

# **THM REDUCTION IN İSTANBUL WATER TREATMENT PLANTS**

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# THM s

- **CHCl<sub>3</sub>** Chloroform
- **CHCl<sub>2</sub>Br** Bromodichloromethane
- **CHClBr<sub>2</sub>** Dibromochloromethane
- **CHBr<sub>3</sub>** Bromoform

# AIM

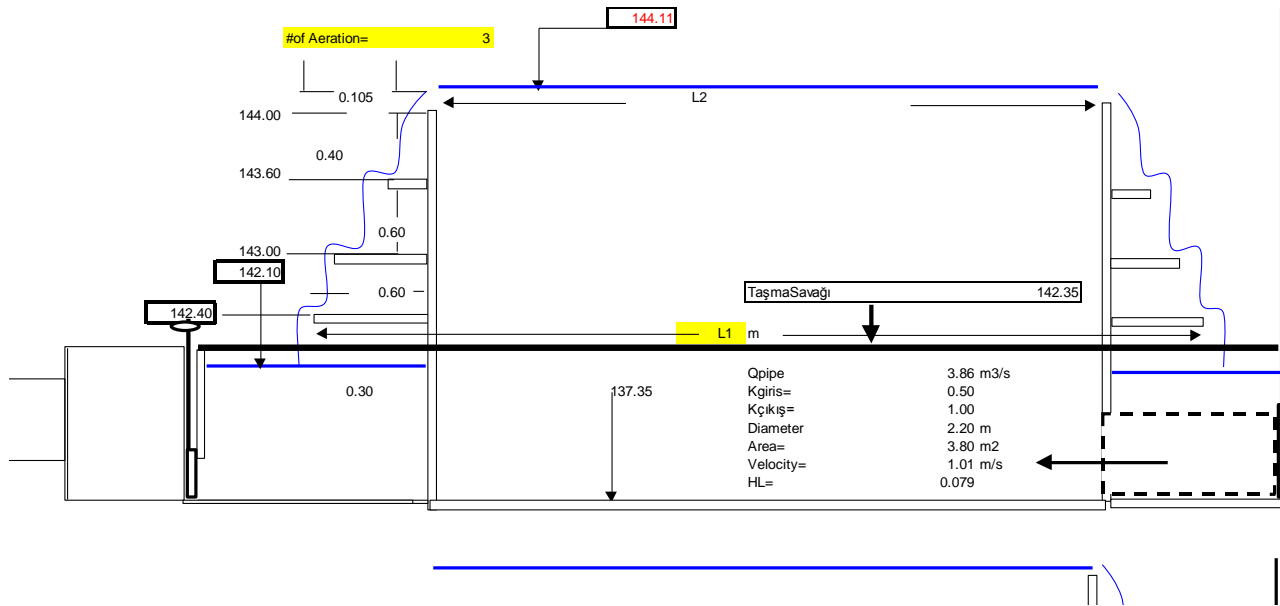
To Control the THMs in the Water Treatment Plants in Istanbul.

CASE STUDY : FSM PLANT

# RESULTS:1

The TTHM levels that were around 460 mg/L were reduced by half as the **preozonation** system started and as the **prechlorination** was stopped.

# CASCADE AERATION





## RESULTS: 2

Change of water source from Sazlidere reservoir that has a TOC value of 1.6 mg/L to Terkos reservoir with a TOC value of 1.0 mg/L, reduced the TTHM values to less than 50 ppb.

