The hydrologic effects from intense ground-water pumpage in East-Central Hillsborough County, Florida

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ABSTRACT

Well problems, water shortages, local flooding, and induced sinkholes have been periodic problems for residents in East-Central Hillsborough County. This agricultural area has experienced dramatic, short-term water-level declines in the Floridan aquifer from seasonal ground-water withdrawals. Sudden declines in the potentiometric surface are caused by intense irrigation pumpage, primarily for frost and freeze protection and fruit setting. Citrus and strawberry crops are protected from occasional freezes by the application of warm ground water to maintain minimum soil temperatures of 0 C (32 F). Local residents with inadequately constructed wells lose their source of water when the potentiometric surface is lowered to depths where their wells do not function. Some residents have lost their water supply for a week or more, and many have incurred damage to their pumps. Drawdowns of the potentiometric surface in some areas have induced sinkholes causing property damage for some residents and concern for others. In addition, the high application rates for frost and freeze irrigation have created run-off problems resulting in local flooding to some residents. Fortunately, there has been no serious damage to houses in affected areas.

This report summarizes the consequences of heavy freeze irrigation and considers local hydrogeology. A finite-difference computer model is used to quantify the regional impacts on the potentiometric surface of the Floridan aquifer from estimated irrigation pumpage. Management recommendations for alleviating the problems are also discussed.

Introduction

The Dover Area, delineated by the Southwest Florida Water Management District (SWFWMD) to include Townships 28 and 29, Ranges 21, 22 and portions of 20, lies between the cities of Tampa and Plant City, Florida (Figure 1).

It is an agricultural area historically devoted to growing strawberries and citrus. This East-Central portion of Hillsborough County is experiencing an intensification of these pursuits as well as the spread of urban sprawl. One result of this increased land use is a large rise in use of ground water. Consumption is high and extremely variable. Agricultural water users account for most of the water use with peak irrigation periods for setting fruit, and frost and freeze protection. The total, average-annual, permitted agricultural water-use in the Dover area is 26 MGD with a maximum daily withdrawal of 286 MGD. Production from 412 permitted wells and 24 surface withdrawals, believed to be used during setting periods and freezes is estimated to be 300 MGD. The large number of production wells located in a relatively small area create problems during freeze conditions. Common problems are shallow wells going "dry", well water becoming cloudy, pumps failing and sinkholes developing. These problems result from reduction of the Floridan aquifer's potentiometric surface.

The freeze of January 1985 was particularly demonstrative of the area's problems. The synergetic effect of increased withdrawal rates, unseasonally low water levels, and severity of low temperatures produced record lows in the potentiometric surface. Sinkholes, well problems and water shortages were recorded in record numbers during the three day freeze. Similar problems were observed in 1983, 1981, 1979, and 1977.

The Dover Area has special well construction stipulations for wells with diameters of 6 inches or larger, which were implemented in 1981 by SWFWMD to alleviate well-related problems. The stipulations have not been successful in solving Dover's problems. Additional management and regulatory steps are needed to insure safe and beneficial use of the water resource.

