GROUNDWATER CONTAMINATION IN THE CORTARO AREA, PIMA COUNTY, ARIZONA

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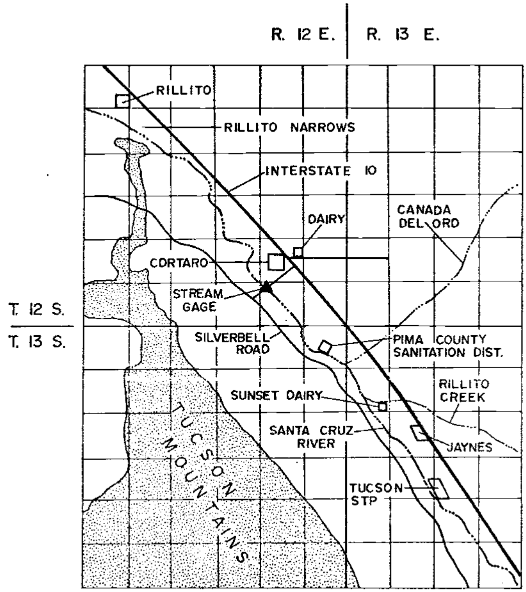
INTRODUCTION

High concentrations of nitrate have been periodically found in water samples from wells north of the City of Tucson Sewage Treatment Plant. Cortaro, Arizona, is about 6 miles north of the plant and 5 miles south of the Rillito Narrows (Figure 1). The Cortaro Area is bounded on the south by the confluence of Canada del Oro with the Santa Cruz River, about 2 miles south of Cortaro. The Tucson Mountains lie to the west and are a complex assortment of volcanic rocks. The igneous and metamorphic sequences of the Tortolita and Santa Catalina Mountains bound the Cortaro Area to the east. The northerly boundary is where a shallow bedrock constriction occurs in the subsurface, a locality known locally as the Rillito Narrows.

Most of the Cortaro Area is within the floodplain of the Santa Cruz River, an ephemeral stream which passes northward through the Tucson Basin. The average rainfall is about 11 inches per year, much of which occurs during summer convective storms. Farming had commenced in the area by the turn of the century and was accentuated in 1920. Shallow water levels ranging from 30 to 50 feet in depth and excellent well yields resulted in a



LOCATION MAP OF CORTARO AREA

Figure 1.

substantial agricultural development. The Cortaro Water Users Association (CWUA) was formed in later years and has continued operation to the present. The CWUA owned and operated about 25 active irrigation wells in the Cortaro Area in 1971 and the annual pumpage was about 18,000 acre-feet. More than 15,000 acre-feet of this water was exported out of the Cortaro Area via canal for agricultural use in the Marana area north of Rillito Narrows. Under natural conditions, the Cortaro Area had perhaps the most favorable groundwater characteristic in Arizona.

In recent years, groundwater contamination has been observed in the Cortaro Area, from both chemical and bacteriological aspects. However, no published, detailed study of groundwater quality has been accomplished in this area. It is the purpose of the author to explore the possible sources of groundwater contamination, the extent of the contamination, and the relation to future water resources management in the Tucson Basin. In the light of more knowledge on the technical aspects of the effects of disposal of Tucson sewage effluent, more optimal decisions can be made by water resource managers in the future.

TUCSON SEWAGE EFFLUENT

The Tucson Sewage Treatment Plant consisted of a primary treatment plant prior to 1951, when the first of three secondary plants was constructed. The present plant includes two activated sludge units and one trickling filter. The volume of sewage effluent from this plant was 2,800 acre-feet in 1940, 4,600 acre-feet in 1950, 16,300 acre-feet in 1960, and 33,000 acre-feet in 1970 (DeCook, 1970). Prior to 1951 most of the effluent was used for crop irrigation near the treatment plant, and excess volumes were percolated into the Santa Cruz River channel. A contract was finalized in 1955 with local farmers for the use of all the sewage effluent not used for irrigation at or near the plant. The excess effluent was used to irrigate about 1,500 of 2,100 irrigable acres near Cortaro from 1955 to 1970. The amount of effluent used on cropland near Cortaro was estimated to be

5,000 acre-feet in 1956, 8,000 acre-feet in 1960, 10,000 acre-feet in 1965, and 12,000 acre-feet in 1969.