# RESULTS:3

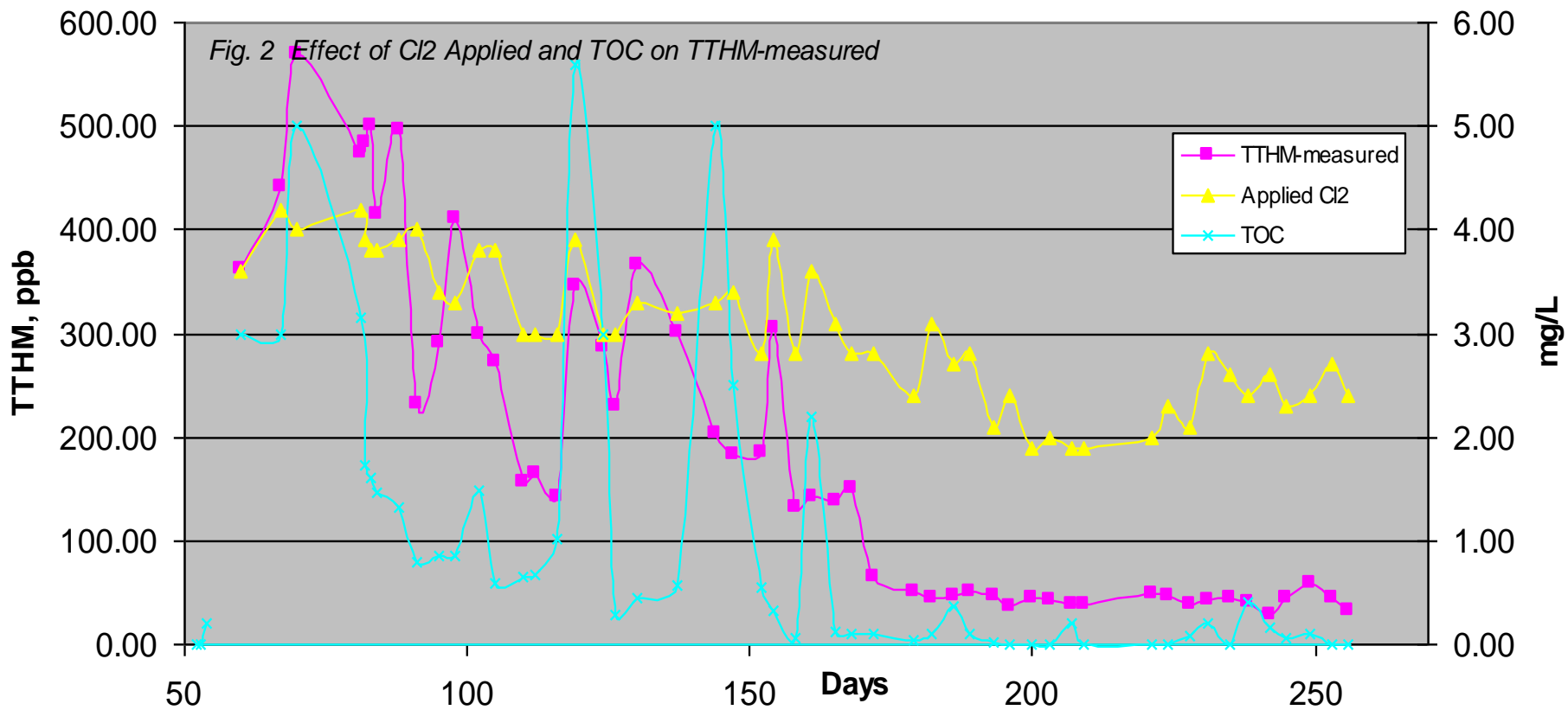
A mathematical model that correlates TTHM to:

- pH,
  - Temperature,
  - Applied Chlorine,
  - TOC,
  - Ammonia and
  - Bromide concentrations
- was developed.



