Turbidity Study - 2004

City of Tucson
Water Quality Management Division
Technical Support and Development Services

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Objective

Analyze the 2004 turbidity data to look for potential contamination existing in or entering the distribution system, and then determine the sources/reasons for the high turbidities. Investigate correlations between turbidity and other parameters such as temperature, pH, electrical conductivity, bacteriological positives, and seasonal conditions. Compare the water quality in 2004 to that of 2002 and 2003 with respect to turbidity.

Introduction

Turbidity is a measure of the "cloudiness", or opacity of water. All natural waters are turbid to some degree, surface waters generally more so than groundwater. It can be caused by the presence of solid particles made up from various items including clay, silt, plant and animal debris, corrosion products, and limescale. Turbidity is measured in Nephelometric Turbidity Units (NTU), which is a measure of water's ability to scatter light. The higher the NTU, the higher is the water's ability to scatter light, indicating higher amounts of solid particles existing in the water. There are no regulations for turbidity of ground water systems, but it is generally accepted that drinking water supplies have turbidities of 1 NTU or less.

Tucson Water operates 11 separate drinking water distribution systems throughout Metropolitan Tucson. The main system (10-112) provides water to more than 98% of Tucson Water customers. The remaining 2% are served by ten small isolated systems located in the outlying areas of metropolitan Tucson. The Water Quality Management Division of Tucson Water conducts extensive monitoring at 262 dedicated sampling stations, located at various points within the Tucson vicinity, which are representative of the water customers receive. Dedicated sample stations SR-268 and SR-273 were installed in the isolated system 10-169 during August of 2004. This was necessitated because of population growth in the Corona

de Tucson area. Turbidity measurements, along with other field parameters, are conducted each month at the dedicated sampling stations. Monitoring at the dedicated sample stations demonstrates the quality and safety of water throughout the distribution system.

Measurement of turbidity at the dedicated sampling stations has been ongoing since 2002, furnishing three complete years of data for study. Turbidity has become an additional tool to better monitor our system, and to discover potential problems early.

Benchmarks

In the previous reports for 2002 and 2003, two benchmarks were used for analyzing turbidity data. They were the generally accepted limit of 1 NTU for surface drinking water, as published by the World Health Organization and the statistical 95% confidence limit of the data set for the year being analyzed. The 95% confidence limit was chosen to provide an internally imposed benchmark or target that was more stringent for Tucson Water's ground water supply than the higher benchmark for surface waters. The 95% confidence limit is calculated as two standard deviations above the mean or average of the data set. In 2002 and 2003 the 95% confidence limits were 0.43 and 0.49 NTU respectively.

Since this limit is calculated using a variability measure of the data, this benchmark has increased as the variability in turbidity has increased. In the 2004 data set, the 95% confidence limit increased to 0.64 NTU ($0.22_{avg} + (2*0.21_{stddev})$). An increasing benchmark is not conducive to increasing water quality. Therefore, for this and subsequent reports, a new

internal benchmark will be used. As the previous benchmarks were roughly one half of the generally accepted 1 NTU limit, the internal benchmark for turbidity will remain at about that level, and 0.5 NTU will be used. For analytical purposes in this report, there are then two targets for comparison, the generally accepted threshold for drinking water of 1 NTU and the internally imposed benchmark of 0.5 NTU.

Analysis/Results

For 2004 there were 3,130 turbidity analyses at the dedicated sampling stations. General statistics for the entire data set (2002 – 2004) are shown in Table 1. Two analyses were purposefully left out of the 2004 statistics, as they are known anomalies. In August, at SP-732 located at 9233 E. 38th St., the turbidity measured 11.3 NTU. This reading was taken at the same time that the flushing crew was flushing the mains in the area of the sample point. SP-732 was again sampled after flushing was completed and the turbidity was back into the normal range. All other readings in 2004 for this sample point were less than 0.30 NTU. This is further evidence that flushing mains may temporarily cause turbidities to increase to unacceptable ranges around the area being flushed. It is a good practice to flush at night so that these areas can clear up again before consumption increases the following day. The other analysis removed from the statistics was taken at SP-740 located at 7851 S. Castlebay St.. This reading was taken when the pipe to the sample spigot was cracked. It measured 3.5 NTU and was influenced by outside material entering the sample through the crack. All other readings in 2004 for this sample point were less than 0.40 NTU.

