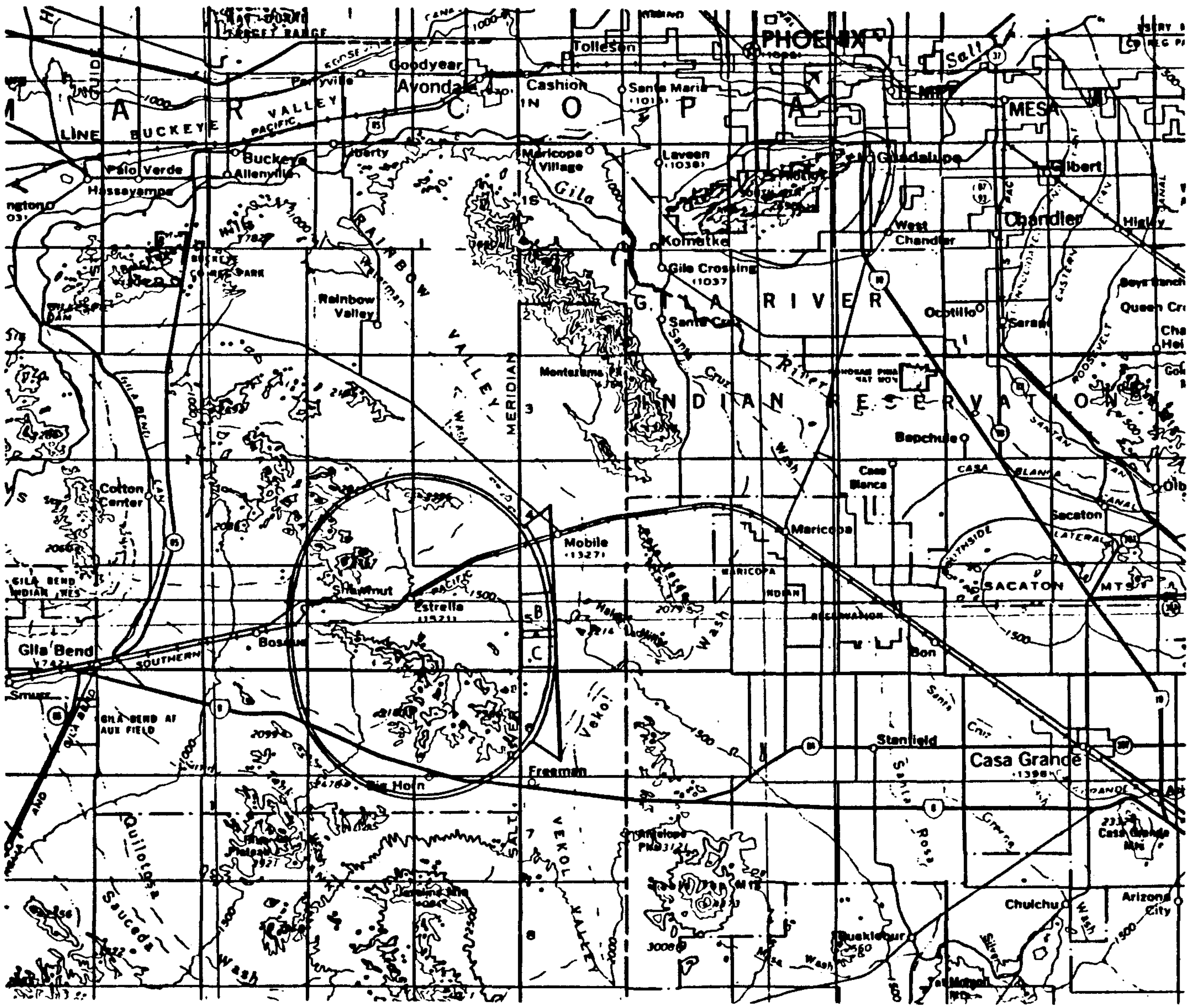


Figure 1. Regional Location Map

miles of this over thick alluvial deposits with large ground-water reserves. The potential for subsidence in this type of material is well documented throughout the State (Strange, 1982).

Subsidence - A Review

Land surface subsidence can result from many causes including hydrocompaction, collapsing cavities formed from dissolution of minerals, and the dewatering of unconsolidated sediments. In southern Arizona most subsidence is caused by the dewatering of fine-grained sediments. This subsidence is usually a general lowering of the land surface, occasionally with differential subsidence near pediments that can form earth fissures (Strange, 1982). Where subsidence has occurred in Arizona, relationships have been found between water-level decline and subsidence. Theoretically, any overdraft of ground water in unconsolidated materials will result in some subsidence, but it is generally undetectable. As a rule of thumb, in Arizona, water-table declines of 100 feet are thought to be sufficient to initiate noticeable subsidence. Two ways to avoid land subsidence caused by ground-water withdrawal are 1) dewatering only non-compactible deposits; or 2) having ground-water declines less than some threshold value. This threshold value as defined by Holzer (1981) is when the vertical effective stress exceeds the preconsolidation stress (or the maximum antecedent effective stress to which a deposit has been subjected, and which it can withstand without undergoing additional permanent deformation). The controlling factor is the characteristics of the material to be dewatered. These include (1) the thickness of the alluvium; (2) the percentage of fine sediments; (3) the degree of cementation or competency of the material; and (4) the extent of compaction which has taken place during the geologic history of a given unit.

Methodology.