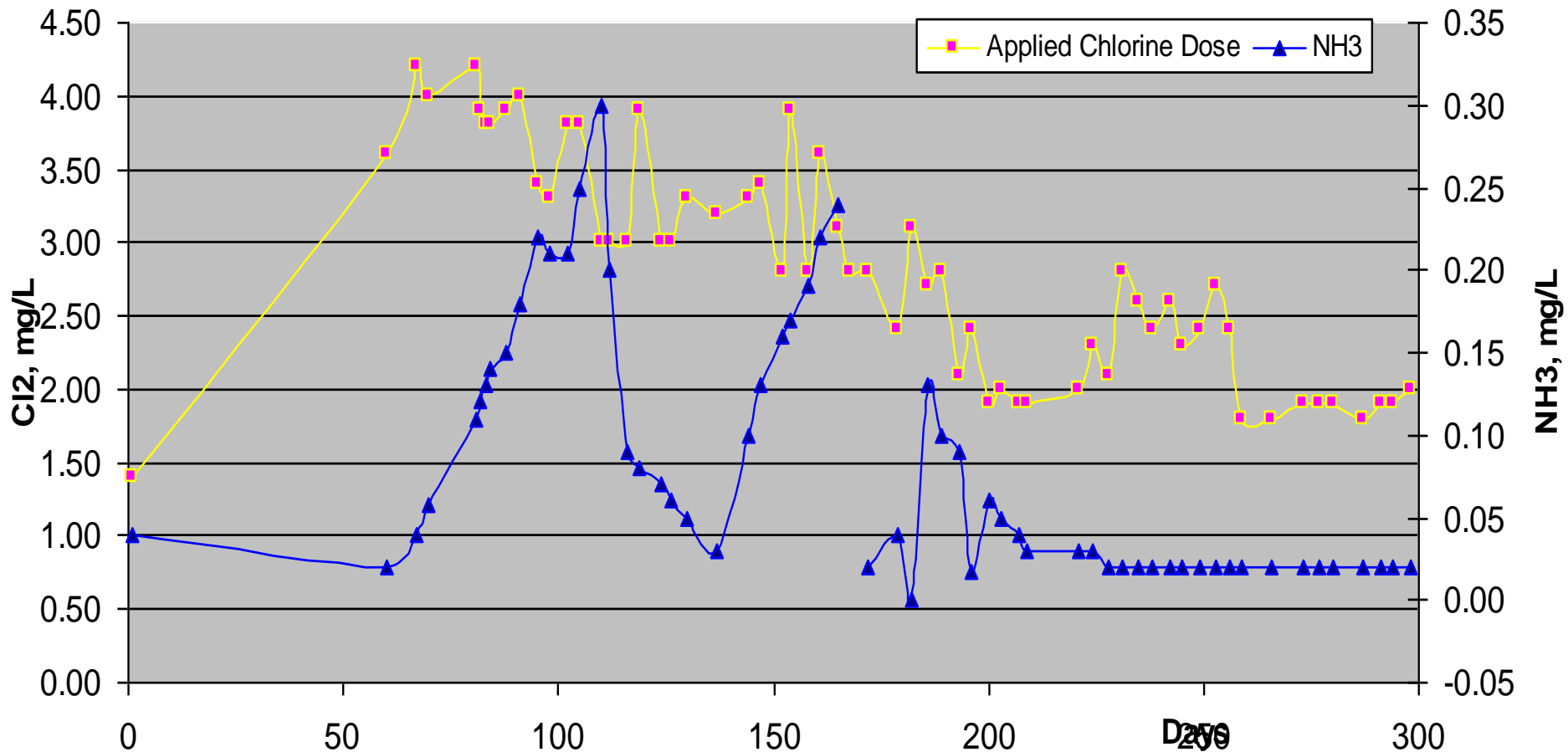


# The Effect of Chlorine and TOC to TTHM Formation

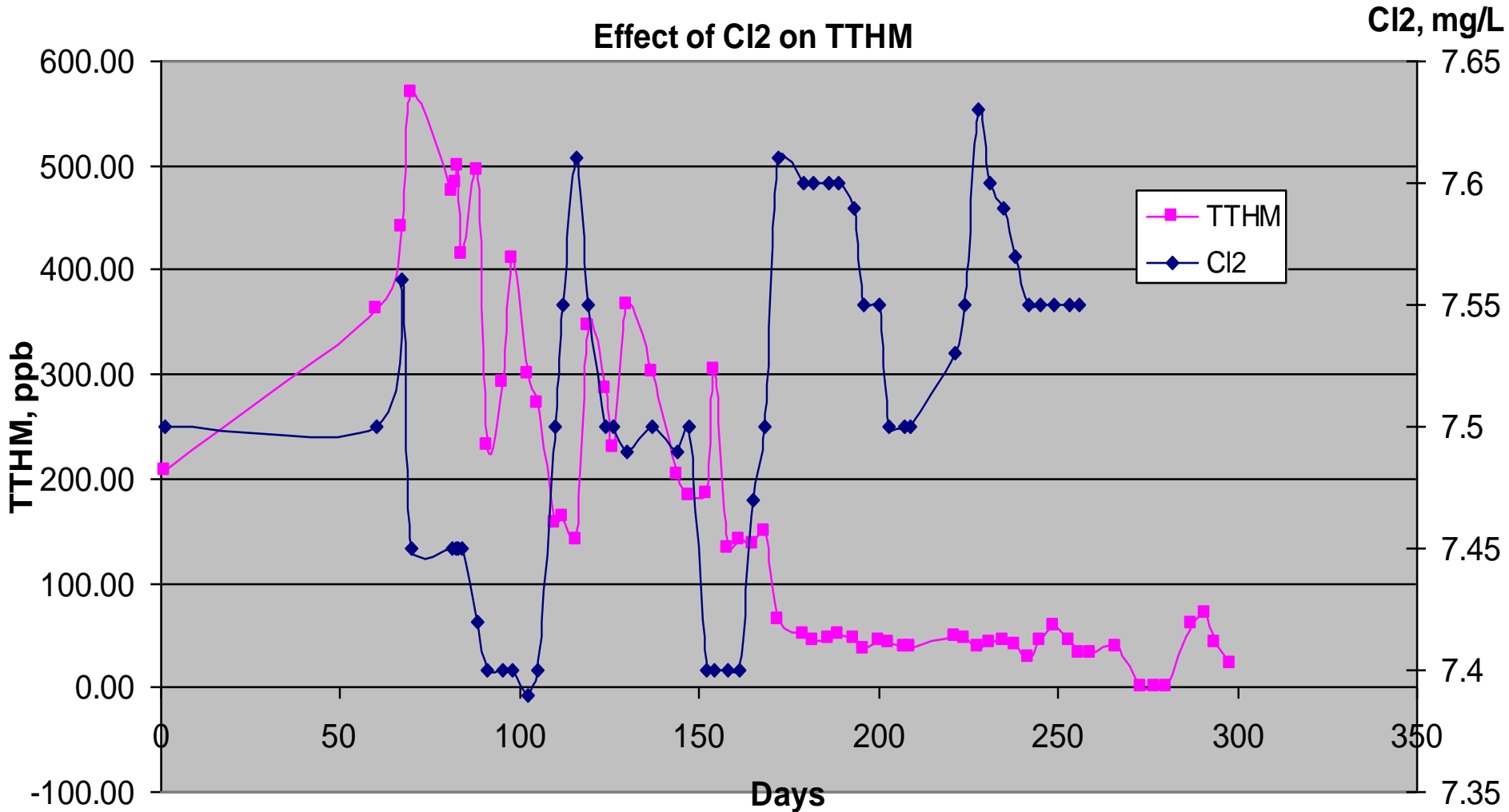