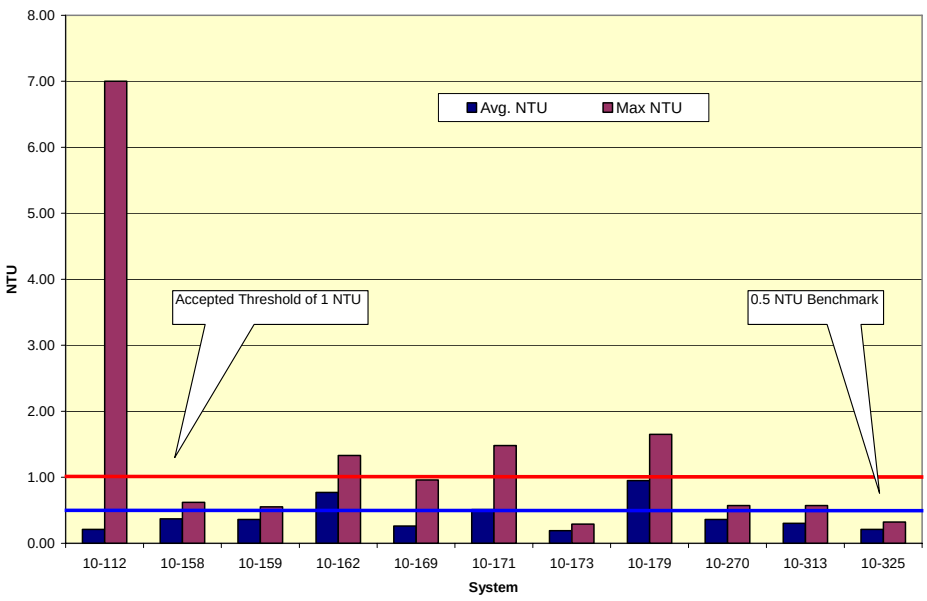
Table 1: General Statistics

Turbidity	2004	2003	2002
Average	0.22	0.21	0.17
Maximum	7.00	2.79	2.63
Minimum	0.03	0.04	0.01
Standard Deviation	0.21	0.14	0.13

Comparing the 2004 data to the previous years shows that the average turbidity has increased from 0.17 NTU in 2002 to 0.21 in 2003, and to 0.22 on 2004. The standard deviation increased from 0.13 and 0.14 in 2002 and 2003, to 0.21 in 2004. This indicates that occurrences and magnitude of high turbidity readings increased over the previous years. In other words, the overall turbidity of the system did not increase significantly as shown by the average reading of 0.22 NTU as compared to 0.21 last year, but the frequency of high readings as well as the magnitude of those readings, increased causing the standard deviation to increase to 0.21from the 0.14 standard deviation of 2003.

Looking at the internal threshold of turbidities higher than 0.5 NTU resulted in 96 analyses above that limit, 57 of which came from the main distribution system and 39 which came from the other isolated systems. This does not compare favorably with 2003 in which only 67 analyses were above that limit. The maximum turbidity increased from 2.79 NTU in 2003 to 7.00 NTU in 2004. Turbidity readings exceeded 1 NTU 26 times in 2004 as compared to 21 times in 2003.

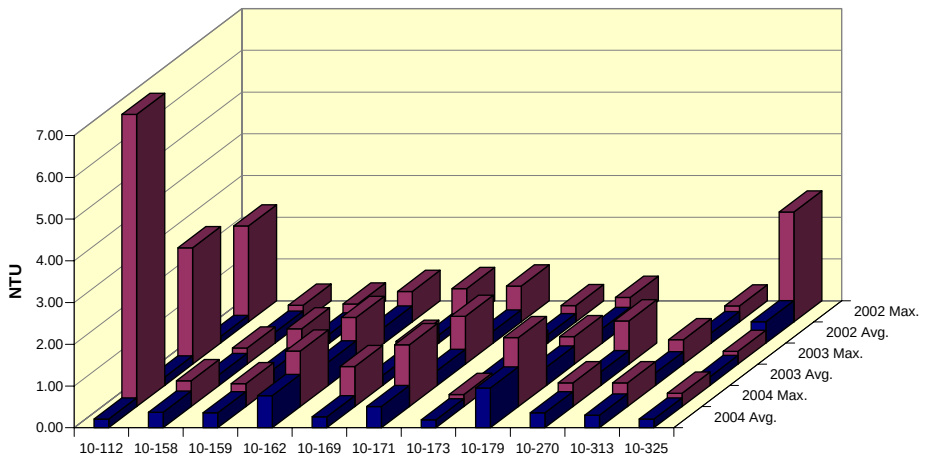
Figure 1 - Maximum and Average Turbidity by System for 2004



Maximum and Average Turbidities

Figure 1 shows the average and maximum turbidities for the 11 systems comprising the Tucson Water Distribution system. Figure 2 shows the average and maximum turbidities for the systems from 2002 to 2004. On average for 2004, as was also the case in 2002 and

Figure 2 - Average and Maximum Turbidity by System 2002 - 2004 system



2003, all systems were below the accepted threshold of 1 NTU. However, System 10-179, which is the Thunderhead system averaged 0.95 NTU. With regards to the 0.5 NTU internal target, two additional systems averaged higher. System 10-162 (Silver Bell West) averaged 0.77 NTU and system 10-171 (Catalina) averaged 0.51 NTU.