As larger amounts of sewage effluent became available, increasing volumes were percolated in the Santa Cruz River channel. An estimated 2,300 acre-feet were percolated in 1956, 5,100 acre-feet in 1960, 9,200 acre-feet in 1965, and 16,800 acre-feet in 1969. Matlock (1966) found an infiltration rate of about 2 feet per day in the river channel between the treatment plant and Cortaro Road (6.3 miles). Use of the effluent for irrigation in the Cortaro Area was halted in October, 1970. Thus, in 1971 more than 90 per cent of the sewage effluent was percolated into the Santa Cruz River channel. From 1969 to 1971, the amount of effluent disposed of in the channel almost doubled, from about 17,000 to 32,000 acre-feet.

OTHER SOURCES OF CONTAMINATION

Because of the excellent aquifer characteristics and low natural contents of dissolved solids in the groundwater, little chemical contamination has occurred except for nitrate. The city treatment plant serves all of Tucson south of Rillito Creek and west of Pantano Wash, whereas the Pima County Sanitation District, or Ina Road, treatment plant serves the Canada del Oro, Catalina foothills, and Tanque Verde areas. The Ina Road plant consists of sewage lagoons near the Santa Cruz River north of Canada del Oro. About 500 acre-feet of effluent were produced in 1970, however, upon completion of a large interceptor in 1972, the volume will increase to about 5,600 acre-feet per year.

A sanitary landfill is in the same area as the county treatment plant and is a potential source of nitrogen compounds. A meat-packing plant and several dairies are also in the Cortaro Area. Several small housing development and the KOA Campground have septic tank disposal systems. Anhydrous ammonia is widely used from March through June on the farmland of the area. Despite these and natural sources of nitrogen compounds in the Cortaro Aria, City of Tucson sewage effluent is the primary source of nitrogen forms.

GEOLOGY AND HYDROLOGY

The thickness of alluvium ranges from less than 200 feet near the edge of the valley to about 600 feet in the central part beneath the present-day river. Five miles north of Cortaro, a bedrock constriction acts as a barrier to groundwater movement. This barrier produces relatively shallow groundwater levels, which range from 80 to 120 feet in depth. Water levels declined from 1920 to about 1965. However, water levels have stabilized or slightly risen since 1965 due to the increasing volume of sewage effluent recharge. Water level measurements in 1972 for the CWUA wells indicated an average rise of nearly three feet per year. The direction of groundwater movement is to the northwest. Wilson and DeCook (1968) studied infiltration of runoff in the Santa Cruz channel at a site one mile south of the Tucson sewage plant. Results indicated that about one-third of the recharged water reached the water table almost instantaneously, whereas slow drainage of the remainder from the unsaturated zone took up to 6 months.

A flownet, chemical analyses, and water temperatures at the well discharge suggest two distinct sources of groundwater. Groundwater in the eastern portion is from Canada del Oro underflow, mountain-front recharge from the Tortolita and Santa Catalina Mountains, and infiltration of Canada del Oro streamflow (Davidson, 1970). Groundwater in the western part of the Cortaro Area is from Santa Cruz River underflow, underflow of percolated sewage effluent, and infiltration of Santa Cruz River streamflow and sewage effluent. Sewage effluent formerly applied for irrigation in excess of crop requirements has also been a significant source of recharge. A rough water balance calculation shows that by 1965, an approximate balance of input and output to the groundwater was in effect, with about 35,000 acre-feet of input. Transmissibilities are high in the Cortaro Area, averaging about 350,000 gallons per day per foot for short-term pump tests run on CWUA wells in 1966. These excellent aquifer conditions minimize the effects of contamination from sewage effluent and other sources.