# The Applied Chlorine and Raw Water NH<sub>3</sub> Levels in FSM

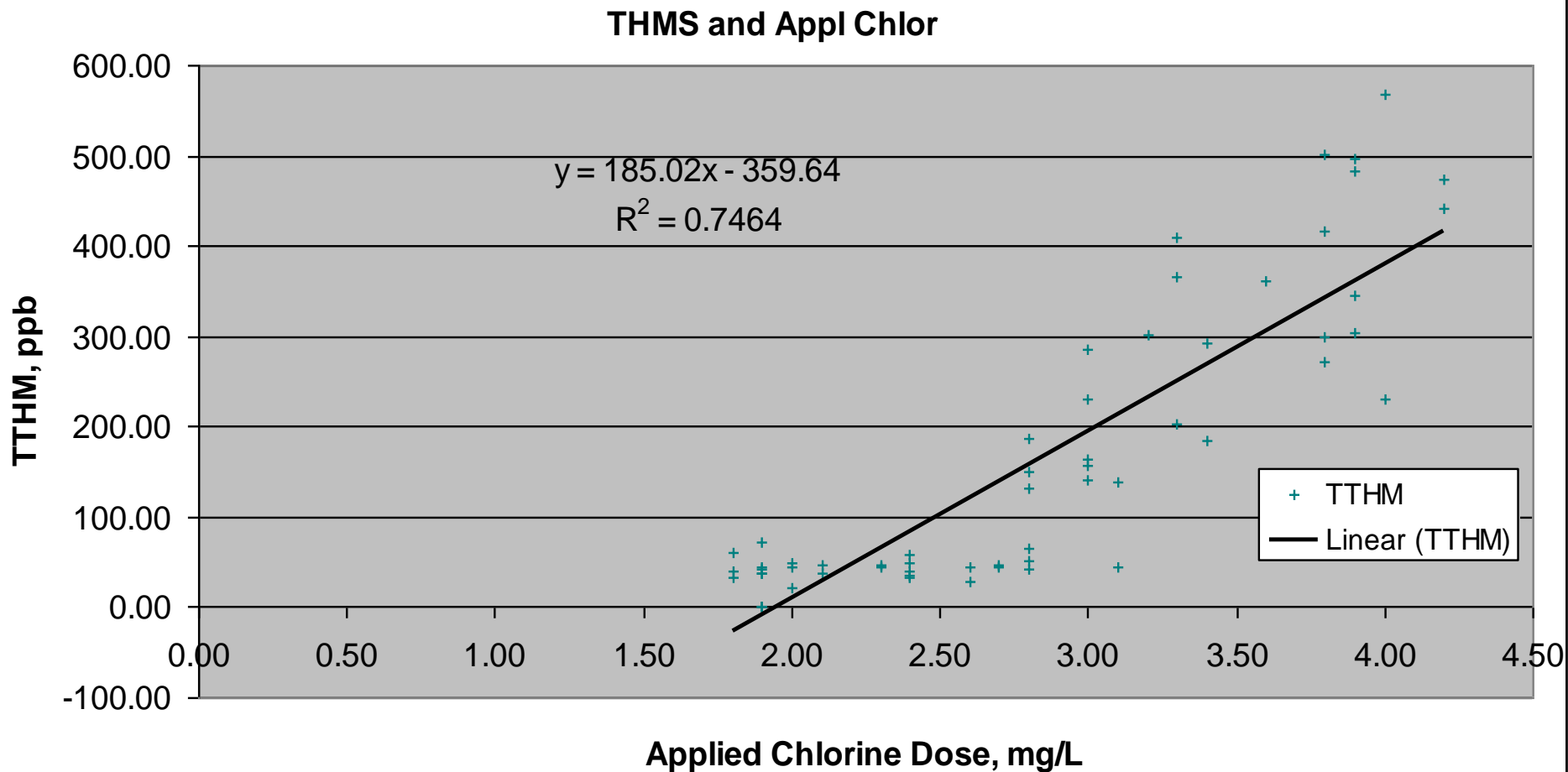
Fig. 3 Change of NH<sub>3</sub> in Raw Water