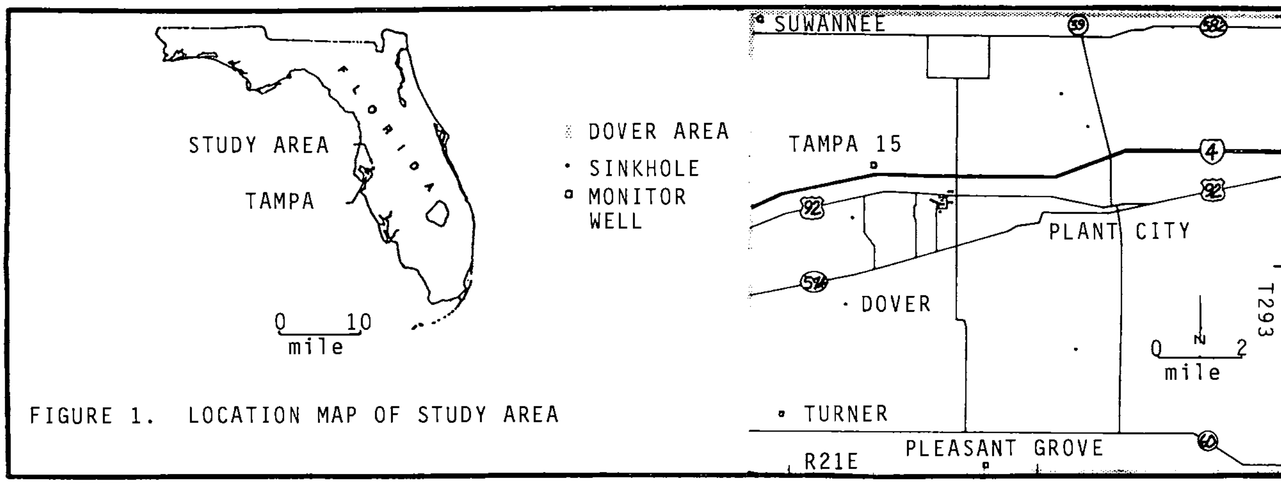

FIGURE 1. LOCATION MAP OF STUDY AREA

Background

The Dover Area, 39,600 hm^2 (98,000 acres), is mostly agricultural with some urbanization encroaching along the major roads. Of the 4,500 hm^2 (11,000 acres) in this area permitted for agricultural use, 2,400 hm^2 (6,000 acres) have permitted frost and freeze protection (Consumptive Use Permit Files (CUP), 1985). Approximately 1,600 hm^2 (4,000 acres) of strawberries, 688 hm^2 (1,700 acres) of citrus and 121 hm^2 (300 acres) of nurseries have freeze irrigation systems. The estimated distribution of permitted pumpage used during a freeze is centered south of Dover (See Figure 1). The peak withdrawal rate averaged over the entire area is 3064 GPD/acre, but occurs only during freeze conditions which are normally during night hours and rarely last more than five consecutive days.

Winters have a good combination of cool temperatures to reduce agricultural pest problems but mild temperatures to keep freeze damage to a minimum. To protect against occasional freezes, farmers pump warm groundwater onto their crops, using the water's latent heat to keep the plants alive. Strawberry plants are kept alive by being insulated with a layer of ice to maintain a constant 0 C (32 F). Citrus trees are protected by having ground water applied around their roots.

The recent past has been climatically unusual for the Dover area. Of the past 5 years, 4 have been abnormally cold. The past two years have had 100-year freezes with the January freeze of 1985 being one of the worst freezes ever reported. The January 1985 freeze was a record cold snap for that time period because it was an advective freeze. Wind chill is much worst from an advective freeze. Freezing temperatures recorded for the early mornings of the 21st, 22nd and 23rd are record lows of -6.7 C (20 F) and -5.6 C (22 F) for the 21st and 22nd, respectively.

Water Levels

The potentiometric surface of the Floridan aquifer in the Dover Area ranges from 30.5 m (100 ft) to less than 6 m (20 ft), National Geodetic Vertical Datum (NGVD). The direction of ground-water flow is from northeast to southwest with a steepening gradient in the west. The United States Geological Survey (USGS) has four monitor wells within or nearby the Dover Area. Tampa Deep Well No. 15, Turner Well, Suwannee Well and the Pleasant Grove Well continuously record water levels in the Floridan (See Figure 1). For the period of record (1958 to present), the Tampa Deep Well No. 15 has a high-maximum water level of 21.92 m (71.91 ft) NGVD, and a low-maximum of 14.26 m (46.77 ft) NGVD. Likewise, the Turner Well (1963 to present) has a high and low of 7.13 m (23.40 ft) and 3.31 m (10.87 ft) NGVD, respectively.