REGIONAL NITRATE AND CHLORIDE DISTRIBUTION

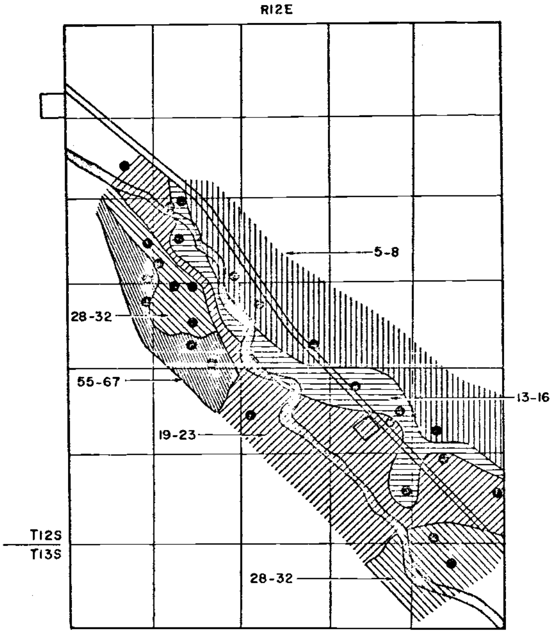
The Agricultural Engineering Department, University of Arizona, collected water samples for chemical analysis in June and October of 1970 and 1971 from many wells in the Cortaro Area. Cluff, DeCook, and Matlock (1971) discussed some of the analytical results for 1970 and suggested the complexity of assessing the nitrate situation. The areal distribution of nitrate shows several groups of wells with contents over 45 parts per million (ppm), or the U.S. Public Health Service limit recommended for potable water. One large area with nitrate exceeding 45 ppm in the groundwater was beneath farmlands surrounding the Tucson Sewage Treatment Plant, where sewage effluent has been used for irrigation for many decades. Laney (1970) had previously noted the relation of high nitrate to farmlands where sewage effluent was used for irrigation. A large holding pond (near Ruthrauff Road) which was used as part of the sewage effluent distribution system also occurred above the high nitrate zone. Two other localities with nitrate contents over 45 ppm were near Cortaro where sewage effluent was formerly used for crop irrigation. Nitrate contents greater than 25 ppm generally occur in groundwater beneath the Santa Cruz River floodplain, except near the confluences of Rillito Creek and Canada del Oro with the main channel.

Chloride is perhaps an ideal tracer in the environment due to its mobility in the groundwater, the low content in natural groundwater, and the abundance in sewage effluent. Chloride contents clearly demonstrate the influence of sewage affluent on groundwater of the Cortaro Area. Contents over 90 ppm occur for at least 3 or 4 miles downgradient from the Tucson Sewage Plant and reflect the movement of sewage effluent percolated from farmlands and the large holding pond near the plant and from the Santa

Cruz River channel. Chloride contents greater than 90 ppm also occur beneath farmlands formerly irrigated with sewage effluent near Cortaro. The average chloride content of sewage effluent from the City of Tucson treatment plant has ranged from 80 to 90 ppm in recent years. The distribution patterns for nitrate and chloride do not exactly follow the present-day channel of the Santa Cruz River, and suggest that the percolated effluent follows high transmissibility zones in the aquifer.