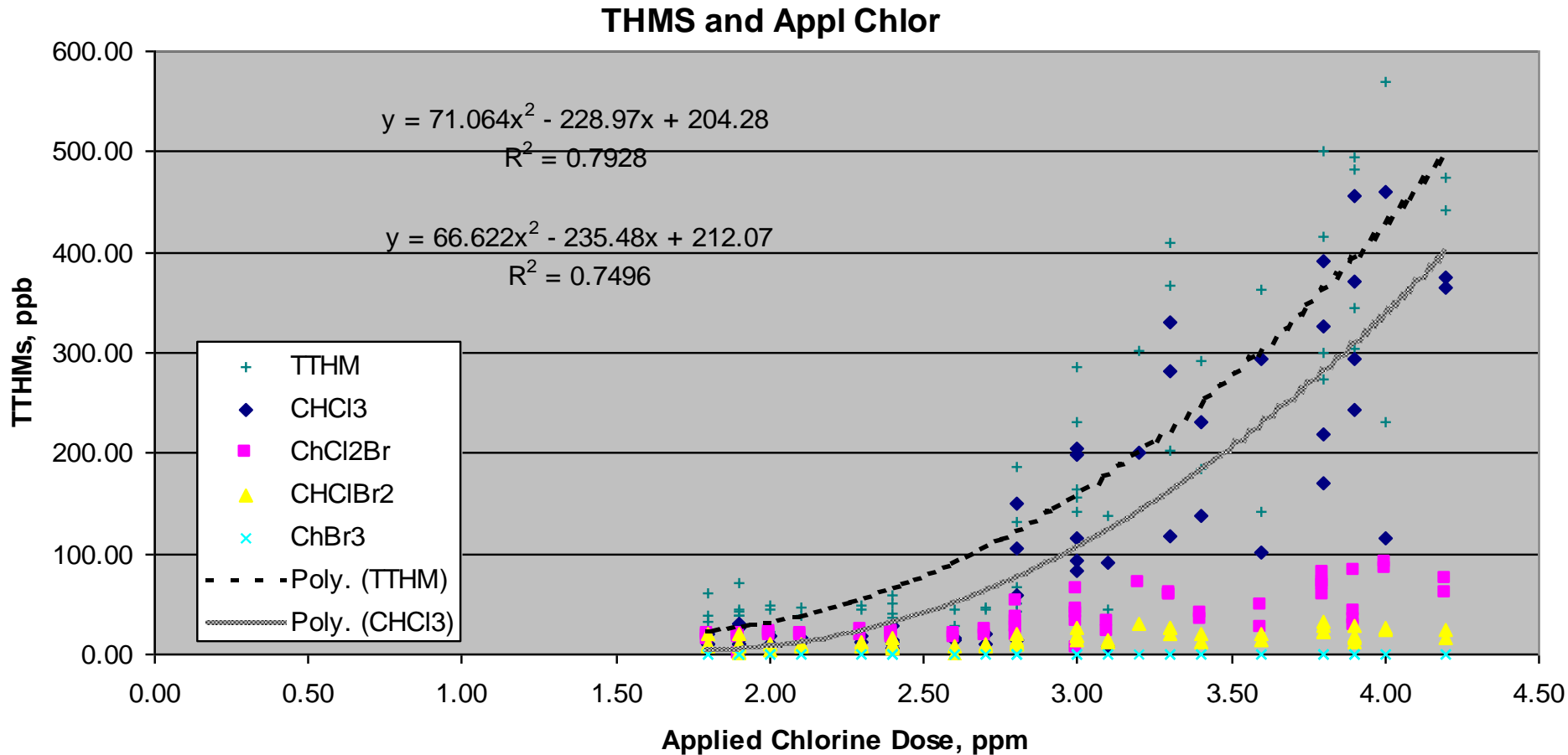
# Effect of Applied Chlorine Dose to TTHM Formation



# Effect of Applied Chlorine Dose to TTHM Formation in FSM



# Effect of Applied Chlorine Dose on THM formation in FSM



# Urano et al. (1983)

- $\text{TTHM} = k (\text{pH}-a)^1 \text{TOC}^1 \text{Cl}_2^m t^n$  (1)

- $\text{TTHM} = 3.5 \times 10^{-3} \exp(-4.47 \times 10^3 / T_{\text{kelvin}}) (\text{pH}-2.8) \text{TOC} \text{Cl}_2^{0.25} t^{0.36}$  (2)

*(Black et al. 1996)*

## *California State Project Model*

- $\text{TTHM} = 7.21 (\text{TOC})^{0.004} (\text{UV254})^{0.534}$   
 $(\text{CIDose}-7.6 \text{ NH}_3\text{-N})^{0.224} t^{0.255} (\text{Br}+1)^{2.01}$   
 $T^{0.480} (\text{pH}-2.6)^{0.719}$
- $\text{CHCl}_3 = 0.997 (\text{TOC} * \text{UV254})^{0.580}$   
 $(\text{CIDose})^{0.814} t^{0.278} (\text{Br}+1)^{-4.27} T^{0.569} (\text{pH}-$   
 $2.6)^{0.759}$

