EFFECTS OF THE GREEN VALLEY WASTEWATER TREATMENT FACILITY UPON GROUNDWATER QUALITY

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Abstract

The Green Valley Wastewater Treatment Facility (GVWWTF) is about 20 miles south of Tucson, Arizona. Locally, the aquifer consists of interbedded sands, silts and gravels. Depth to water near the facility is about 160 feet with transmissivity ranging from 32,000 to 48,000 gpd/ft. Ground water quality has historically been poor near the facility due to deep percolation of irrigation return flow. With the retirement of farm land, however, ground water quality has improved considerably. The only problem with well water downgradient of GVWWTF has been with total coliform where several samples exceeded public drinking water standards. Current inflow of about 1.1 mgd will increase to 4.5 mgd by 2005. Flow net and mass balance analyses indicate effluent recharge by percolation beds will increase from 1060 AF/year to 4130 AF/year during this period. A mass balance model predicts TDS will increase from about 585 to 615 mg/l, nitrate-N will increase from 9.2 to 9.9 mg/l, chloride will increase from 50 to 75 mg/l, and sulfate will decrease by 25 mg/l to 115 mg/l. Further study of pond disinfection for prevention of microbiological contamination is suggested. Additionally, effluent reuse and an enhanced monitoring program including upgradient and downgradient wells are encouraged.

Introduction

The purpose of this study was to evaluate the past, current and future impacts of the Green Valley Wastewater Treatment Facility (GVWWTF) upon the regional aquifer in the vicinity of the facility. The GVWWTF is about 20 miles south of Tucson, Arizona, near the northern edge of the community of Green Valley (Figure 1). The study area is bounded on the west and northwest by Interstate 19 and the community of Santo Tomas, on the north by Farmers' Investment Company's (FICO) pecan orchards and Val Verde subdivision, on the east by FICO irrigated land, and on the south by retired irrigated land owned by Anamax Mining Company.

Historically, the land immediately surrounding the GVWWTF was used for irrigated agriculture. In the mid-1960's Anamax Mining Company bought or leased and retired the property. Currently, the land is used for cattle grazing. The retirement subdivision of Green Valley was established in 1963. Most of the community was sewered at this time, and in December, 1964, Pima County constructed a wastewater treatment facility. The facility contained 2 ponds, and effluent was chlorinated before being discharged into the Santa Cruz River. A third pond was constructed in July, 1972.

During 1980 and 1981 the GVWWTF was expanded to accomodate increased flows. Sewage entering the plant now passes through two sets or aeration lagoons. The effluent then proceeds to holding ponds and finally flows into 4 percolation beds where the effluent infiltrates rather than being discharged to the Santa Cruz River.

Between now and 2005 pond inflow is expected to increase from 1.1 to 4.5 mgd. This study analyzes the historical and current data, and attempts to predict what effects the increased rate of effluent recharge will have on the regional ground water quality.

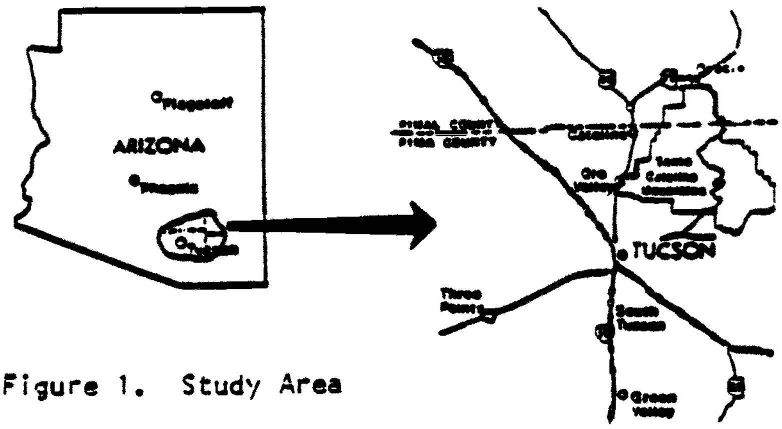


Figure 1. Study Area

Hydrogeologic Conditions Of The Study Area

The geology of the study area consists of, in descending order, surficial deposits, the Fort Lowell Formation, and the Tinaja Beds. These deposits are of fluvial and lacustrine origin (Davidson, 1973). The surficial deposits contain unconsolidated sediments ranging in size from coarse gravel to silt. Along the Santa Cruz River surficial deposits are very permeable. The Fort Lowell Formation consists of loosely packed to weakly cemented material ranging in size from silty sands to silty gravel. The formation is approximately 135 ft thick in the study area and has historically provided most of the ground water. The Fort Lowell Formation unconformably overlays the Tinaja Beds. The Tinaja Beds are finer grained than the Fort Lowell Formation. Only the upper 10 to 20 feet of the beds were penetrated by the new monitor wells drilled for this project.