Because it was not feasible to obtain the geotechnical properties necessary to determine the preconsolidation stress nor the competency of the alluvial material over an area as large as the proposed SSC site for the initial proposal, the potential for subsidence was investigated considering only water-table decline. In order to evaluate the potential for subsidence based strictly on prediction of future ground-water withdrawal accurate information on amounts and locations of previous withdrawals and on projected future demands is needed. The approach taken here was to determine the maximum previous water-table decline, calculate the possible future decline over the lifetime of the project and examine if the total drawdown will exceed 100 feet at the ring location.

WELL AND SSC LOCATION SYSTEM

The well numbers used in this report follow numbering which is based on land subdivision and is the same system as is used by the Arizona Department of Water Resources and the Water Resources Division of the U.S. Geological Survey. Where reference is made to mile markers (e.g. mile 0 to mile 5) it is referring to milepoints around the SSC ring. The system runs clockwise from mile 0 to mile 52, with mile 0 being at the northern end of the long axis which bisects the ellipse circumscribed by the tunnel.

REGIONAL GROUND-WATER USE

Although subsidence has been observed in the adjacent, but hydrologically separate, Salt River Valley and Lower Santa Cruz basins, the Arizona-Maricopa SSC site has been located in an area with no measured or suspected subsidence from ground-water withdrawal. The basins traversed by the proposed site include Waterman Wash, northern Vekol Valley, and Bosque, a sub-basin of the Gila Bend basin (Figure ~~2~~ 1). The area encompassed by and surrounding the site is essentially undeveloped with less than 30 people living within three miles of the site circumference. Virtually all of the land within the site and much of the land surrounding the site is either federally (BLM) or state controlled with scattered parcels of private land along the east and southeast portions (Figure 3). No industry was present in the three basins traversed by the site until 1988, when construction began on the Arizona Hazardous Waste Facility (AHWF) five miles west of the town of Mobile.

There are no operating wells currently within the site circumference. Off site, two areas of heavy pumping are noticeable from Arizona Department of Water Resources (ADWR) maps (Sebenik, 1979; Stulik, 1981). These are the Gila Bend and northern Waterman Wash agricultural areas. Both of these areas are 7 to 10 miles away from the proposed SSC location, and ground-water decline at the site from this pumping is minimal. A description of each basin and its past ground-water pumping, water-level changes, and possible future ground-water withdrawals is given below.

Waterman Wash

The Waterman Wash basin is in a northwest-trending valley about 30 miles long and 10 miles wide which is bounded by the Buckeye Hills to the north, the Haley and Booth Hills and Palo Verde Mountains to the south, the Sierra Estrella to the east, and the North Maricopa Mountains to the west. Waterman Wash, with a drainage area of about 400 mi^2, flows northward and exits the valley between the Buckeye Hills and the Sierra Estrella.

The portion of the site traversing the Waterman Wash basin is considered to have the greatest chance for water-table declines of a magnitude exceeding the already mentioned 100 feet. The concern is for both, ground-water withdrawal from current activities, and possible future activities if the SSC is built at the Maricopa site. The concern from current activities is for the mile 0 to mile 5 portion of the tunnel. There are five large-capacity irrigation wells 1.5 to 3.0 miles north of this area in addition to the heavily pumped northern portion of the basin. Currently, the five nearby wells, which once irrigated 1,500 acres, are pumping well below their rated capacity and two of them are inactive (ADWR, 1987). Despite this localized region of pumping, ground-water level data suggests no localized cone of depression. The water table gradient shows only a slight deviation from what you would expect from looking at the water table decline and slope in the rest of the basin. Based on existing data, since 1950 declines of 55 to 60 feet have occurred in the region around the pumped area. To estimate the potential water-table decline from the five irrigation wells previously mentioned, calculations using the wells maximum possible pumping rates and the actual 1986 pumping rates, were completed using using a range of aquifer properties. Results show that assuming reasonable aquifer properties (transmissivity and specific yield) and future pumping requirements the cumulative decline from 1950 to 2027 beneath the SSC site will be less than 100 feet (Appendix 1). In addition an SSC exploration borehole drilled approximately one-mile south of this irrigated area and one-mile north of the site showed the strata which could potentially be dewatered to consist of moderately to well-sorted sand grading into a moderately sorted fine to medium gravel. The uncased hole remained open for a month, until backfilled, indicating a competent, well-consolidated material.

Further to the south, at mile 7 to mile 13, ground-water declines are approximately 20 feet since 1950. This decline is virtually all from the basin-wide lowering which has occurred in response to the pumping in the north, (see below) as minimal pumping has taken place in the southern part of the basin.

Currently 40,000 to 45,000 acre-feet per year of ground-water is pumped from Waterman Wash basin (Frank, 1988). This is a 20 to 30 percent decrease compared to the mean withdrawal the previous 30 years. Approximately 1.75 million acre-feet have been withdrawn since 1950 when large-scale irrigated agriculture first began. The yearly ground-water withdrawals can be seen in Table 1.

Over 90 percent of the ground-water use has been for agriculture. Most of the pumping is done in an 18 mi^2 area in the north end of the valley as evidenced by the resulting cone of depression (Figure 3). A cross-section showing water level changes from 1951, 1962, and 1981 across the cone of depression is shown in Figure 4. Despite these large water table declines, field examinations have revealed no physical signs of subsidence, such as protruding well heads or earth fissures. Further south, a National Geodetic Survey level line follows the Southern Pacific Railroad line through Mobile and across the northern third of the site. Comparison of the elevations from 1949, 1967, and observed elevations in 1980 reveals no subsidence at the site or northeasterly along the railroad in Mobile Valley (Winikka, pers. commun., 1987).