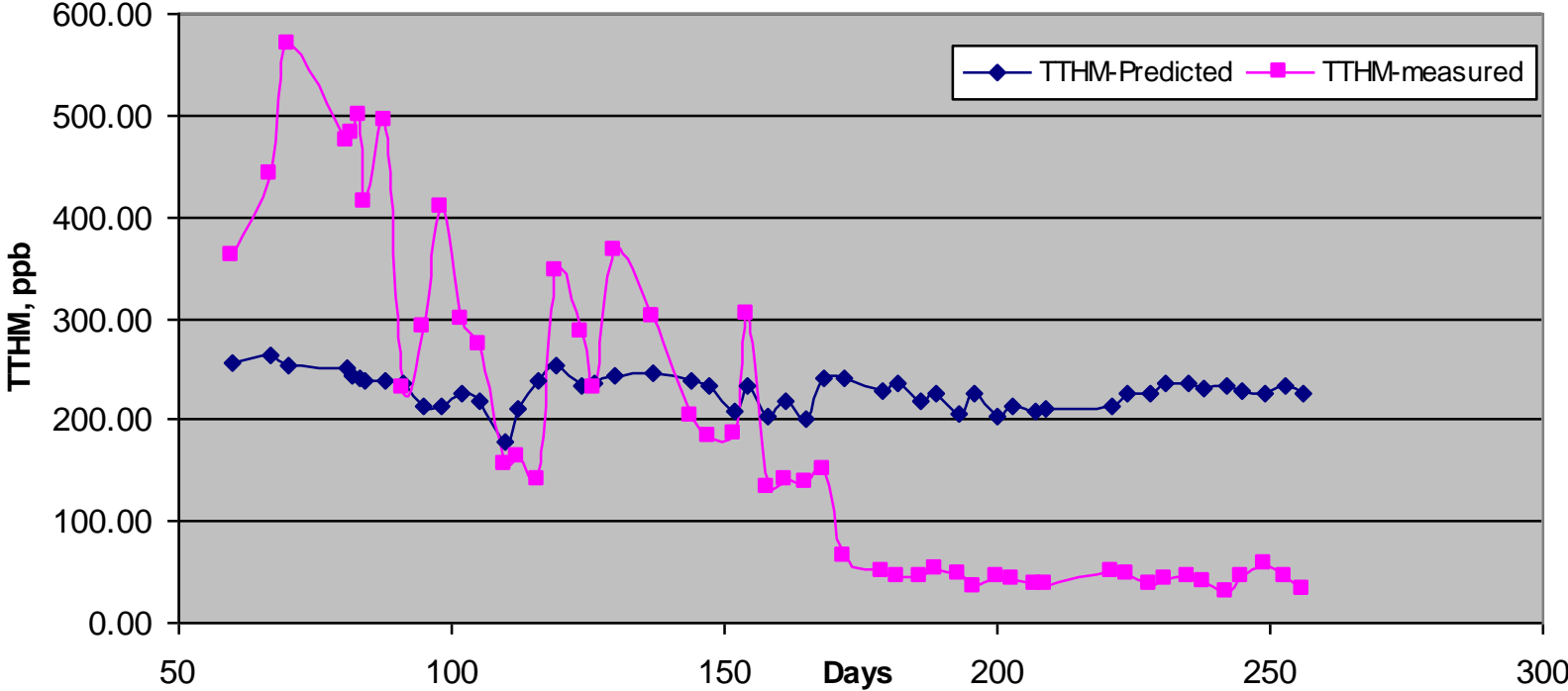


# *(Black et al. 1996)*

- $\text{CHCl}_2\text{Br} = 4.05 (\text{TOC} * \text{UV254})^{0.567}$   
 $(\text{CIDose}-7.6 * \text{NH}_3\text{-N})^{-0.351} t^{0.366} (\text{Br})^{0.291} t$   
 $0.366 (\text{pH}-2.6)^{0.568} T^{0.568}$
- $\text{CHClBr}_2 = 22.9 (\text{TOC} * \text{UV254})^{0.567}$   
 $(\text{CIDose}-7.6 * \text{NH}_3\text{-N})^{-0.352} t^{0.292} (\text{Br})^{1.04} t$   
 $0.366 (\text{pH}-2.6)^{0.325} T^{0.491}$
- $\text{CHBr}_3 = 1.28 (\text{TOC} * \text{UV254})^{-0.167}$   
 $(\text{CIDose}-7.6 * \text{NH}_3\text{-N})^{-2.22} t^{0.294} (\text{Br})^{1.48} t$   
 $0.294 (\text{pH}-2.6)^{1.98} T^{0.553}$