The ground water flow-regime has changed since 1970. At that time water levels beneath the Santa Cruz River floodplain, near the GVWWTF, were 125 ft. below the land surface and declining at 4 ft/yr. A 1970 equipotential map shows that ground water moved northeast during this time. A 1981 equipotential map shows that ground water flow had shifted to the northwest and that a recharge mound was beginning to form beneath the GVWWTF. The shift in direction of ground water movement was probably due to mine pumpage to the northwest. The water levels in 1981 ranged from 160 to 180 ft. beneath the floodplain.

Currently, water levels are approximately 160 ft. below land surface beneath the floodplain. Due to wetter years and mine shutdowns there has been less agriculture and industrial pumpage. Thus, local water levels have recovered. Since the 1983 floods, water levels near the GVWWTF have risen by as much as 10 feet. Figure 2 illustrates the 1985 water levels and flow regime.

The regional aquifer near the GVWWTF is recharged by percolation from the treatment ponds and by streamflow infiltration. A water balance calculated pond recharge at about 1000 AF/year. The water balance estimated streamflow infiltration to be 600 AF/yr/mi. Osterkamp (1973), estimated streamflow infiltration to be 300 AF/yr/mi. The difference is due to the fact that the recent data reflect the impact of several relatively wet years and the flooding of 1983. Recharge from the ponds will increase as the volume of treated water increases. By 2005 pond recharge should equal approximately 4100 AF/yr.

Ground water is pumped for public supply, irrigated agriculture, industry, and livestock. Total pumpage in 1984 was approximately 3,000 AF, down 60 percent from the average between 1971 and 1980.

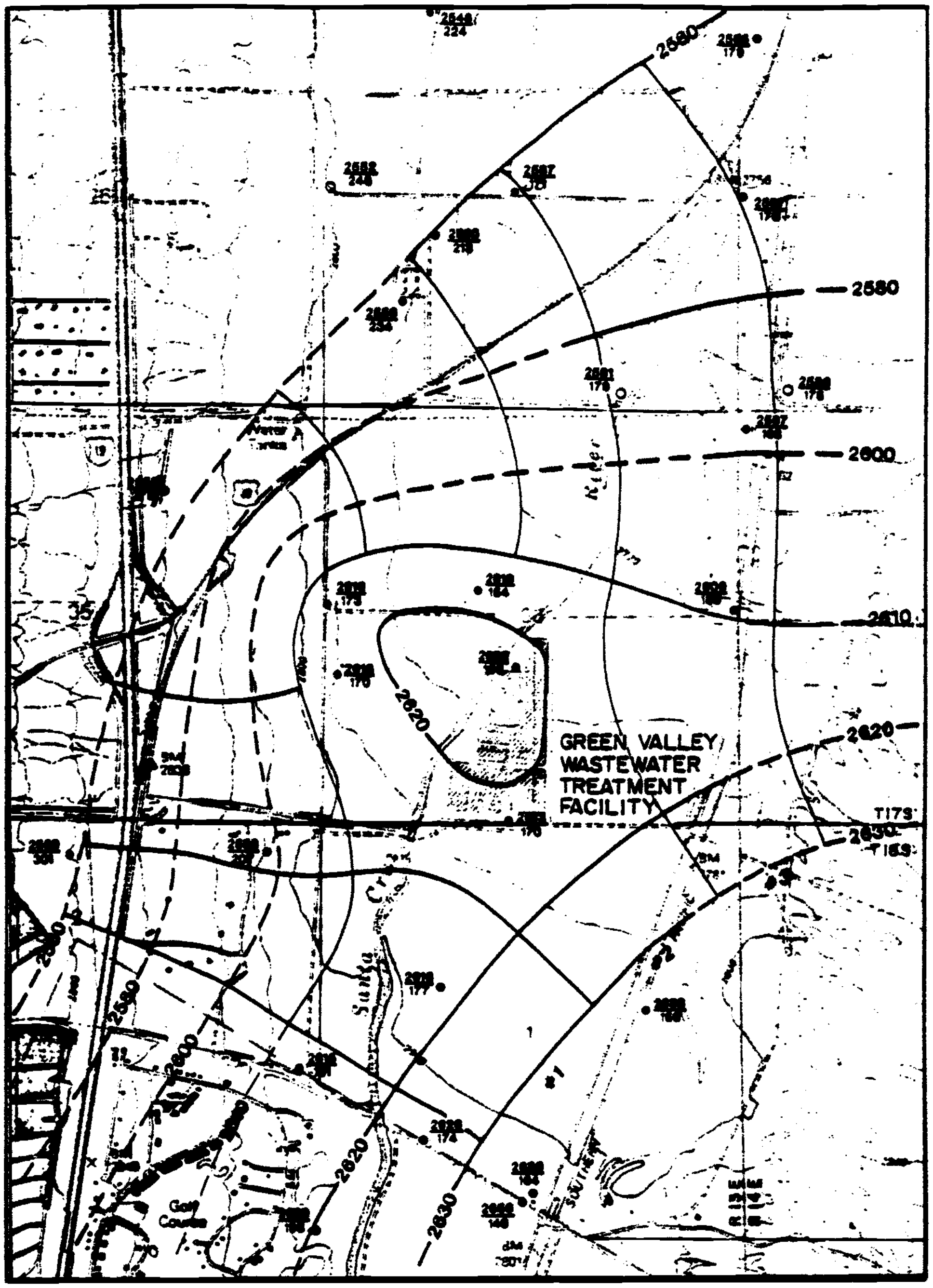
In early 1985 short term aquifer tests were conducted at two newly constructed monitor wells (MW-1 and MW-2) near the GVWWTF (Figure 3). Transmissivity values averaged 48,000 gpd/ft near MW-1 and 32,000 gpd/ft near MW-2. The higher value corresponds to the area closest to the river, where the alluivum is better sorted and contains less fine-grained material. These transmissivity values were used in the flow-net analysis.