Table 1

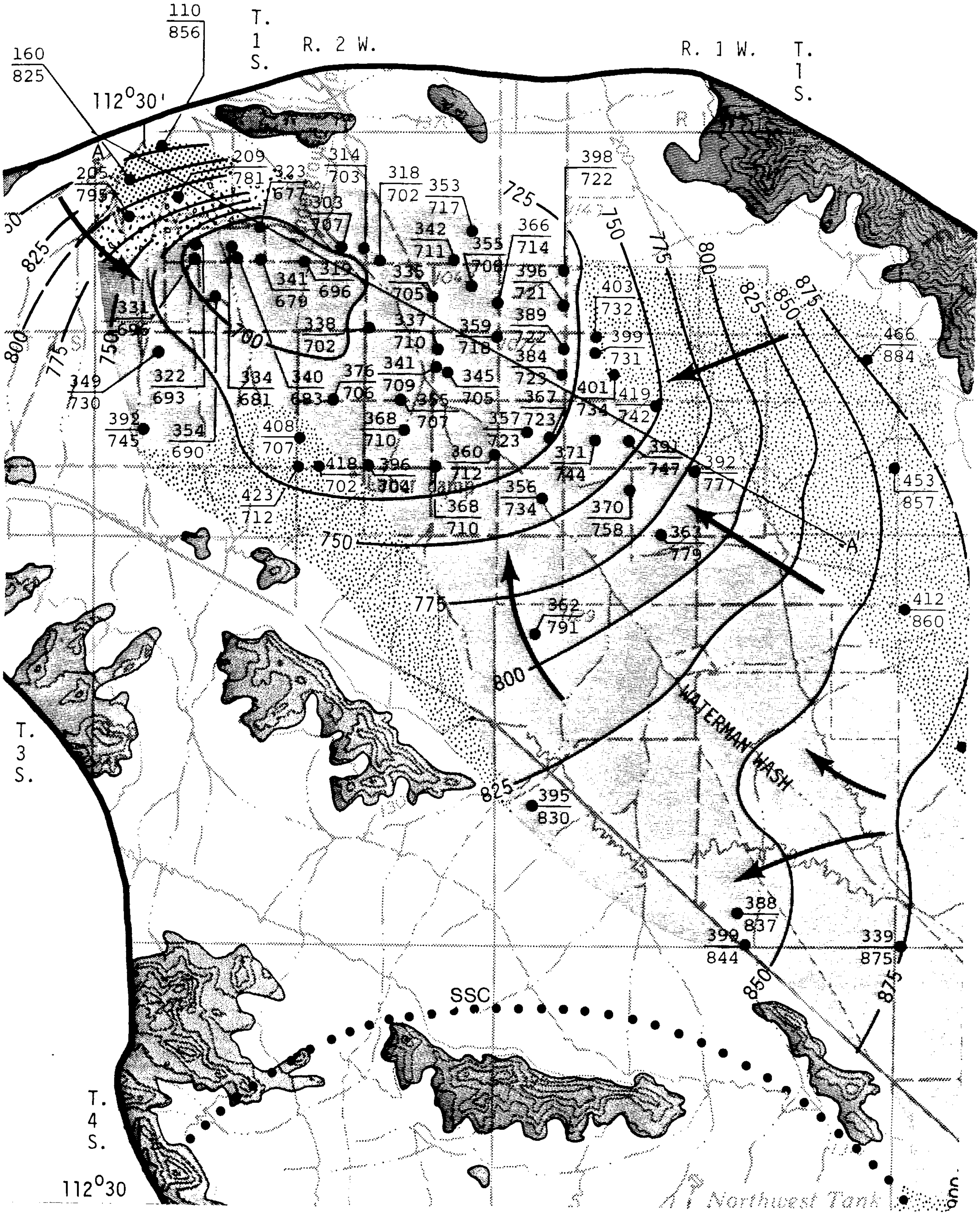
Estimated Ground-water Pumpage in the Waterman Wash Area

YEAR	PUMPAGE IN THOUSANDS OF ACRE-FEET	YEAR	PUMPAGE IN THOUSANDS OF ACRE-FEET
1940	*	1964	50
1941	*	1965	45
1942	*	1966	45
1943	*	1967	52
1944	*	1968	54
1945	*	1969	60
1946	*	1970	55
1947	*	1971	55
1948	1	1972	57
1949	1	1973	55
1950	5	1974	69
1951	10	1975	64
1952	17	1976	70
1953	28	1977	72
1954	30	1978	54
1955	40	1979	67
1956	40	1980	65
1957	40	1981	65
1958	45	1982	60
1959	50	1983	55
1960	60	1984	55
1961	65	1985	50
1962	50	1986	~40
1963	50	1987	~40

* pumpage less than 500 acre-feet per year.