SAMPLING OF LARGE-CAPACITY WELLS

Sampling of shallow wells of low yield often reflects local conditions, such as nearness to septic tank disposal systems, rather than the gross water quality of the aquifer. In order to understand the gross aquifer characteristics, one should sample large-capacity wells which have been pumping for several weeks or months. Twenty large-capacity wells operated by the CWUA were sampled monthly by the author during the 1971 and 1972 irrigation seasons. Hach field test kits were used for nitrate (cadmium reduction method) and chloride (Mohr titration) determination. Water temperature and electrical conductivity were also measured. Results for nitrate showed that these wells could be grouped according to the average contents measured (Figure 2). The lowest nitrate wells (5-8 ppm) were to the northeast and the highest nitrate wells (55-67 ppm) were to the west. This distribution is related to three primary factors: (1) the regional direction of movement of groundwater in the area; (2) the occurrence of



AVERAGE NITRATE(PPM) FOR CORTARO WELLS
1971-1972

Figure 2.

lands formerly irrigated with sewage effluent; and (3) well construction.

Wells with nitrate contents exceeding 55 ppm were in the western part of the Cortaro Area, where dilution by low nitrate water from the east does not occur. As Davidson (1970) noted, there is no mountain-front recharge from the Tucson Mountains to the west. These wells are thus primarily affected by underflow from the Santa Cruz River and infiltration of excess applied sewage effluent for irrigation. All wells with nitrate concentrations exceeding 55 ppm had the top of the perforated casing within 50 feet of the land surface. Percolating water can enter these wells above the water table, because the present-day level averages about 100 feet in depth. This cascading water acts as a short circuit and can substantially reduce the ordinary travel time of water from the land surface to the water table. The same group of wells do not penetrate more than 150 feet of the aquifer, and thus tend to sample relatively shallow water. The shallow groundwater tends to have higher nitrate contents because the primary nitrogen sources are at the land surface.

CHEMICAL HYDROGRAPHS

Chemical hydrographs were prepared for all wells for both nitrate and chloride. These hydrographs can reflect many parameters. The total nitrogen content of sewage effluent is variable seasonally and from year to year. The total nitrogen content of sewage effluent from Plant No. 1, an activated sludge unit, averaged 20 ppm in 1971, with a maximum of about 40 ppm in the spring and a minimum of 10 ppm in the fall. The total nitrogen decreased from 30 ppm in 1969 effluent to 25 ppm in 1970 and 20 ppm in 1971, apparently due to decreases in the influent total nitrogen (E. J. Trueblood, Tucson Sewage Plant, personal communication, 1971). A plot of the average nitrate and chloride for the CWUA wells sampled shows a direct relation (Figure 3) between the two anions. This relation is highly suggestive that sewage effluent is the primary source of both anions.

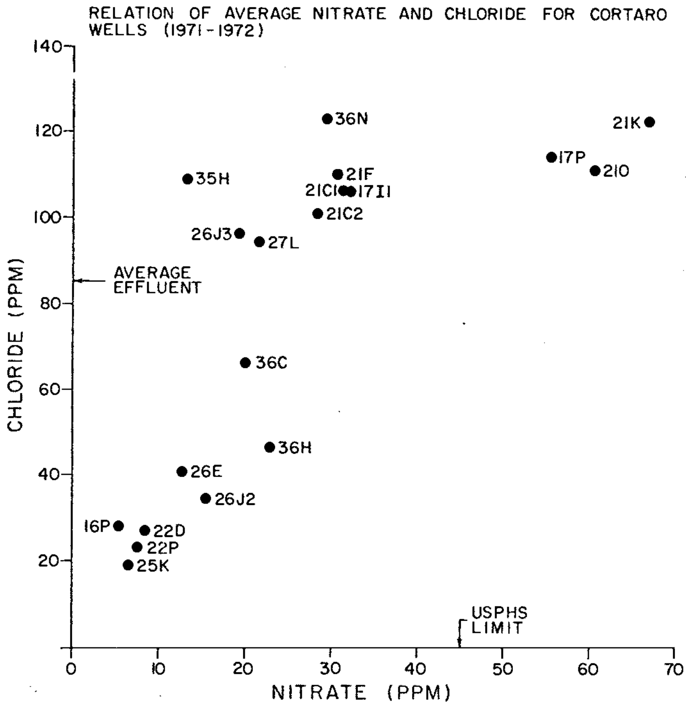


Figure 3.