As stated earlier, turbidity readings exceeded the 1 NTU accepted level 26 times in 2004. This number is up from 21 exceedances in 2003. There were 13 in the main system 10-112, and 13 in three of the isolated systems (10-162, 10-171, 10-179). While this number is up for 2004, it represents only 0.8% of the data. The 26 exceedances are shown in Table 2. The distribution of analyses that were above the 0.5 NTU benchmark is shown in Table 3.

Table 2: NTU Readings above the generally accepted level of 1 NTU

System	Point	Address	T	R	S	Date	NTU
10-112	SP-115	720 E. Prince Rd.	13	14	30	3/3/04	1.24
10-112	SP-140	3700 W. Orange Grove Rd.	13	13	5	5/20/04	1.31
10-112	SP-140	3700 W. Orange Grove Rd.	13	13	5	6/22/04	1.17
10-112	SP-155	4750 N. La Cholla Blvd.	13	13	22	8/16/04	1.21
10-112	SP-155	4750 N. La Cholla Blvd.	13	13	22	11/15/04	1.02
10-112	SP-170	6200 N. 1st Ave.	13	13	12	10/20/04	1.33
10-112	SP-260	6600 N. Swan Rd.	13	14	2	2/23/04	7.00
10-112	SP-260	6600 N. Swan Rd.	13	14	2	3/24/04	4.83
10-112	SP-260	6600 N. Swan Rd.	13	14	2	4/21/04	1.04
10-112	SP-260	6600 N. Swan Rd.	13	14	2	5/24/04	3.82
10-112	SP-260	6600 N. Swan Rd.	13	14	2	10/19/04	1.90
10-112	SP-595	8427 E. 2nd Pl.	14	15	9	12/22/04	1.26
10-112	SP-738	4616 S. Breckinridge Dr.	14	15	36	7/1/04	1.01
10-162	SR-262	12402 N. Luckett Rd.	11	11	31	1/26/04	1.33

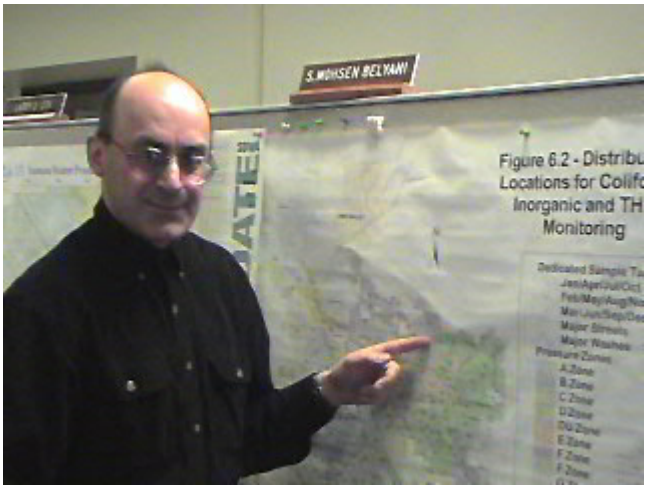
10-162	SR-262	12402 N. Luckett Rd.	11	11	31	12/22/04	1.13
10-171	SR-271	3131 W. Graham St.	11	14	4	2/12/04	1.08
10-171	SR-271	3131 W. Graham St.	11	14	4	7/19/04	1.48
10-171	SR-271	3131 W. Graham St.	11	14	4	8/23/04	1.21
10-171	SR-271	3131 W. Graham St.	11	14	4	9/27/04	1.07
10-171	SR-271	3131 W. Graham St.	11	14	4	11/23/04	1.46
10-179	SR-278	6260 S. Mesquite Tr.	15	16	8	4/26/04	1.10
10-179	SR-278	6260 S. Mesquite Tr.	15	16	8	5/4/04	1.04
10-179	SR-278	6260 S. Mesquite Tr.	15	16	8	9/28/04	1.65
10-179	SR-278	6260 S. Mesquite Tr.	15	16	8	10/21/04	1.45
10-179	SR-278	6260 S. Mesquite Tr.	15	16	8	11/23/04	1.38
10-179	SR-278	6260 S. Mesquite Tr.	15	16	8	12/6/04	1.36