The range in extremes of recorded levels at the Tampa Deep Well No. 15 has increased in recent years due to low levels set during freeze situations. Hourly water levels of 13.11 m (43.25 ft) on January 23, 1985, 13.43 m (47.34 ft) on December 27, 1983, and 14.85 m (48.72 ft) on January 13, 1981 are noted. Hydrographs from the Tampa Deep Well No. 15 and thermographs from the Dover Research Center recorded during past freeze events are compared in Figure 2.

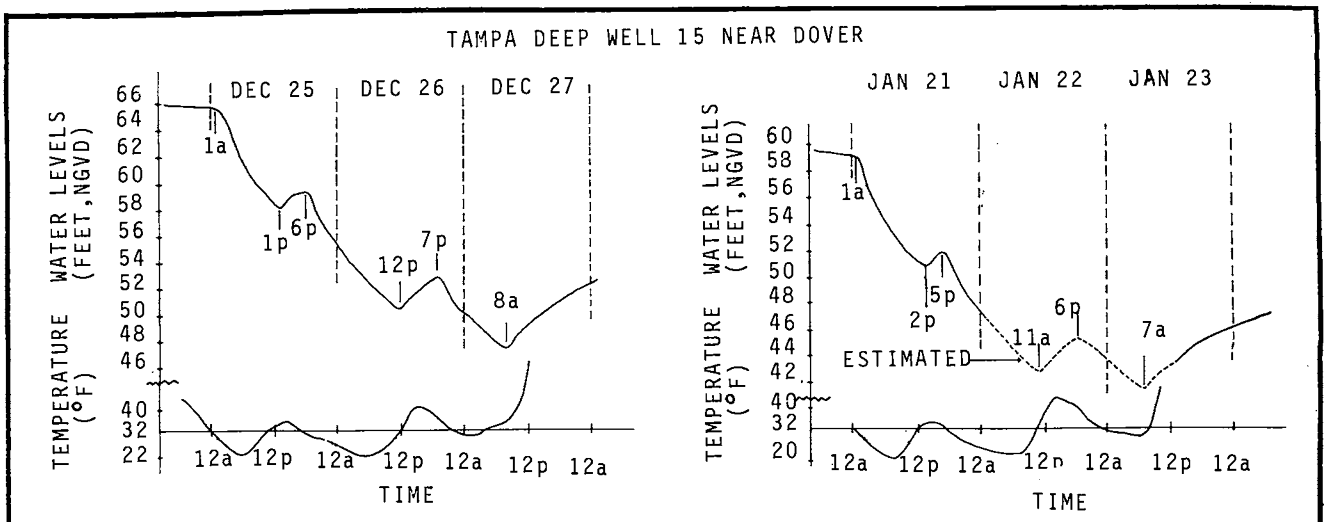

FIGURE 2. 1983 and 1985 FREEZES RECORDED ON HYDROGRAPH AND THERMOGRAPH

Hydrogeology

The surficial aquifer consists of sands and sandy-clays of undifferentiated Holocene and Pleistocene deposits. Its thickness varies due to the sporadic presence of peat and clay lenses. From the top of the water table to the first consistent confining unit, aquifer thickness ranges from 4.7 - 15.2 m (15 to 50 ft). Shallow wells yield 0.003 - 0.006 m^3/s (50 to 100 GPM) from this aquifer as transmissivity values can be less than 186 m^2/s (2,000 GPD/ft).