Ground water velocities in the study area were calculated from permeability, porosity, and hydraulic gradient data. Permeabilities ranged from 650 to 500 gpd/ft^2; porosities ranged from .30 to .35; and hydraulic gradient ranged from 40 to 60 ft/mi. Thus, ground water velocities were calculated to range from 800 to 1200 ft/yr.

Methodology

The effects of the GVWWTF were assessed by combining water quality data with ground water flow data. First, a survey of wells that were available for water quality sampling was made. From the survey a water quality monitoring network was established (Figure 3). Next, two monitor wells, one immediately downgradient (MW-1) and one about a quarter a mile downgradient (MW-2) of the ponds were drilled. Then, historical water quality data were assembled to determine the water quality conditions before the GVWWTF was built, and a sampling program was established to determine current water quality conditions.

The sampling program collected data from existing wells, the two new monitor wells, two effluent ponds, and an aeration lagoon. The wells were tested for major constituents and those indicator constituents from



Green Valley Wastewater Treatment Facility Monitoring Study

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FIGURE 2 WATER LEVEL ELEVATIONS, 1984-85 WITH FLOW-NET STRUCTURE

- ● Well location with water level elevation (feet above MSL) and depth to water below land surface elevation
- ○ Well location (well depth >1500 feet and perforated interval >300 feet) with water level elevation (feet above MSL) and depth to water below land surface elevation
- —2600— Water level elevation contour (feet above MSL, dashed where inferred, bold contours are 20 feet intervals, lighter contours are 10 feet intervals)
- \| #1 \| Streamtube used for ground water flow calculation. (Note: Streamtube #2 is divided into subtubes to aid calculations.)