Table 3: Turbidity Occurrences above 0.5 NTU in the Distribution Systems

System	10-112	10-158	10-159	10-162	10-169	10-171	10-179	10-270	10-313
NTU>0.5	57	3	1	11	2	8	10	3	1

Main system Exceedances in 2004

The exceedances of 1 NTU in the main system occurred at only seven sample locations. There were five readings above 1 NTU at SP-260 and two each at SP-140 andSP-155. SP-260 located at the Skyline Country Club Estates had four exceedances in 2003. This sample point appears to be on a spur line feeding only a swimming pool. That line may be corroding. SP-140 is located in the Orange Grove and Thornydale area, while SP-155 is in the La Cholla and Ruthrauff area. More frequent flushing in these areas would probably help lower these turbidities. Shortly after the 2003 report was published, the area around SP-595 was flushed resulting in lower turbidities until late December of this year.



Looking at the internal benchmark of 0.5, the same trends appear at SP-140, SP-155, and SP-260. Additionally, the turbidity at SP-930 in the Country Club and Valencia area appears to be going up. There were four readings between 0.5 NTU and 1 NTU at that location. All other sample points within the main system had two or less instances of turbidities above 0.5

NTU. There were a total of 57 readings above 0.5 NTU in the main system in 2004. They occurred at 36 sample locations.

Isolated Systems Turbidity Discussions

- 10-158 is the Valley View isolated system located West of Sierrita Mountain Rd. and North of Hilltop Rd. There are two wells in the system. This system averaged 0.37 NTU for 2004, but it experienced three instances of turbidities above 0.5 NTU. The maximum turbidity reading was 0.62. These could have been caused by system improvements made during the year.

- 10-159 is a small system in the Diamond Bell Ranch area. The system averaged 0.36 NTU for 2003, and experienced only one instance of high turbidity. The maximum turbidity reading was 0.55 NTU. It is supplied by two wells, and the distribution system underwent quite a few improvements during the year.

- System 10-162 is the small system, named Silverbell West that is serviced by well W-001A. That well has been producing corrosion products that are influencing the turbidity, and a new well for this system is almost complete. For 2004, the system averaged 0.77 NTU, which is up from the 2003 average of 0.56 NTU and the 2002 average of 0.38 NTU. It experienced high turbidity in eleven of the twelve months that it was sampled in 2004, with the maximum reading being 1.33 NTU. Start up of the new well for this system should greatly improve the turbidity there.

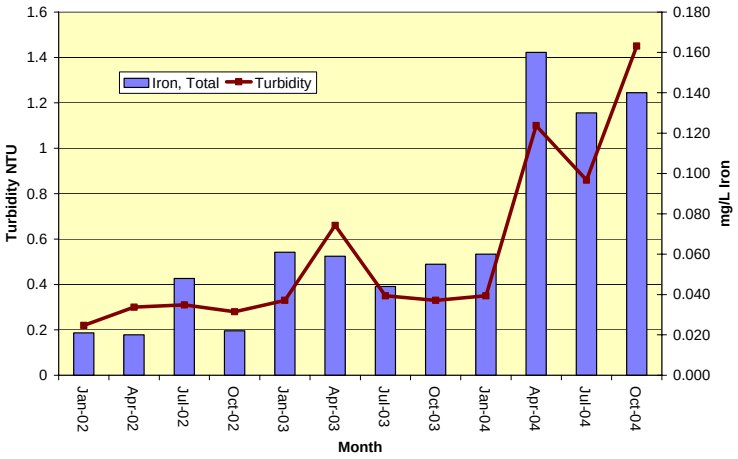
- System 10-169 serves the Corona de Tucson area, receiving water from two wells. It averaged 0.26 NTU for 2004, and had two instances of high turbidity at 0.58 and 0.96

NTU. Both high readings occurred in October 2004, at two dedicated sample locations, and were probably caused by the rapid expansion of this system due to new construction in the area. This is the system that required two new sample stations during the year because of growth in the area.

- System 10-171 serves a small area in Catalina and it too receives water from two wells. It averaged 0.51 NTU for 2004, but experienced eight high readings during the year. The maximum NTU reading here in 2004 was 1.48. The high readings came from SR-271 located on Graham St. in Catalina, while the turbidities at SR-276, which is farther North, were always in acceptable ranges. This system has experienced high turbidities in all three years that this report has been written. It would probably help this situation if the frequency of flushing this system was increased.