Near the bottom of the surficial aquifer, clay content increases. Phosphate nodules, waxy-clay stringers, and dense colloidal-clay lenses are found interbedded with sandy-clays. This unit is the Bone Valley Formation (Pliocene/Miocene). Much of this material is reworked with sandy-clays of the underlying Hawthorn Formation (Miocene) and makes complex and inconsistent lithologies. The complex and variable interbedded layers of the Hawthorn Formation create varying degrees of competency with different load-bearing capabilities, shrink-swell ratios and cohesivenesses. At an average depth of 19.8 m (65 ft) below land surface the lower Hawthorn Formation consists of limestone and dolostone. This unit is also interbedded with layers of carbonate clay, olive-green clay, phosphate and chert nodules. Portions of the lower Hawthorn can be sufficiently confined above and below such that an artesian system is present. Generally, the entire interbedded sequence of the Hawthorn Formation is an aquiclude of the Floridan aquifer.

The Floridan aquifer underlies the Hawthorn Formation at approximately 30.4 m (100 ft) below land surface. A marker bed of chert is used to delineate the top of the Tampa Formation, which is the top stratigraphic unit in the Floridan aquifer. The Tampa Formation has as an irregular, eroded surface and extends an average of 23 m (75 ft) to depths of 55 m (180 ft) below land surface. The formation is a micritic, moldic, sandy limestone unit. Underlying this unit is the Suwannee Formation (Oligocene) which is a massive homogeneous limestone. Wells which have their production zone in the Tampa or Suwannee yield approximately 0.012 m^3/s (200 GPM). The Ocala and Avon Park Formations follow in the stratigraphic sequence with 152 to 274 m (500 to 900 ft) of limestone and dolostone. The limestone varies from a calcilutite to coquina. The Avon Park can be highly fossiliferous and has some dolomitic layers. Wells cased below the Suwannee Formation, 61 to 91 m (200 to 300 ft) below land surface and produce from the Ocala and or Avon Park, yield in excess of 0.06 m^3/s (1,000 GPM) as transmissivity values can exceed 18,580 m^2/s (200,000 GPD/ft).

The prevalence of fractures and joints in the limestone is not unique to Florida geology. LANDSAT imagery (Littlefield, et al., 1984) shows many large photolinears passing through the Dover Area. The photolinears are related to surface expressions of fractures, or changes in soil types, vegetation, soil moisture, surface sags or depressions, or alignment of streams and valleys. Littlefield et al. indicates that areas with major lineament intersections have the greatest probability of sinkhole development (1984).

Discussion

Observed Impacts

A review of 3,200 SWFWMD well-construction permits issued for the Dover Area indicates 85% are domestic wells, 11% are agricultural (7% used for freeze protection) and 3% are for public supply. Wells with 4-inch diameters are the most common with 69% of the total. They have an average depth between 49-61 m (160 and 200 ft) and an average casing depth of 38 m (125 ft). Twenty-four percent of the wells are 2-inch in diameter and generally are the wells which experience problems during freeze conditions. Wells with centrifugal pumps stop functioning once water levels drop 7.6 m (25 ft) below land surface. The pumps lose suction and often burn out. Wells with jet pumps and insufficient drop pipes also have difficulties.

Although previous warnings and recommendations have been given by SWFWMD, insufficient or improper well design remains the primary reason for well-related problems. Of the 350 complaints logged by SWFWMD staff during the January 1985 freeze, most complaints from Dover residents are of this nature.

Irrigation pumpage during the January freeze created an extreme lowering of the potentiometric surface. The water level was lowered an estimated 5.2 m (17 ft) in Tampa Deep Well No. 15 during the three day freeze. Besides well problems, the lowered potentiometric surface was responsible for inducing 27 sinkholes. The majority of sinkholes occurred around the U.S. 92 - Tanner Road intersection on the night of the 22nd and morning of the 23rd. A few sinkholes were reported opening on the 24th and one occurred two weeks later, on February 4, 1985. Sinkholes were reported from the MacIntosh - Sheffield intersection area, near Juanita, Forbes and Sam Allen Roads, and near Trapnell Elementary (See Figure 1).