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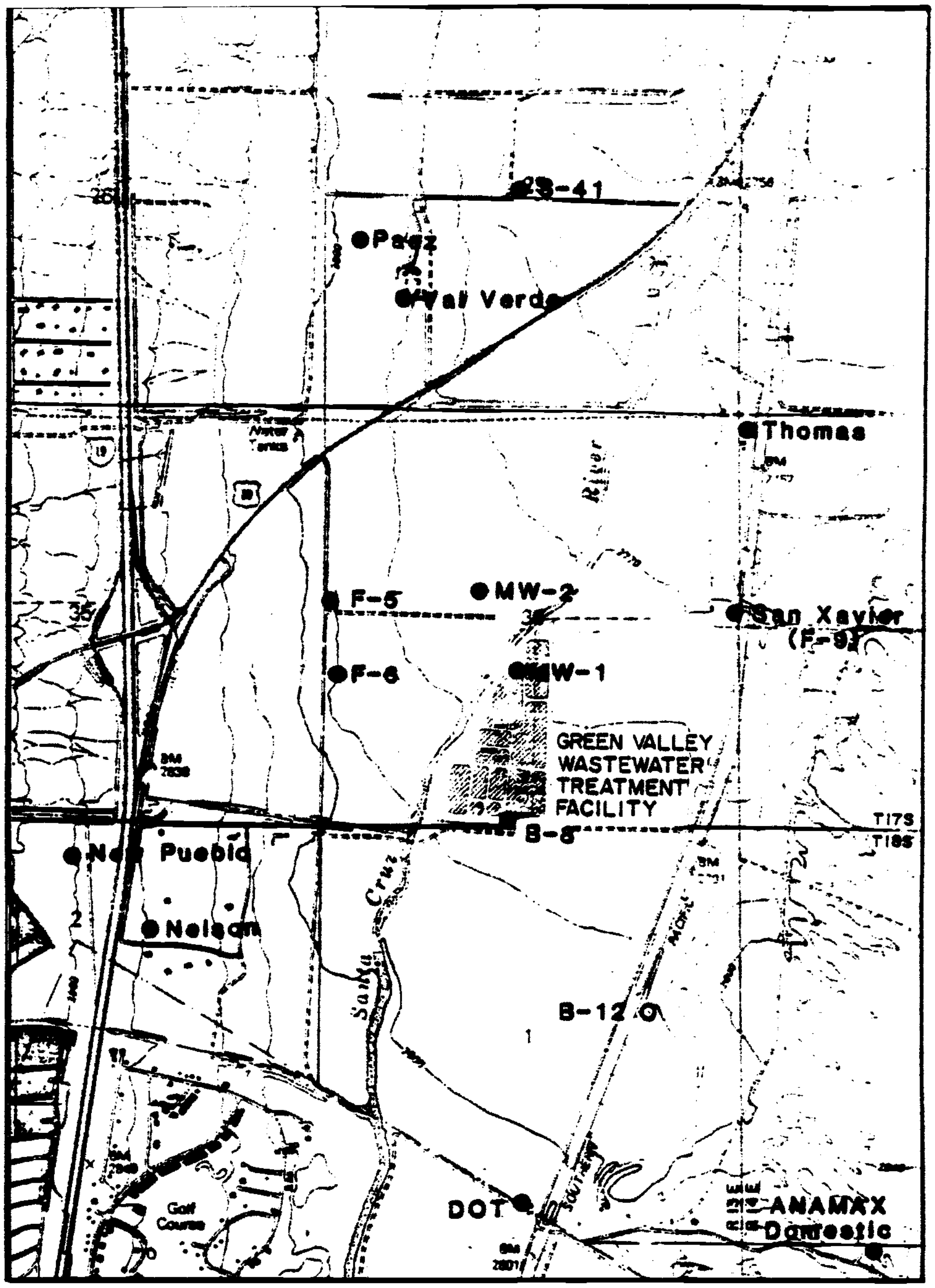

Green Valley Wastewater Treatment Facility Monitoring Study

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FIGURE 3. WELL LOCATIONS - WATER SAMPLING SITES

N

● Monitor - 3 ——— Well Name

\\———— Well Location

O Refers To Historical Water Quality Data Point which effluent pond water could probably be traced. Indicators include NO_3, Cl, TDS, fecal and total coliform bacteria, pthalate esters, enteric viruses, nitrogen isotopes, boron, and sodium. Sulfate also appeared useful in distinguishing between effluent recharge and irrigation return flow.