- System 10-179, named Thunderhead, serves a small area East of Old Spanish Trail adjacent to the Saguaro National Park East. It now receives water from two wells. This system averaged 0.95 NTU for 2004, which is twice what it averaged in 2003. It had ten occurrences of turbidity greater than 0.5 NTU, and the maximum reading for this system was 1.65 NTU. Corrosion products from inside the well are suspected as the cause of this turbidity. A chlorine material balance was measured on well G-006A, which is one of the two wells feeding this system. Results showed that 44% of the chlorine being added to the well in the form of pellets was not being recovered from the well. Figure 3 shows turbidity plotted against Iron content for SR-278, which is the dedicated sample tap for this system. From the chart it is noted that as the iron content has risen the turbidity has also gone up. Further investigation is underway.

Figure 3: SR-278 Iron and Turbidity 2002-2004



- System 10-270 is the Sierrita Foothills system that is serviced by well G-010. The well and distribution system underwent a lot of modernization in 2004. It averaged 0.36 NTU for the year, with a maximum reading of 0.57 NTU. The three turbidity readings slightly above 0.5 NTU were probably due to the modernization construction.

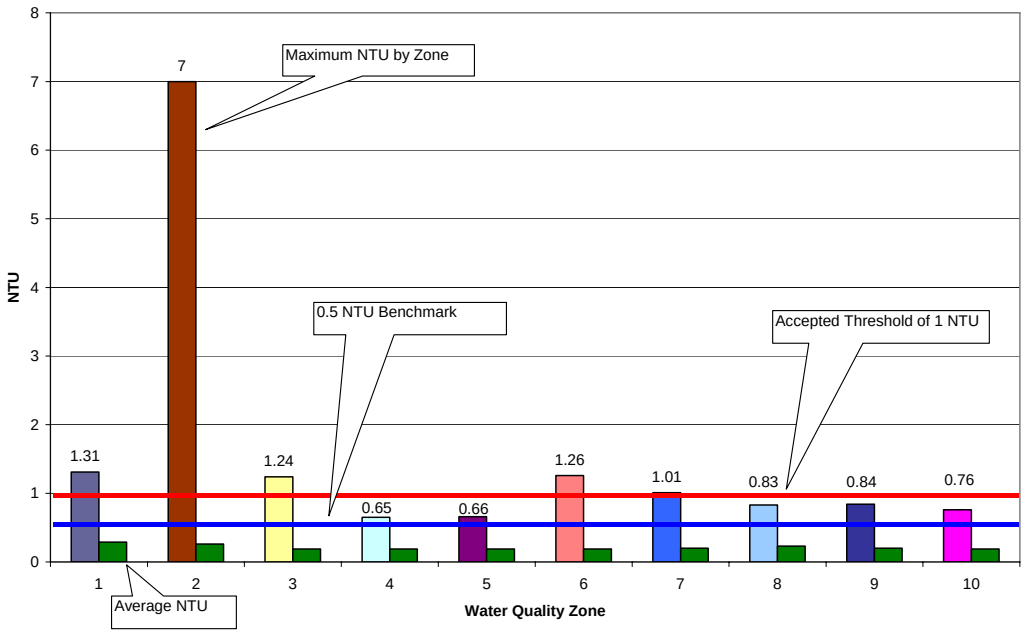
- System 10-313 is the small system serving the Fire and Police academy on South Wilmot Road. This system is also serviced by only one well, and it averaged 0.30 NTU for the year. It experienced one instance of high turbidity at 0.57 NTU

These smaller systems are much more susceptible to higher turbidity readings than is the main system. Maintenance, modernization construction, deterioration of equipment including corrosion, or other possible system upsets on the one or two wells supplying their water can have a greater influence on the condition of the smaller system.

Water Quality Zones within the Main System

The main system 10-112 is divided into 10 water quality zones. These zones had average and maximum turbidity readings as shown in Figure 4. The chart shows that while the

Figure 4: 2004 Average and Maximum turbidity for the Main System Zones



average turbidity for each zone was well below the internal benchmark of 0.5 NTU, all zones had maximum readings above this benchmark. Five of the zones experienced maximum readings above the generally accepted threshold of 1 NTU. Zone 2 had the highest turbidity reading at 7.0 NTU. It is where SP-260 is located. As was previously explained, it may be experiencing corrosion in the feeder line to the sample point. The numbers of high occurrences in the main system's zones are shown in Table 4.

Table 4: Occurrences of Turbidity Greater than 0.5 NTU in the Main System's Zones

Zone	1	2	3	4	5	6	7	8	9	10
No. Above 0.5	9	12	4	2	6	4	3	9	7	1

When compared by locality within the city, zones 3,4,6, 7, and 10 had the fewest occurrences of high readings. In 2003 zones 4 through 7,and 10 had the fewest occurrences. Zones 1,2,8, and 9 had the highest numbers of occurrences. Sample Points SP-140, SP-155, and SP-260 influenced zones 1,2, and 8. These have already been discussed. Zone 9 experienced seven readings above 0.5 NTU, which came from six different sample points. That indicates that this increase in occurrences of high turbidities may be throughout the zone.