Several well hydrographs demonstrated a seasonal nitrate pattern similar to that of total nitrogen in the effluent. However, several more years of record are necessary to confirm this relation. If this relation occurs, it indicates rather rapid infiltration of sewage effluent in the Santa Cruz River channel. Low nitrate and chloride contents in the fall for groundwater may be due to dilution by flood flows in the Santa Cruz River during July and August. Many wells show similar nitrate and chloride hydrographs, whereas others have opposite trends. As noted by

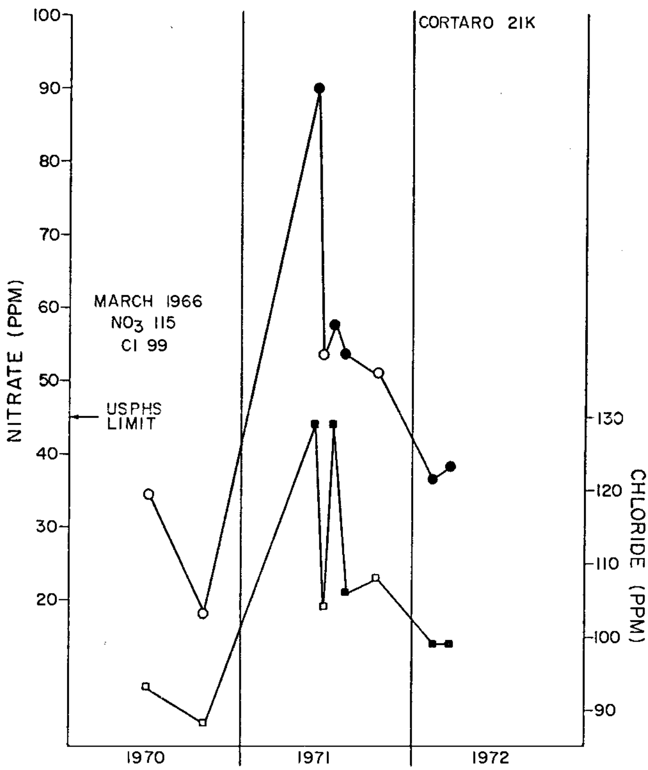

CORTARO 21K
NITRATE (PPM)
100
90
80
70
60
50
40
30
20
MARCH 1966
NO_3 115
Cl 99
USPHS
LIMIT
CHLORIDE (PPM)
130
120
110
100
90
1970
1971
1972

Figure 4.

Schmidt (1972) in the Fresno, California area, these opposite trends may be related to denitrification.

The most dramatic changes that occurred in 1971 and 1972 are related to the recent alterations in the method of disposal of sewage effluent. Wells with the highest nitrate contents have shown a rather uniform decline from about 90 ppm in May, 1971 to 35 ppm in April 1972 (Figure 4). Sewage effluent was removed from farmlands in this area in the fall of 1970. The remaining nitrogen sources would include agricultural fertilizers and sewage effluent in the Santa Cruz River channel. CWUA wells to the east, which have low nitrate and chloride contents, have shown increasing contents. Nitrate concentration for one well increased about 8 ppm per year and chloride about 10 ppm per year (Figure 5). This situation is likely due to the increasing volumes of sewage effluent percolated from the river channel north of Cortaro since 1970. The significance of other nitrate sources besides sewage effluent seems to be confined to within several thousand feet of the source, such as the dairy east of Cortaro.