# California State Project Model

Fig 3. TTHM-Predicted Using Equations in Table 2 and TTHM-measured



**THM PREDICTIVE MODELS(California State Project Model)**

**TTHM** = 7.21\*TOC^0.004\*UV254^0.534\*(ClDose-7.6\*NH3N)^0.224\*t^0.255\*(Br+1)^2.01\*t^0.480\*(pH-2.6)^0.719

**CHCl3** = 0.997\*(TOC\*UV254)^0.580\*(ClDose)^0.814\*t^0.278\*(Br+1)^0.427\*t^0.569\*(pH-2.6)^0.759

**CHCl2Br** = 4.05\*(TOC\*UV254)^0.567\*(ClDose-7.6\*NH3N)^0.351\*t^0.366\*Br^2.91\*t^0.568\*(pH-2.6)^0.568

**CHClBr2** = 22.9\*(TOC\*UV254)^0.253\*(ClDose-7.6\*NH3N)^0.352\*t^0.292\*Br^1.04\*t^0.491\*(pH-2.6)^0.325

**CHBr3** = 1.28\*(TOC\*UV254)^0.167\*(ClDose-7.6\*NH3N)^0.222\*t^0.294\*Br^1.48\*t^0.553\*(pH-2.6)^0.198

Br= 0.24 mg/L  
t= 24 h

|           |     | TARIH      | TTHM   | CHCL3 | CHCl2Br | CHClBr2 | CHBr3 | Sum Predicts | Predict TTHM | Predict CHCl3 | Predict CHCl2Br | Predict CHClBr2 | Predict CHBr3 | tC     | pH offline | pH   | CIKIKi | Tatbk C12 Son | Tatbk C12 *100 | TOC Cikis | TOC* 100 | NH3  | NH3-N | TOC TOM | TOC Ciki | UV fro |       |
|-----------|-----|------------|--------|-------|---------|---------|-------|--------------|--------------|---------------|-----------------|-----------------|---------------|--------|------------|------|--------|---------------|----------------|-----------|----------|------|-------|---------|----------|--------|-------|
| Before O3 |     |            |        |       |         |         |       |              |              |               |                 |                 |               |        |            |      |        |               |                |           |          |      |       |         |          |        |       |
| 1         | 1   | 13.08.1999 | 208.20 | 0.21  | 121.90  | 62.00   | 22.40 | 1.90         | 144.36       | 197.15        | 9.96            | 1.17            | 69.53         | 63.71  | 28.00      |      | 7.5    | 1.40          | 140.00         | 3         | 300      | 0.04 | 0.03  |         |          |        | 0.056 |
| 2         | 60  | 11.10.1999 | 362.20 | 0.36  | 293.00  | 49.40   | 19.80 | 0.00         | 65.04        | 254.85        | 18.73           | 0.68            | 41.26         | 22.00  | 7.34       |      | 7.5    | 3.60          | 360.00         | 3         | 300      | 0.02 | 0.02  | 0.29    | 2.8      |        | 0.056 |
| 3         | 67  | 18.10.1999 | 441.70 | 0.44  | 365.80  | 60.50   | 15.40 | 0.00         | 101.23       | 264.76        | 42.80           | 1.29            | 54.24         | 2.89   | 23.00      |      | 7.6    | 4.20          | 420.00         | 5         | 500      | 0.04 | 0.03  | 0.24    | 2.4      |        | 0.105 |
| 4         | 70  | 21.10.1999 | 568.90 | 0.57  | 459.20  | 84.80   | 24.90 | 0.00         | 61.53        | 254.79        | 19.37           | 0.64            | 38            | 3.51   | 18.00      |      | 7.5    | 4.00          | 400.00         | 3.16      | 316      | 0.06 | 0.05  | 0.37    | 3.6      |        | 0.059 |
| 5         | 81  | 01.11.1999 | 474.80 | 0.47  | 374.50  | 75.20   | 25.10 | 0.00         | 37.87        | 251.03        | 7.85            | 0.26            | 24.97         | 4.79   | 16.00      |      | 7.5    | 4.20          | 420.00         | 1.73      | 173      | 0.11 | 0.09  |         |          |        | 0.024 |
| 6         | 82  | 02.11.1999 | 483.10 | 0.48  | 371.40  | 84.00   | 27.70 | 0.00         | 37.81        | 244.38        | 6.50            | 0.24            | 24.61         | 6.47   | 16.00      |      | 7.5    | 3.90          | 390.00         | 1.6       | 160      | 0.12 | 0.10  | 0.22    | 2.2      |        | 0.021 |
| 7         | 83  | 03.11.1999 | 500.40 | 0.50  | 390.80  | 80.50   | 29.10 | 0.00         | 38.18        | 240.99        | 5.69            | 0.22            | 24.29         | 7.99   | 17.00      |      | 7.5    | 3.80          | 380.00         | 1.47      | 147      | 0.13 | 0.11  |         |          |        | 0.018 |
| 8         | 84  | 04.11.1999 | 415.30 | 0.42  | 325.40  | 68.20   | 21.70 | 0.00         | 36.47        | 239.42        | 4.72            | 0.18            | 22.61         | 8.95   | 17.00      |      | 7.5    | 3.80          | 380.00         | 1.33      | 133      | 0.14 | 0.12  |         |          |        | 0.014 |
| 9         | 88  | 08.11.1999 | 495.60 | 0.50  | 455.60  | 28.00   | 12.00 | 0.00         | 23.95        | 238.34        | 0.69            | 0.03            | 9.38          | 13.85  | 15.00      |      | 7.4    | 3.90          | 390.00         | 0.8       | 80       | 0.15 | 0.12  | 0.2     | 2        |        | 9E-04 |