Relationships and Causes

Other relationships investigated such as temperature, pH, electrical conductivity again did not appear to have correlations with turbidity. Additionally, there were seven bacteriological positives in 2004, none of which were associated with high turbidity measurements. Table 5 shows the sample points where the positives occurred.

Table 5: Occurrences of Bacteriological Positives and associated Turbidities

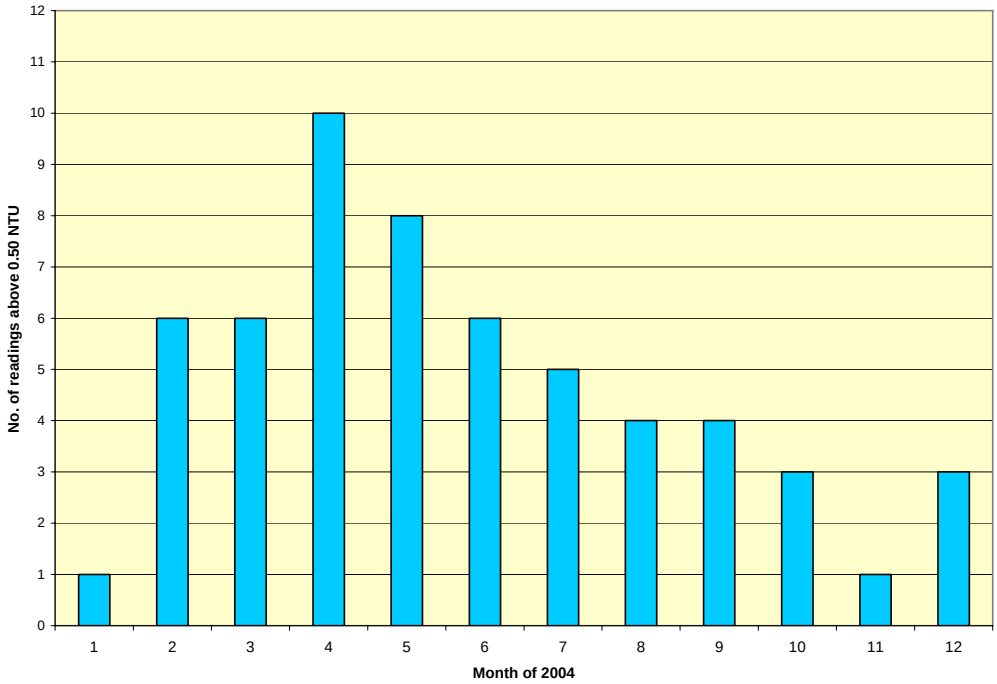
System	Point	Address	T	R	S	Date	NTU
10-159	SR-259	15710 W. Diamond Bell Rd.	16	10	35	1/27/04	0.40
10-112	SP-260	6600 N. Swan Rd.	13	14	2	8/17/04	0.38
10-112	SP-290	4732 E. Calle Barril	13	14	14	8/17/04	0.14
10-112	SP-585	9405 E. Sierra St.	14	15	10	6/9/04	0.22
10-112	SP-732	9233 E. 38th St.	14	15	27	5/10/04	0.29
10-112	SP-732	9233 E. 38th St.	14	15	27	12/12/04	0.22
10-112	SP-988	9230 W. Henry St.	14	12	30	10/14/04	0.17

Of these seven sample locations only two experienced turbidities above 0.5 NTU during the entire year. SP-260, which has been discussed in detail earlier in this report, experienced turbidities above 0.5 NTU eight of the twelve months in 2004. The Coliform positive there, however, occurred in January when the turbidity was only 0.40 NTU. SR-259 experienced a turbidity of 0.55 NTU in May of 2004, but in January when it tested positive for E. Coli as well as Total Coliform, the turbidity was 0.40 NTU. There is no discernable correlation between turbidity and bacteriological positives for Tucson Water.