from: Stulik, 1982; and ADWR data files

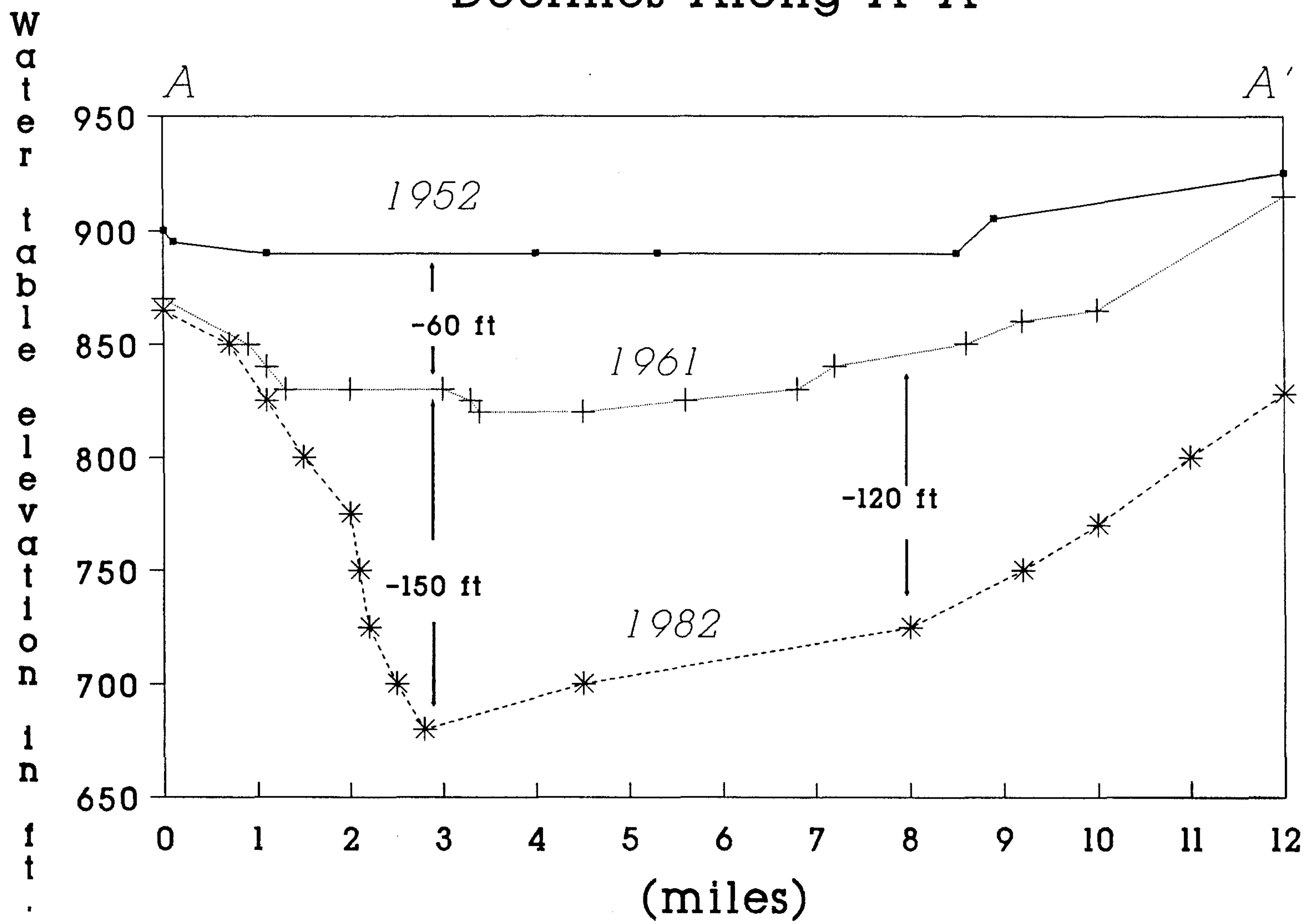
Future Ground-water Needs. The land-use future of the Waterman Wash basin appears to be a relatively rapid demise of farming replaced by a gradual growth into a satellite community of the Phoenix metropolitan area. Approval has already been given for phase I of Estrella, a master-planned community comprising 20,000 acres in the north and northeastern part of the Waterman Wash



Cone of Depression in Northern Waterman Wash basin

Figure 3

Cross-sections Showing Water-table Declines Along A-A'



source: ADWR data files

FIGURE 4

basin. The plans, which include a variety of industrial, commercial, hotel, retail, and residential opportunities, report a population that could reach 200,000. Annual water demand for a community this size would be approximately 30,000 to 40,000 acre-feet, approximately 30 to 45 percent less than average long-term withdrawal from the basin. Most of the neccessary water will probably come from the Waterman Wash basin through the purchase and retiring of the basin's agricultural land for it's water rights. Because of its proximity to Phoenix and the SSC site, its large ground-water reserves, and the development already scheduled, if the SSC were to be built at the Arizona site, the Waterman Wash basin area would be a likely candidate for future growth of high-tech and the associated service industries. This growth, if uncontrolled, could accelerate ground-water decline beneath the site. If this scenario becomes apparrent, extensive geotechnical and hydrological work will be necessary to better understand the mechanical properties of the material that could be dewatered, and the actual amount of water-table decline that may take place. Legal measures such as controlling how much and where growth occurs and/or the use of ground water and the decline of the water table may be necessary.

Current land ownership maps show that only very limited growth can occur in the Waterman Wash basin other than the Estrella development already mentioned. Of the approximately 400 mi^2 which make up the basin's drainage area, about 50 mi^2 is privately owned, 10 mi^2 is state owned, and the remaining 340 mi^2 is Federal land administered by the BLM. The Estrella development includes 31.25 mi^2 of the private land with the rest either near the town of Mobile or scattered throughout the basin in 1/4 or 1/2 mi^2 allotments. As a result, the Mobile area is the only region in the basin where unplanned growth of any concentration could occur.