The reported sinkholes are cover-collapse sinkholes (Sinclair, 1982), meaning they occur rather quickly. Subsurface cavities allow the weight of the overburden to cause collapse, once the buoyant force of the water or water pressure is reduced. The cavities are related to irregularities in the top of the Tampa Formation, inconsistencies of clay layers in the Hawthorn Formation and/or to vertical fractures. With change in water levels or water pressure, spalling of clay layers progate a downward movement of material to fill the cavities and cause land subsidence or sinkholes at the surface. The mounding of the water table from freeze irrigation coupled with the reduction of the potentiometric surface in the Floridan aquifer accelerates the process. The range in size of reported sinkholes is 0.6 to 23 m (2 to 75 ft) in diameter, with an average of 6 m (20 ft). Depths range from 0.6 to 7.6 m (2 to 25 ft). Eight sinkholes near the US 92 - Tanner Road intersection are aligned in a northwest direction, a common fracture orientation.

Recorded water-level data from the surficial aquifer during the January 1985 freeze was not available. Unofficial reports, well-owner complaints and scattered field observations indicated the water table was impacted only in localized areas. In some areas drawdown was noted, while in other areas run-off created flooding problems.

Simulated Impacts

To quantify the effects of the January freeze on the potentiometric surface, a computer model of the Dover Area is used to simulate the ground-water impact. A two-layer, isotropic, transient, stress-type model is produced with a quasi-three-dimensional, finite-difference ground-water flow model (McDonald and Harbaugh, 1984). A 35-hour period of estimated withdrawal is simulated to determine the drawdown effects on the aquifer system. Aquifer characteristics used in the simulation are derived from pumping tests by the USGS and Florida Bureau of Geology (Stewart, et al., 1978). The modeled drawdowns (Figure 3) are compared with measured water-level declines in four monitor wells located in the modeled area. An average-absolute error of 1.5 feet is determined by comparing daily hydrograph lows from Tampa Deep Well No. 15, Turner Well, Suwannee Well and Pleasant Grove Well with appropriate flow-cell locations in the model. Superimposing the simulated drawdowns onto the September 1984, Floridan potentiometric-surface map (Barr, 1984), a simulated-stressed potentiometric-surface map is produced (Figure 4). The actual potentiometric surface during the peak withdrawal must look somewhat different, because prior to the freeze the potentiometric surface was lower than in September 1984 and the computer model does not account for a regional flow gradient. However, the extent of impact, in relative terms, is illustrated by the simulation. Maximum drawdown for a quarter-square mile cell simulated by the model is 40 feet. Simulations with smaller grid intervals indicate drawdowns of 55 feet. Hall and Metcalf (1978) have calculated drawdowns between 50 and 60 feet that occurred during a 1977 freeze. Areas which had more than 6.1 m (20 ft) of simulated drawdown are coincident with areas of reported sinkholes.

The computer model indicated minimal effects to the water table, however, no pumpage or recharge is simulated in the surficial aquifer. Consequently, no water table mounding or significant drawdowns are observed. Induced recharge through the semi-confining unit from leakage does create a small amount of drawdown in the surficial aquifer.

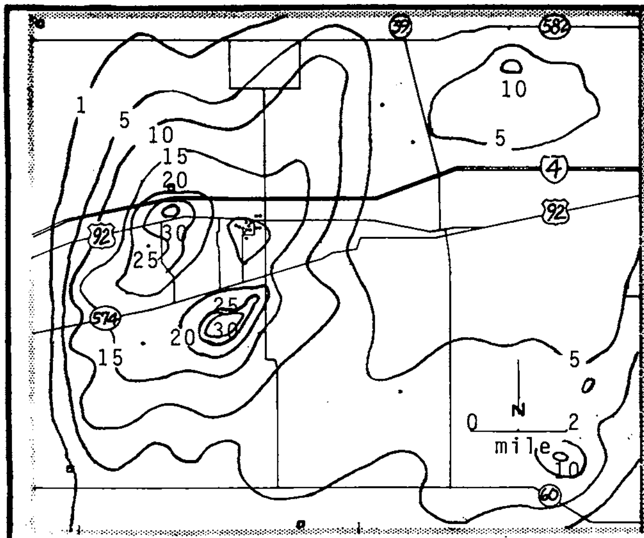

FIGURE 3. DRAWDOWN OF POTENTIOMETRIC SURFACE AFTER 35 HOURS OF PUMPAGE(CONTOUR INTERVALS IN FT.)