The causes for high turbidity in the Tucson Water systems appear to include:

- System interruptions including hard stops and starts
- Inadequate flushing frequencies (SP-140, SP-155, 10-171)
- Flushing sections of the system during high consumption times of the day (SP-732)
- System expansion or modernization when new sections of piping are being connected to existing systems (10-158, 10-159, 10-169, 10-270)
- Instances of corrosion occurring in well casings, column pipe, well site piping, and system valve bodies (SP-260, 10-162, 10-179)

Figure 5: Main System High NTU Frequency 2004



Seasonal Impacts on Turbidity

In order to look at turbidity relationships concerning seasonal influences such as rain, and volume of water moving through the system, a frequency chart was again generated to show the distribution of high readings (above 0.5 NTU) by month for 2004. This frequency distribution is shown in Figure 5. For 2004 the distribution is again fairly normal, but with the peak number of high readings occurring in April. In 2003 the frequency distribution showed two peaks occurring in April and August. In 2002 the peak frequency of high turbidity readings occurred in August. No pattern of peak turbidity periods has been shown over the three years that this has been monitored. This further justifies the idea that other causes of turbidity may be influencing the Tucson Water system more than seasonal effects of high demand and rainfall.

Figure 6: Main System High Turbidities VS Avg. Water Demand 2004

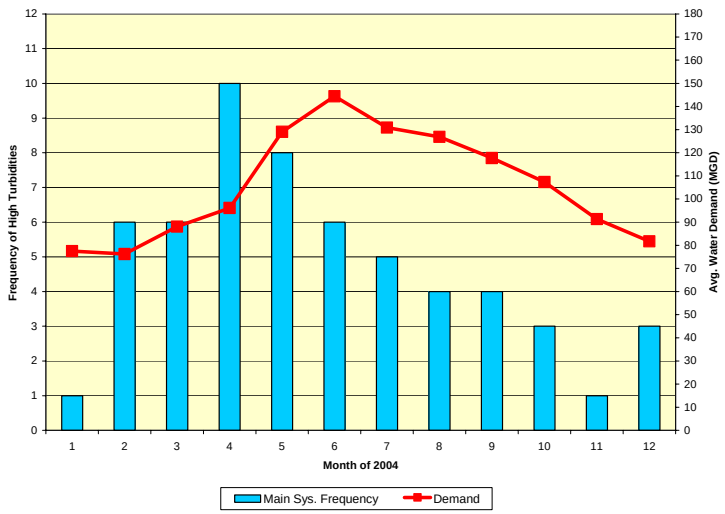


Figure 7: Main System High Turbidities VS Rainfall 2004

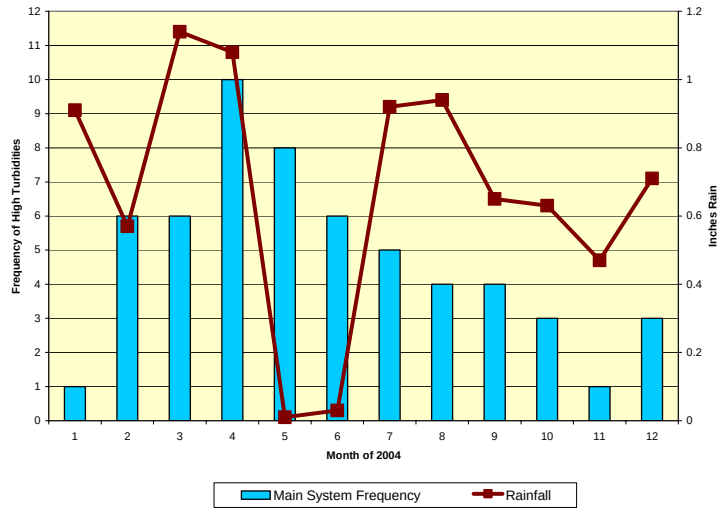
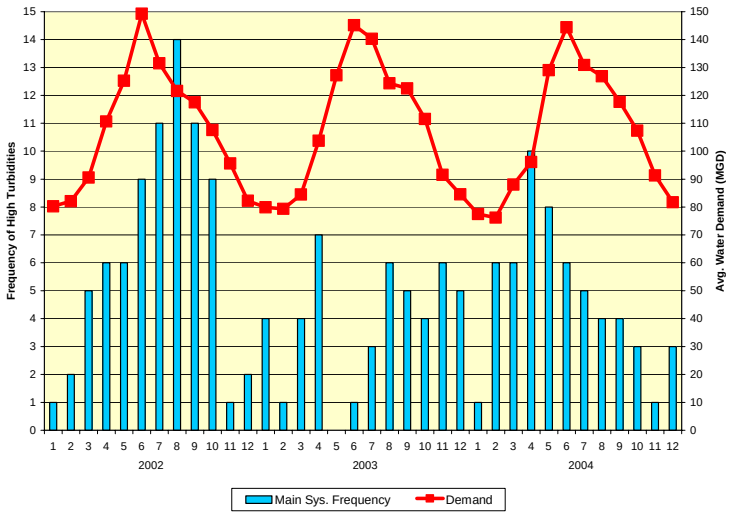


Figure 6 and Figure 7 show water demand averages and rainfall totals overlaid on the distribution. They again show a very weak correlation between turbidity and both water usage and rainfall.