Water level data were collected from wells in the monitoring network. From the data a flow-net was constructed (Figure 2). The flow-net allowed ground water flow upgradient and downgradient from the GVWWTF to be calculated. Then, by combining the flow data, the water quality data, the river recharge data, and the pond recharge data, a mass balance model was calibrated. After calibration, the volume of pond recharge was increased by projected estimates from Pima County Wastewater Management (1985), and resulting downgradient water quality was predicted. The mass balance equation is as follows:

$$C_D V_D = CuVu + CrVr + CpVp$$

where C_D = Concentration of downgradient underflow, V_D = Volume of downgradient, Cu = Concentration of upgradient underflow, Vu = Volume of upgradient underflow, Cr = Concentration of river recharge, Vr = Volume of river recharge, Cp = Concentration of pond recharge, Vp = Volume of pond recharge. The mass balance model predicted future downgradient concentration of NO_3, Cl, SO_4, and TDS.

Evaluation Of Impacts Of GVWWTF On Groundwater

Historical Water Quality

During the 1940's and 1950's the land surrounding the GVWWTF was primarily used for irrigated farming. Between 1936 and 1949 active iriated acreage quadrupled from 300 acres to 1130 acres (Upper Santa Cruz Mines Task Force, 1983b).

Water samples from well F-5 (Figure 3) appeared representative of water outside the irrigated floodplain and natural background conditions. Around 1946 total dissolved solids (TDS) concentration was about 400 mg/l, sulfate was 66 mg/l, chloride was less than 20 mg/l, and nitrate was between 1 and 5 mg/l. Wells B-8 and B-12 were on irrigated land, and water samples from these wells contained high sulfate values of about 120 mg/l. Irrigated acreage doubled again in the 1950's and a corresponding increase in TDS occured.

The GVWWTF was constructed in 1963. Data from the mid-1960's show nitrate content in well water to be about 45 mg/l. This value probably reflects the impact of irrigation return flow, which was estimated to be about 3700 AF/yr, rather than effluent recharge, which was only about 460 AF/yr.

By the 1970's, TDS data from well water outside the Santa Cruz River floodplain was low (300 mg/l). Well water within the floodplain was elevated beyond 500 mg/l. Overall TDS ranged from 300 to 980 mg/l, sulfate from 35 to 300 mg/l, chloride from 14 to 80 mg/l, and nitrate from 1 to 100 mg/l. Note that elevated TDS concentrations occurred upgradient and downgradient from the GVWWTF. This suggests that irrigation return flow was more likely responsible than effluent recharge for the increase.

Percolation Pond and River Quality

Currently, the groundwater beneath the GVWWTF is mixture of effluent recharge, river recharge, and ground water underflow. Data from the GVWWTF percolation ponds suggest that nitrate, carbonate, bicarbonate, TDS, and pH are seasonably controlled (Table 1). Lower winter temperatures result in less algal growth and a corresponding reduction in nitrogen removal. Algal growth also controls pH chemistry which results in reduced carbonate and bicarbonate concentrations. The lower winter temperatures also reduce ammonia volitalization, thereby increasing total nitrogen content.

These effects indicate that in winter more nitrate is available for groundwater recharge than in summer. Estimates suggest that in winter 11-12 mg/l of total nitrogen are available, and in summer 5 mg/l of total nitrogen are potentially available for ground water recharge.

TDS concentrations in the percolation ponds ranged from 687 to 720 mg/l, with the higher values coming from summer data. Presumably, the increased summer evaporation concentrates TDS in the pond water. Pond data from 1981-82 showed TDS values to be about 600 mg/l. The increase in recent years was probably due to recent pond clogging which inhibits recharge and allows more evaporation. With regular pond maintenance to reduce clogging, TDS values should lower.

Chloride values from the percolation ponds ranged from 115 to 161 mg/l. Chloride is a good indicator for pond recharge because the natural concentration of chloride in ground water is much less than the pond concentration. Also chloride is mobile, relatively free of ion exchange, non-absorptive, and biologically inactive, all properties of a good indicator.

Microbiological data from February, 1985 show that fecal coliform, total coliform, and fecal streptococci exceeded 16,000 most probable number in 100 ml (MPN/100 ml). Pima County Wastewater Management Department began a pond chlorination treatment program for algae control in March 1985. By August, 1985 sampling results showed fecal coliform reduced to 96 MPN/100 ml, total coliform to 144 MPN/100 ml and fecal streptococci to 16 MPN/100 ml. Pond chlorination was still in effect as of October, 1985.