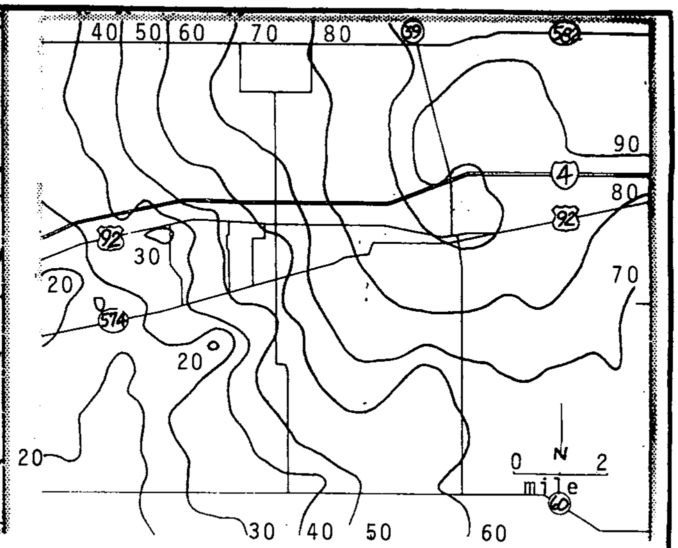

FIGURE 4. ESTIMATED POTENTIOMETRIC SURFACE OF FLORIDAN AQUIFER AFTER 35 HOURS OF PUMPAGE(CONTOUR INTERVAL-10 FT.)

Over 2,200 well logs (SWFWMD well construction files, 1985) are utilized to develop a topographic map of the top of the first-carbonate layer. The surface is compared with simulated water levels to determine if dewatering of the Floridan aquifer may have occur during the freeze. Due to the nature of the data, averaging effects, and approximation of the potentiometric surface, specific areas of dewatering is not determined. Localized dewatering related to fractures is recognized as a possibility but is not depicted. Areas which have the greatest simulated drawdowns also have the thickest confining units.

The computer model is calibrated against hydrographs of only four monitor wells and is not a verified model. Thus, simulation results are considered to give only the relative magnitude of impacts over the area. The model shows a regionally extensive area affected by withdrawals, and areas with large simulated drawdowns (>20 feet) correspond with areas which actually experienced well problems and/or developed sinkholes. Heavily impacted areas generally coincide with areas having the thickest confining layers.

Conclusions

Withdrawals for frost/freeze and plant-setting irrigation from the strawberry growing industry have a significant impact on the potentiometric surface of the Floridan aquifer in the the Dover Area. Fortunately, these events occur only occasionally and are of short duration. Problems associated with these withdrawals include: failure of domestic wells/pumps; sinkhole formation; flooding from irrigation runoff. The first and major problem of pump failure can be alleviated considerably with proper well construction. Recommendations on well design and construction from SWFWMD need to be clearly communicated to local residents and well drillers or more specific stipulations be placed on all well construction permits in this area. Surface-water engineering may solve some local flooding problems. Tailwater recovery systems for large irrigation fields are being studied by SWFWMD as a solution to excessive run-off. Tailwater recovery may also reduce ground-water withdrawals by recycling return water. The problem of sinkhole inducement is a potentially serious problem in terms of property damage and safety. Legal and economic issues make the hydrogeologic problems even more difficult. Reduction of intense ground-water withdrawals would reduce the occurence of sinkholes in this area. Drip irrigation systems can reduce water use and are being investigated by local grower's associations and SWFWMD to determine if such systems are applicable.

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