Water usage in 2004, as in past years, peaked in June. Rainfall totals actually peaked in March and April because of heavy spring rains. The summer monsoons created another peak in July and August. The frequency of high turbidities peaked in April after water demand rose from about 80 MGD to 100 MGD, and rainfall had been above one inch for two

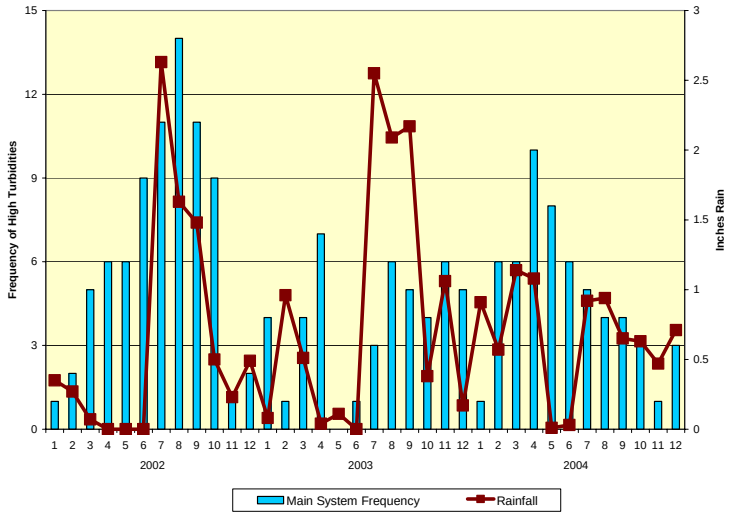
months. The frequency then tailed off through the remainder of the year while the demand continued to rise through June to about 140 MGD. Then the demand too tailed off for the balance of the year. Rainfall again peaked during July and August without a corresponding effect on turbidity. From these two graphs it appears that water demand has a stronger effect on turbidity than does rainfall. It may even be that peak periods of rainfall help with regards to turbidity because demand drops off when customers do not need to water their yards.

Figure 8: Main System High Turbidities VS Avg. Water Demand 2002 - 2004



The increase in turbidity as water usage increases may again be attributed to starting wells that are not normally operated in order to supply the increased demand. Some wells, known to be "sanders", are only operated at times of high water demand. In addition, the increased flow rates can pick up particulates that have settled in the pipelines.

Figure 9: Main System High Turbidities VS Rainfall 2002 - 2004



In order to better see the relationship of water usage and rainfall with turbidity, Figures 8 and 9 show high turbidity frequencies plotted against water demand and average rainfall for the combined years of 2002 through 2004.

From these two charts it appears there are times that when water demand or rainfall increases, so do elevated turbidity readings. Mathematically however, there is no proof of this. Calculated correlation coefficients (R^2) for demand and rain related to high turbidity frequencies are less than 0.2 demonstrating no correlation for either case.

Conclusions

The forthcoming interpolations are based on our analysis of the data.

- The entire Tucson Water System, averaging 0.22 NTU in 2004, operated at turbidity levels well below the generally accepted threshold of 1 NTU for years 2002 through 2004. Three small isolated systems (10-162, 10-179, and 10-171) operated above the 0.5 NTU internal benchmark.
- Turbidity readings above 1 NTU only occurred 26 times in 2004, out of a total of 3,130 readings (less than 1 per cent). This is a great assurance that we produce a high quality water.
- System upsets, maintenance/modernization work, flushing events, flushing frequency, and corrosion of equipment may cause high turbidity readings, especially in the small isolated systems, as evidenced by system 10-162 and 10-179.
- From the graphs there appears to be a weak correlation between water demand, rainfall, and occurrences of high turbidity, but there is no mathematical evidence of these correlations.
- No correlation has been found between turbidity and temperature, pH, electrical conductivity, or bacteriological positives either in 2002, 2003, or 2004.

- Except for certain sample points known to be experiencing the effects of equipment deterioration or needing more frequent flushing, no specific areas of high turbidity were found within the main system. However, because of the general increase in turbidity in zone 9, that area warrants attention for further increases.
- Over the period of the last three years, turbidity appears to be slightly increasing.

Insight

This investigation revealed that overall Tucson Water continues to provide drinking water of the highest quality and aesthetics. Additionally, keeping track of turbidity assures that the high quality and aesthetics are maintained. Tracking turbidity can quickly alert us to changes in water quality. Problems can then be recognized early on and corrected before they become disastrous.

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