No enteric viruses were found in the pond water. This is probably

TABLE 1
CURRENT WATER QUALITY DATA FROM SAMPLING SITES NEAR
THE GREEN VALLEY WASTEWATER TREATMENT FACILITY

			Major ions, all concentrations in mg/l										General information (1)				
Location	Name	Date	Ca	Mg	Na	K	CO3	HCO3	Cl	SO4	NO3	B	pH-l	ec-l	TDS	C/A	Lab (2)
D(17,13)25caa	FICO 8-41	03/06/85					0.0		57.1		97.5	0.15	6.9	1110	800		BC Labs
D(17,13)25cbb	Paez Well	03/06/85					0.0		50.0		45.2	0.10	7.1	865	607		BC Labs
D(17,13)25cbd	Valle Verde	02/28/85	95.0	12.0	53.0	4.0	0.0	230.0	26.9	130.0	47.0	0.05	7.7	750	527	1.2	BC Labs
D(17,13)34add2	San Xavier M&G	02/02/85					0.0		76.6		60.2						BC Labs
		02/25/85	140.0	22.0	53.0	3.0	0.0	287.0	70.9	160.0	62.9	0.12	7.0	1025	693	0.9	BC Labs
		05/28/85					0.0		32.3		117.0	0.10			733		BC Labs
		08/21/85					0.0		25.9		97.5	0.10			715		BC Labs
D(17,13)36bcc	ANAMAX F-5	02/27/85	102.0	22.0	44.0	3.0	0.0	271.0	46.0	125.0	39.9	0.10	7.7	820	577	1.2	BC Labs
D(17,13)36bdd	G.V. Well #2	02/26/85	114.0	20.0	58.0	5.1	0.0	302.0	51.7	135.0	40.8	0.10	7.5	890	620	1.1	BC Labs
		05/28/85					0.0		59.6		39.9	0.10			613		BC Labs
		09/03/85					0.0		55.3		35.4	0.10			590		BC Labs
D(17,13)36caa	G.V. Well #1	02/28/85	159.0	28.0	53.0	4.1	0.0	443.0	106.0	90.0	37.2	0.10	7.4	1170	773	0.9	BC Labs
		02/28/85		25.0	51.0		0.0		111.0	97.0	36.9				678		Tucson Water
		05/28/85					0.0		87.9		26.6	0.10			790		BC Labs
		09/03/85					0.0		110.0		22.2	0.10			750		BC Labs
D(17,13)36cbc	ANAMAX F-6	02/25/85	93.0	16.0	44.0	4.1	0.0	280.0	32.9	100.0	30.1	0.10	7.7	750	533	1.7	BC Labs
		05/28/85					0.0		33.0		19.5	0.10			503		BC Labs
		08/21/85					0.0		25.5		20.4	0.10			455		BC Labs
D(17,13)36cd1	G.V. Aeration Lag 2a	02/13/85	43.0	6.4	129.0	16.0	10.2	321.0	111.0	75.0	12.4	0.40	8.4	1040	660	2.3	BC Labs
D(17,13)36cd2	G.V. Perc. Pond #1	09/23/81	29.5	5.5	154.0	16.4	88.6	16.5	147.0	78.0	0.9	0.46	10.0	930	540	1.1	BC Labs
		08/19/85					0.0		161.0		1.8	0.47			720		BC Labs
D(17,13)36cd3	G.V. Perc. Pond #2	02/27/85	43.0	8.3	135.0	15.0	0.0	328.0	115.0	85.0	4.4	0.44	8.4	1020	687	1.7	BC Labs
D(17,13)36cd4	G.V. Effl. Structure	05/28/85					0.0		152.0		0.4	0.40			720		BC Labs
D(17,13)36cdd	ANAMAX 8-8	02/15/85	73.0	10.0	57.0	3.6	12.0	196.0	13.0	115.0	31.9	0.32	8.4	660	447	0.9	BC Labs
		02/15/85	66.0	11.0		16.0	0.0		14.0	128.0	37.4				438		Tucson Water
D(17,14)31bbb	Thomas Well	02/28/85	112.0	19.0	49.0	3.3	0.0	266.0	28.3	145.0	75.3	0.08	7.8	860	610	0.6	BC Labs
D(18,13)01cdd	DOT Well	02/27/85	120.0	32.0	51.0	3.0	0.0	303.0	26.6	200.0	61.0	0.10	7.4	1150	720	0.6	BC Labs
D(18,13)02adb	Nelson Well	06/05/85					0.0		89.7		77.1	0.10			730		BC Labs
D(18,13)02bab	Old New Pueblo	03/06/85	40.0	6.0	35.0	3.2	0.0	184.0	6.0	40.0	1.8	0.10	8.1	410	273	1.3	BC Labs
D(18,14)07bab	ANAMAX Domestic	09/03/85					0.0		58.5		102.0	0.24			1150		BC Labs