Closer to the site, ground-water use will increase in the Mobile area because of requirements for the hazardous waste facility. The facility has been granted rights to pump up to 800 ac-ft/yr from a well north of Mobile. This will be an increase in what is currently withdrawn in the area but is not expected to cause declines sufficient to be of concern.

<u>Summary</u>

Although the most likely of the three basins traversed by the SSC, land surface subsidence due to ground-water withdrawal is not expected to occur in the Waterman Wash basin. The large distance from the zone of past and current pumping, the decrease in future pumping, and the overall geologic and geotechnical characteristics of the site suggest that subsidence is not a concern. Future, time-delayed subsidence caused by previous dewatering of fine-grained sediments is not thought to be a problem because, based on available well log information, the necessary concentration and thickness of silts or clays are not present to any extent either horizontally or vertically in the zone that has or will be dewatered. However, to reinforce these conclusions regular monitoring of ground-water declines and more specific geotechnical testing should be undertaken.

Vekol Valley

Northern Vekol Valley is a north-trending valley about 12 miles long and 5 to 10 miles wide. It is bounded by the Table Top and Vekol Mountains to the east, the Sand Tank and South Maricopa Mountains to the west, and the Booth and Haley Hills to the north. Vekol Wash flows northward exiting through a narrow gap between the Haley Hills and Table Top Mountains.

Land surface subsidence is not considered to be an issue for any part of the SSC facilities in Vekol Valley. The SSC alignment is located up on the pediment of the southern Maricopa Mountains. Ground-water use in the northern Vekol Valley is limited to small-scale agriculture, livestock watering, and domestic needs. Most of the wells in the valley pump less than the minimum needed to require owners to report the withdrawals to the ADWR and so accurate data on ground water use is not available. However, probably less than 50 acre-ft/yr is withdrawn from the aquifer. The wells with long-term water level data available (pre-1960) indicate a slight rise, of 1 to 8 feet, of the water table. Therefore, the hydrologic system is considered to be in steady-state.

In the early 1980's the northern Vekol Valley was identified by the U.S. Dept. of Interior as the optimal source of ground water to satisfy Public Law 95-328 which guaranteed the Ak-Chin Indian tribe 85,000 acre-ft/yr of water. On the basis of studies by Wilson (1979), Matlock (1981), and other available information it was specified that a well field and pipeline capable of delivering 30,000 acre-ft of water annually to the Ak-Chin Indian Community be constructed, with the balance coming from a CAP allocation. The Indians subsequently turned down Vekol Valley ground water and accepted a CAP allocation and money instead. As a result, the valley has remained essentially unpumped.

In the course of their studies the USGS developed a numerical model based on the detailed geohydrologic concepts developed previously (Hollett and Marie, 1987). The same model was run changing only the pumping rate and schedules. The revised scenario includes two wells each pumping at 1,225 gpm for 25 years. Results showed that the 75,000 acre-ft of water which would be removed from storage after 25 years would cause the water table to decline about 60 feet at the wells to 10 feet at a distance of four miles from the well (Brooks and Coggeshall, 1988). The 75,000 acre-ft represents a depletion of about 20 percent of estimated recoverable ground water in storage to a depth of 450 feet below the water table.

Although much of the land north of Interstate Highway 8 is privately owned, no increased development, and hence ground-water use, is expected to occur in the immediate future because of the lack of utilities and roads. Future large ground-water declines are dependent soley on the SSC being built at the Arizona site. If large-scale growth and its accompanying ground-water withdrawal do take place the subsidence issue will have to be addressed for the roads and pipelines in the valley.

<u>Summary</u>

The placement of the SSC up on the pediment, the negligible water-table decline, and the absence of any thick, fine-grained deposits that could be dewatered suggest that pumping in the northern Vekol Valley for the SSC will not cause any land surface subsidence. The only potential concern will be for the access road from Interstate 8 and the utility lines from the Vekol Valley well field. Water level declines may be much greater than currently predicted depending on development that may occur on private land east of the site should the SSC be constructed at the Arizona Site. Legal measures may be necessary to control the water table decline.

Gila Bend (Bosque)

The Bosque area, an eastern extension of the Gila Bend basin, is about 15 miles long, 2 to 10 miles wide, and is bounded by the Maricopa Mountains to the north and east, the Sand Tank Mountains to the south, and the Gila River to the west (Wilson, 1979). The major drainage is Bender Wash which flows northwest into the Gila River.

The Bosque basin is the most unknown of the three basins with regards to its subsurface properties. The basin is considered to be either a graben or half-graben filled with as much as 3,000 ft of basin-fill material. What is known about the basin geology and hydrology comes from work done by the USGS as part of their Ak-Chin Water Supply study (Wilson, 1979).

The Bosque basin-fill deposits are divided into an upper, a middle, and a lower unit by Wilson (1979). The upper unit is 700-900 feet thick. It is composed of unconsolidated grayish-brown coarse to fine gravel, sand, silt and clay. The saturated thickness ranges from 100 feet to more than 500 feet. The middle unit is 800 to 1,450 feet thick. It is mainly unconsolidated to poorly consolidated grey-brown fine to very coarse sand and fine to coarse gravel. This unit overlies an erosion surface cut on the lower unit. The thickness of the lower unit is unknown. The unit consists of volcanic rocks interbedded with moderately to weakly cemented conglomerates. A USGS test hole, in C-6-3 2ada (one-half mile west of SSC milepost 38), was drilled to a depth of 1,149 feet. The material penetrated by the well consisted mainly of clayey silty sand (Wilson, 1979).