SUMMARY

Based on available data, little contribution of nitrate from sources other than sewage effluent is apparent. Natural or background contents of nitrate are less than 5 to 8 ppm. Most of the high nitrate contents in water from large-capacity wells are related to farms where sewage effluent was formerly used for crop irrigation. After October, 1970, virtually all of the excess

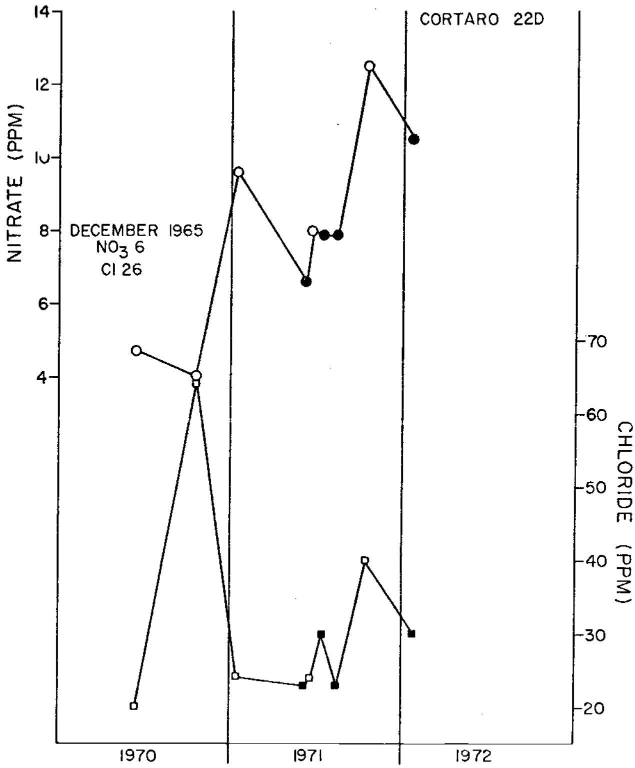

CORTARO 22D
NITRATE (PPM)
14
12
10
8
6
4
DECEMBER 1965
NO_3 6
Cl 26
CHLORIDE (PPM)
70
60
50
40
30
20
1970
1971
1972

Figure 5.

sewage effluent not used at or near the plant was disposed of in the Santa Cruz River channel. Data show decreasing nitrate contents in groundwater beneath lands where effluent was formerly applied for irrigation, and increasing contents for wells near the Santa Cruz River. Evidence suggests that a large amount of denitrification occurs when the sewage effluent percolates from the Santa Cruz River channel. This occurs in the reach south of Ina Road where the channel is narrow and continuously wetted. Anaerobic conditions favor the retention of nitrogen in the soil and nitrification may not occur. In the channel north of Cortaro, a periodic wetting and drying should favor nitrification. Measurements of nitrogen species content in the surface effluent suggest that little nitrification occurs south of Cortaro, but significant nitrification occurs near Rillito Narrows.

It is not yet clear if or when an equilibrium will be established for nitrate contents in groundwater of the Cortaro Area. However, current data suggest that the disposal of effluent in the Santa Cruz River channel may be viewed as a possible form of tertiary wastewater treatment. If large amounts of phosphate and nitrate are removed during percolation, as has been suggested in the Phoenix area by Bouwer, Lance, and Rice (1971), then recharged effluent could possibly be used for municipal purposes by the City of Tucson. Cluff, DeCook, and Matlock (1971) have suggested a transfer of sewage effluent to Avra Valley for irrigation use. Another alternative is herein proposed. The City of Tucson could develop the source of recharge by means of a well field along the Santa Cruz River, assuming legal complications could be resolved. The beneficial use of this water could be for recreation and municipal purposes with careful chemical and biological monitoring.

This study of groundwater nitrate will hopefully be eventually combined with studies of the surface effluent flow in the river by Sebenik, Cluff, and DeCook (1972) and specific studies in the unsaturated zone by L. G. Wilson (personal communication, 1971). In this manner, perhaps a true understanding of the effects of sewage effluent on groundwater of the Cortaro Area can be obtained before large-scale water management schemes are enacted. Present data suggest little contamination of the gross aquifer system, a situation primarily due to the excellent aquifer conditions. As the volume of sewage effluent greatly increases in the future, this situation will likely change.

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