Footnotes:
1) pH-l = pH, measured in the laboratory; ec-l = electrical conductivity, measured in the laboratory; TDS = total dissolved solids (mg/l)
C/A = Cation/Anion balance, obtained by dividing the difference between thetotal equivalent weights of anions and cations by the equivalent weights of anions
2) Laboratories:
BC Labs - Bakersfield, California;
Tucson Water - Tucson, Arizona;

due to chlorination and possibly the fact that an elderly population, such as that served by the GVWWTF, generally contains few enteric viruses (Gerba, 1985).

The percolation ponds were sampled for phthalate esters resulting in detection of 32 ppb of diethyl phthalate. VOC constituents and organics were undetected (Pima County Wastewater Management, 1984). Nitrogen isotopes were also sampled resulting in a $\delta^{15}N$ of 23.0, indicating a human origin (Gormly and Spalding, 1979). This value was much higher than the Santa Cruz River value of 7.6 and helps distinguish between the two recharge sources.

TDS content for Santa Cruz River water averaged about 200 mg/l, total nitrogen was about 5 mg/l, and the water was a calcium bicarbonate type (Laney, 1972; Upper Santa Cruz Mines Task Force, 1983b).

Indicators of Effluent Recharge

Chloride was probably the best indicator of effluent recharge during the study. Ground water immediately downgradient of GVWWTF (MW-1) showed a chloride content of 106 mg/l which indicates that a majority of this water was effluent derived. Further downgradient, effluent appears to be diluted by river recharge, and chloride content in these wells declines significantly. Effluent comprised about 25% of MW-2 (52 mg/l) based on mass balance calculations. San Xavier well (79 mg/l) may have received perched effluent moving laterally, but further study is needed to confirm this.

Nitrate in well water downgradient of the GVWWTF appears to be seasonally controlled, similar to pond data. Maximum pond loading occurs in the winter months, and the downgradient well was highest in nitrate during winter sampling. Nitrate concentrations downgradient of GVWWTF are below drinking water limits of 45 mg/l. Apparently, streamchannel recharge and processes such as ammonia volitilization, adsorption, and nitrification have diluted and reduced nitrate in well water near the GVWWTF. Other wells further from the GVWWTF along the floodplain were higher in nitrate, reflecting past irrigation return flows.

Fecal and total coliform were not identified in well water immediately downgradient of the GVWWTF (MW-1). This suggests that bacteria are removed in the normal process of percolation of chlorinated effluent. However, more data are necessary to determine if bacteria are completely removed during percolation of unchlorinated effluent.

An attempt to "fingerprint" fecal coliform bacteria found in San Xavier Rock and Gravel well (SX well) was made because it was suspected to have been affected by perched effluent which may have cascaded into the well. Twenty-nine bacteriophage were examined for their ability to lyse fecal coliform isolates from GVWWTF ponds, a nearby septic tank, and the SX well. By comparing no lysis or greater than 50% lysis for each phage it was found that there was a 52% similarity between the septic tank and the SX well, and a 27% similarity was found between the septic tank and percolation pond isolates. This suggests that the coliforms in the SX well may be related to the percolation ponds, although this evidence is inconclusive (Gerba, 1985). Another potential source, a wash was adjacent to the well also needs "fingerprinting" before final conclusions can be drawn.

Enteric viruses were not discovered in downgradient well water during the study. Further pond and well sampling for viruses is probably necessary when the ponds are not being chlorinated.

Flow-net and Mass Balance

A flow-net and mass balance analysis were used to predict the future water quality of the GVWWTF (Figure 2). By applying Darcy's Law, upgradient and downgradient underflow were calculated to be 2600 AF/yr and 4200 AF/yr, respectively. Pond recharge and river recharge account for the 1600 AF/yr difference, as stated earlier. The results from the flow-net appear reasonable, but because they are based on a range of transmissivity values, they are considered estimates. Water levels near the ponds, have remained relatively constant in recent years, indicating that steady state conditions exist.