The upper unit is the only unit of concern with regards to being dewatered and subsiding. As described above the unit is lithologically highly variable and therefore it can be assumed that its geotechnical and hydrologic properties are likewise variable. However, as in Vekol Valley the concern for subsidence occuring at or near SSC related structures is very low.

Although large quantities of water have been pumped from the Gila Bend basin, ground-water levels are historically relatively static. A thorough survey of ground-water levels and pumpage was completed in 1973 and again in 1979. Results showed that although pumpage has increased significantly throughout the basin since 1973, the effects of ground-water withdrawal were reduced considerably by the effects of ground-water recharge from Gila River floodflows and storage behind the then newly constructed Painted Rock Dam. Essentially all of the current, and proposed future, ground-water development is along a narrow swath which straddles the Gila River and the areas around and southwest of the town of Gila Bend. In a state-wide survey of levelling data evidence of as much as .3 ft (8 cm) of subsidence was detected in the Gila Bend area (Strange, 1983). This was probably very localized and probably occurred prior to the mid-1970's when water levels in the region began to rise.

The Bosque part of the basin is virtually all federal or state controlled land with only 0.5 mi^2 of private land. As a result, the only pumping which has occurred in the vicinity of the SSC is from BLM permitted stock wells. Economics have suspended any grazing in the area and so the Bosque region is currently unpumped. Although no historical ground-water level information is available for the portion of the basin traversed by the SSC, extrapolations from what has occurred in the regions of pumping can be undertaken. Ground-water levels along and near the Gila River fluctuate rapidly depending upon flow in the river. During the 1973-1979 period water level rises of from 0 to more than 60 feet occurred near the river with most of this being attributed to abnormally large streamflows during the winter of 1978-79. This is generally a mounding of water beneath the river and is not representative of the western part of the basin which includes the SSC. However, as water level rises are not immediately propogated out to the Bosque-area neither are water level declines. Therefore, even an increase in pumping along the Gila River is not likely to create any large ground-water declines beneath the SSC site.

The current population of Gila Bend is approximately 3,000. Future growth in the area is likely to be somewhat slow and moderate. Its distance from Phoenix and the poor to moderate ground-water quality will probably impede any rapid growth such as is occurring southeast and west of Phoenix. A major development of over 100,000 acres was under consideration southwest of Gila Bend at the Paloma Ranch. The land for this proposed development is currently used to grow cotton and wheat. The development plans are currently on hold with no starting date announced. In any event, as in the Waterman Wash area, a conversion from agricultural to urban use would result in a net decrease in water use.

<u>Summary</u>

In summary, land surface subsidence due to ground-water withdrawal is not seen as a concern for the western and southwestern portions of the Arizona SSC Site either from current ground-water withdrawals or future withdrawals.

The low density population, the recent rise of the water table in many areas, and the expected slow, future growth all suggest that ground-water declines will be minimal in the Bosque and Gila Bend basins.

Conclusion

Although land surface subsidence caused by ground-water withdrawal is a legitimate concern for large-scale construction in south-central Arizona alluvial basins the available geologic and hydrologic information suggest that it will not be a problem at the Arizona-Maricopa SSC Site. The SSC site is situated such that it lies in basins that either will not or cannot have ground-water declines sufficient to cause land subsidence or that are geotechnically unlikely to subside regardless of regional ground-water declines. However, because of the large area traversed by the SSC, which immediately brings uncertainty to the continuity of the assumptions made of the hydrologic and geotechnical properties, and the uncertainty regarding future growth in the region, it is recommended that a monitoring program consisting of 1st order levelling stations and water level measurements be designed and ready for implementation should the SSC be built at the Arizona-Maricopa Site.

Appendix 1

Numerous drawdown calculations were performed for the northeastern section (mile 0 to mile 5) of the SSC site under various pumping scenarios. The following sections address two questions related to potential subsidence at the Maricopa SSC Site. These are, 1) given that, over a 40 year period, pumping must be controlled around the site, what cumulative pumping rates can be tolerated, for the life of the project, without exceeding a conservative threshold water-table decline of 100 feet at the ring location; and 2) assuming current pumping practices in the Waterman Wash agriculture area continue and that they cannot be controlled until the "safe yield"[1] concept takes effect in 2025, how much water-table decline will occur in the area of mile 0 to mile 5. In answering these two questions for the mile 0 to mile 5 section two assumptions were made. The pumping rate assumed will continue for the life of the projection, and all assumptions inherent in using the Theis solution apply.

Assumption one is judged reasonable because, at worst, pumping will continue at the same rate, but in reality pumping should decrease in the future due to the decline of agriculture. Additionally, if these agricultural lands are converted to urban use a savings of 45 to 70 percent in water use could be realized. Irrigated agriculture currently consumes more than 90 percent of the water used in the Waterman Wash basin. The agreement with the Theis assumptions is considered adequate except for the concept that the aquifer is of infinite

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[1]Safe-yield means that annual ground-water withdrawals do not exceed ground-water recharge. Thus, no general lowering of the water table occurs.

areal extent. Impermeable boundaries in the form of bedrock or clay deposits are a possibility. However, occurrences of these boundaries are not thought to be close enough to greatly change the calculated values.