The mass balance model was calculated using existing data. An average of historical and recent well water quality data represented upgradient underflow. Water quality data from 1981 and Laney (1972) was used for the Santa Cruz River. Recent pond water was averaged for the analysis. Bower (1985) reported nitrogen reduction of 40-60% in percolation systems. Accordingly, total nitrogen input from the percolation ponds in the model were reduced 40%.

The results of the calibration were compared to an average of current downgradient ground water quality data. For TDS, chloride, and sulfate the predictions were within 5% of measured data. Nitrate predictions were 25% greater than measured data. When Osterkamp's (1973) river recharge value of 300 AF/yr/mi was used instead of 600 AF/yr/mi, the nitrate error reduced to 15%. Table 2 shows the results of the calibration for both river recharge values and the predictions based on expected increase in effluent recharge.

The predictions are based on constant values for underflow and river recharge. Also, water quality data were held constant. The results suggest that TDS and chloride concentrations will increase by about 30 and 25 mg/l, respectively. Sulfate concentrations will decrease by 25 mg/l, and NO_3 concentrations will remain constant or drop slightly. Note that these values represent a river recharge value of 600 AF/yr, which reflects 1983 flooding and high flows from 1984. Table 2 also shows the results of using a river recharge value of 300 AF/yr. TDS increases an additional 20 mg/l, and chloride, nitrate, and sulfate values change less than 4 mg/l.

These results indicate that quadrupling the flow into the sewage treatment plant will only slightly affect the regional water quality. Apparently, the pond water quality and regional water quality are similar enough that changing the volume of one produces little change in the water quality of the combination.

A possible source of error in this model is the assumption that the variables are constant. Regional water quality, for example, has been improving in recent years. The effect that the improvement will have on the future water quality can not be determined at this time. Also, the values used in the model are approximations; therefore, the results should also be considered approximations.

TABLE 2

WATER QUALITY PREDICTIONS FROM THE MASS BALANCE ANALYSIS FOR THE YEARS 1990 - 2005

A. Predictions Based on a River Recharge estimate of 600 acre-feet/year

	Year					
Parameter	1985	1990	1995	2000	2005	Change
Pond Recharge acre-feet/year	1060	2040	2390	3590	4130	3070
TDS (mg/ℓ)	585/572	591	596	609	615	+28/42
NO_3 (mg/ℓ)	9.2/11.9	11.0	10.8	10.1	9.9	.7/-2.0
Cl (mg/ℓ)	50/47	59	53	72	75	24/28
SO_4 (mg/ℓ)	140/144	131	128	119	115	-24/-28

B. Predictions Based on a River Recharge Estimate of 300 acre-feet/year

	Year					
Parameter	1985	1990	1995	2000	2005	Change
TDS (mg/ℓ)	586/603	617	621	630	634	+48/31
NO_3 (mg/ℓ)	9.2/10.7	11.5	11.2	10.4	10.1	+.9/-.6
Cl (mg/ℓ)	51/50	62	66	74	78	-27/-28
SO_4 (mg/ℓ)	140/151	137	134	134	120	-20/-31

586/572 - denotes actual value and estimate value from calibration of model

Conclusions And Recommendations

The Green Valley Wastewater Treatment Facility currently has minimal impact upon the groundwater quality in the vicinity of the facility. Downgradient water quality meets all primary drinking water standards, and ground water immediately downgradient of GVWWTF was free from all tested viral and bacterial contaminants. The primary reason the impacts of the GVWWTF are minimal is that the ambient ground water is historically of poor quality due to past irrigation practices. If the recent improvement of ambient water quality continues, the impact of the GVWWTF may increase. A mass balance model predicts that by 2005 deep percolation from the ponds will increase from 1060 AF/yr to 4130 AF/yr, TDS will increase about 30 mg/l, nitrate will increase about 1 mg/l, chloride will increase about 25 mg/l and sulfate will decrease about 20 mg/l.

Because of the minimal impacts of the GVWWTF, no changes in plant operation should be considered. Effluent reuse is recommended to minimize future impacts. The effect of effluent disinfection versus no disinfection in preventing microbiological migration should be studied. An enhanced monitoring program would help refine future predictions of the pond's impacts on ground water. An upgradient monitor well is needed to better determine upgradient water quality. A third downgradient monitor well would add needed control. A continual sampling program of water quality and water levels should be conducted at the GVWWTF and nearby wells.

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