Because drawdown will be taken to be much less than the total aquifer thickness, we can use the Theis (1935) solution to calculate drawdown (S):

$$S = \frac{Q\ W(u)}{4\pi T}$$

$$\text{where } u = \frac{r^2\ s}{4\ T\ t}$$

T = transmissivity
s = specific yield
r = radius of cone of drawdown
t = time in days

solving for the pumping rate, Q,

$$Q = \frac{S\ 4\pi\ T}{W(u)}$$

SAMPLE CALCULATION:

Consider r = 1 mile or 5280 feet

Case 1: assume $T = 600\ ft^2/day$ $s = .05$

Basic Equation:

$$S = \frac{Q\ W(u)}{4\pi\ T}$$

$$u = \frac{r^2\ s}{4\ T\ t}$$

$$u = \frac{(5280\ ft)^2(.05)}{4\ (600\ ft^2/day)(14600\ days)}$$

$$u = .039$$

$$W(u) = 2.70$$

$$Q = \frac{S\,4\,T}{W(u)} \quad \text{then}$$

$$Q = \frac{50\ \text{ft}\ (4)\ (3.14)\ (600\ \text{ft}^2/\text{day})}{2.70}$$

$$Q = 139{,}600\ \text{ft}^3/\text{day or } 725\ \text{gpm}$$

<u>Maximum Allowable Pumping</u>

In this first analysis, the problem is what cumulative pumping rate, over a 40 year period, could be allowed at various distances from the tunnel without exceeding a total of 100 (50 additional) feet of drawdown below the tunnel.

The transmissivities used were determined based on aquifer tests described in reports by the U.S. Geological Survey (Wilson, 1979) and the Arizona State Land Department (White, 1963). Transmissivity, T, values ranging from 4,500 to 13,000 ft^2/day with an average value of 8000 ft^2/day were determined for the upper unit (the unit which would be dewatered) in the Waterman Wash Basin by the USGS. Towards the basin margins the values are generally seen to decrease as evidenced by 700 ft^2/day value found near the town of Mobile and the 800 ft^2/day value determined by Manera (1982) just south of Mobile. However, an exploration drillhole at D-3-1 33ccc, which is only one mile north of milepost 2 encountered saturated material composed of a moderately sorted coarse sand and gravel with minor amounts of fines. Although no aquifer testing was done visual grain size analysis of the aquifer material suggested a hydraulic conductivity (K) value of 25 to 65 ft/day (Todd, 1986). Assuming a 400 foot saturated zone (based on gravity modeling) this gives T values in the range of

10,000 to 26,000 ft^2/day. The K value can be expected to decrease with depth effectively lowering the T value to better match those found elsewhere in the basin. To thoroughly cover the range of possible values, a worst case of T= 600 ft^2/day, a reasonable case of T= 8,000 ft^2/day, and a best case of 20,000 ft^2/day will be used in the calculations. Specific Yields, s, have been estimated by the USGS and private consultants working in the area to be 0.10. This value is generally considered low. In these calculations values of 0.05, 0.10, and 0.25 are used. The results using the worst, reasonable, and best case scenarios can be seen in Table 2.

Table 2

Allowable Pumping Rates
(in gpm)

	1/2 mile[1]	1 mile[1]	2 miles[1]	5 miles[1]
Worst Case Scenario[2]	483	725	1379	8742
Reasonable Case Scenario[3]	4400	5738	8159	17,883
Best Case Scenario[4]	11,007	14,346	20,656	44,104

[1] - distance from centroid of pumping to the SSC
[2] - worst case is T = 600 ft^2/day and s = 0.05
[3] - reasonable case is T = 8000 ft^2/day and s = 0.10
[4] - best case is T = 20,000 ft^2/day and s = 0.25

Currently there are only five large production wells in operation within seven miles of the northeast section of the ring and these are all from 1.5 miles to 3 miles away from the ring. Their total 1986 pumping rate amounted to 2450 gpm (ADWR, 1987). Even under a worst case scenario these wells are a marginal concern at worst. Combining the indications that aquifer properties do not match those of the worst case scenario and the continuing decline in agriculture, and therefore pumping, subsidence due to ground-water decline is not considered a threat.

Water Level Drawdowns Due to Existing Wells

The second part of this study concerns the potential water-level declines due to existing wells within seven miles of the mile 0 to mile 5 section. See Figure 5 for location of the wells. The analyses will use both a well's maximum possible pumping rate as given by the ADWR, and its most recent (1986) pumping rate for a 40 year period. As previously mentioned only five registered (>35 gpm) wells are within seven miles of the northeast section (mile 0 to mile 5) of the ring. The existing well data are summarized in Table 3.

Table 3

Well Designation	Max. Yield (gpm)	Withdrawal in 1986 (acre-feet)	Distance from Tunnel (miles)	Distance from summation point, (X) (miles)
21DCC1	3000	730	~3	~3.25
28CDD	2100	521	~2	~2.25
28DDD	3700	834	~2	~2.25
34ACC	2600	755	~1.75	~1.75
34DCD	3450	1100	~1.3	~1.4

X - distance from well to point X on Figure 5. Point X was determined to be the point along the tunnel alignment where the sum of all the wells drawdown would be greatest.

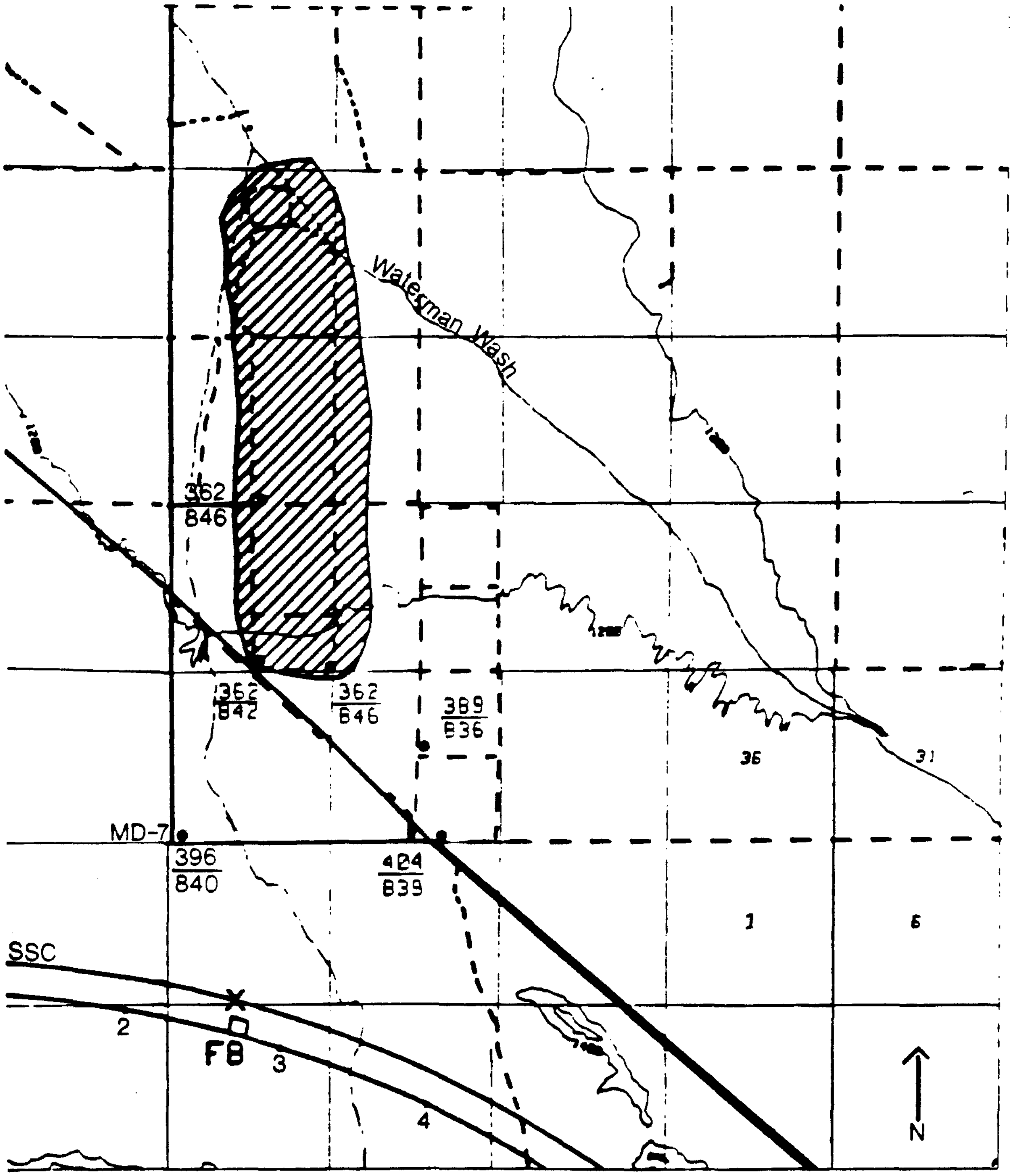

FIGURE 5

1 mile

Wells Used in Subsidence Study

X - estimated point of maximum decline

- irrigated area

Summary of results:

For each well, drawdowns in feet were calculated using the Theis (1935) solution. Drawdowns were calculated, at the summation point X, using a specific yield of 0.10 and transmissivities of 600 ft^2/day and 8000 ft^2/day. Results can be seen in Table 4.

Table 4

Well	Drawdowns assuming max. pumping rates[1] (feet)		Drawdowns assuming 1986 actual pumping rates[1] (feet)	
	W	R	W	R
21 DCC1	22	13	3	2
28 CDD	37	12	6	2
28 DDD	66	21	9	3
34 ACC	70	17	13	3
34 DCD	128	25	25	5
Total	323	88	56	15

Explanation:
W - worst case scenario, T = 600 ft^2/day, s = 0.10
R - reasonable case scenario, T = 8000 ft^2/day, s = 0.10
[1] - pumping rates continuous for 40 years

As the results in Table 4 show, using the current pumping rates, which are expected to decrease in the future, even assuming the worst case aquifer parameters the maximum additional drawdown would be only 56 feet. These results combined with the generally coarse, granular nature of the aquifer indicate that subsidence should pose no future hazard to the region.

The worst case aquifer parameters along with the theoretical maximum pumping rates, do show a potential problem. Future geotechnical and hydrological work will be necessary to better identify the regional aquifer properties. If conditions warrant it, the State has indicated it would purchase the land and retire the water rights.

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