| 10        | 91  | 11.11.1999 | 231.20 | 0.23  | 114.80  | 90.30   | 26.10 | 0.00         | 26.33        | 235.17        | 1.19            | 0.05            | 11.97         | 13.13  | 15.00      |      | 7.4    | 4.00          | 400.00         | 0.85      | 85       | 0.18 | 0.15  |         |          |        | 0.002 |
| 11        | 95  | 15.11.1999 | 291.80 | 0.29  | 231.90  | 39.80   | 20.10 | 0.00         | 46.63        | 214.02        | 1.00            | 0.05            | 13.41         | 32.16  | 14.00      | 7.21 | 7.4    | 3.40          | 340.00         | 0.85      | 85       | 0.22 | 0.18  | 0.33    | 3.2      |        | 0.002 |
| 12        | 98  | 18.11.1999 | 410.00 | 0.40  | 330.10  | 59.00   | 20.90 | 0.00         | 54.40        | 213.82        | 4.74            | 0.24            | 27.3          | 22.12  | 15.00      |      | 7.4    | 3.30          | 330.00         | 1.48      | 148      | 0.21 | 0.17  | 0.24    | 2.4      |        | 0.018 |
| 13        | 102 | 22.11.1999 | 299.30 | 0.30  | 218.90  | 58.40   | 22.00 | 0.00         | 33.63        | 225.32        | 0.58            | 0.03            | 9.488         | 23.54  | 15.00      |      | 7.4    | 3.80          | 380.00         | 0.58      | 58       | 0.21 | 0.17  | 0.41    | 4        |        | 0.001 |
| 14        | 105 | 25.11.1999 | 272.90 | 0.27  | 170.20  | 70.80   | 31.90 | 0.00         | 39.98        | 218.38        | 0.57            | 0.03            | 9.598         | 29.78  | 13.00      |      | 7.4    | 3.80          | 380.00         | 0.65      | 65       | 0.25 | 0.21  |         |          |        | 0.001 |
| 15        | 110 | 30.11.1999 | 156.64 | 0.16  | 93.84   | 44.30   | 18.50 | 0.00         | 255.73       | 178.36        | 0.44            | 0.03            | 12.62         | 242.63 | 11.00      | 7.70 | 7.5    | 3.00          | 300.00         | 0.67      | 67       | 0.30 | 0.25  | 0.73    | 7.2      |        | 0.001 |
| 16        | 112 | 02.12.1999 | 164.20 | 0.16  | 115.90  | 33.30   | 15.00 | 0.00         | 55.98        | 211.50        | 1.76            | 0.10            | 18.24         | 35.88  | 12.00      |      | 7.6    | 3.00          | 300.00         | 1.02      | 102      | 0.20 | 0.16  |         |          |        | 0.006 |
| 17        | 116 | 06.12.1999 | 141.40 | 0.14  | 83.50   | 39.70   | 18.20 | 0.00         | 80.43        | 237.46        | 24.86           | 1.18            | 48.41         | 5.98   | 11.00      |      | 7.6    | 3.00          | 300.00         | 5.6       | 560      | 0.09 | 0.07  |         | 5.6      |        | 0.12  |
| 18        | 119 | 09.12.1999 | 345.60 | 0.35  | 293.50  | 34.50   | 17.60 | 0.00         | 49.54        | 254.07        | 14.27           | 0.49            | 31.24         | 3.54   | 12.00      |      | 7.6    | 3.90          | 390.00         | 3         | 300      | 0.08 | 0.07  |         |          |        | 0.056 |
| 19        | 124 | 14.12.1999 | 286.50 | 0.29  | 205.00  | 64.10   | 17.40 | 0.00         | 26.26        | 234.23        | 0.28            | 0.01            | 6.847         | 19.12  | 12.00      |      | 7.5    | 3.00          | 300.00         | 0.28      | 28       | 0.07 | 0.06  | 0.34    | 3.4      |        | 0.001 |
| 20        | 126 | 16.12.1999 | 230.80 | 0.23  | 197.70  | 6.60    | 26.50 | 0.00         | 24.54        | 236.27        | 0.37            | 0.02            | 7.638         | 16.51  | 12.00      |      | 7.5    | 3.00          | 300.00         | 0.45      | 45       | 0.06 | 0.05  |         |          |        | 0.001 |
| 21        | 130 | 20.12.1999 | 366.00 | 0.37  | 280.90  | 57.90   | 27.20 | 0.00         | 19.83        | 243.53        | 0.45            | 0.02            | 7.685         | 11.67  | 12.00      |      | 7.5    | 3.30          | 330.00         | 0.56      | 56       | 0.05 | 0.04  | 0.41    | 4        |        | 0.001 |
| 22        | 137 | 27.12.1999 | 302.00 | 0.30  | 200.10  | 71.80   | 30.10 | 0.00         | 64.77        | 247.01        | 21.16           | 0.88            | 39.48         | 3.25   | 10.00      |      | 7.5    | 3.20          | 320.00         | 5         | 500      | 0.03 | 0.02  |         | 5        |        | 0.105 |
| 23        | 144 | 03.01.2000 | 203.20 | 0.20  | 116.60  | 60.80   | 25.80 | 0.00         | 45.08        | 237.46        | 9.12            | 0.40            | 29.26         | 6.30   | 11.00      |      | 7.5    | 3.30          | 330.00         | 2.5       | 250      | 0.10 | 0.08  |         |          |        | 0.043 |
| 24        | 147 | 06.01.2000 | 183.80 | 0.18  | 137.20  | 33.70   | 12.90 | 0.00         | 25.44        | 233.64        | 0.43            | 0.02            | 7.809         | 17.18  | 11.00      |      | 7.5    | 3.40          | 340.00         | 0.54      | 54       | 0.13 | 0.11  | 0.57    | 5.6      |        | 0.001 |
| 25        | 152 | 11.01.2000 | 186.10 | 0.19  | 150.70  | 26.20   | 9.20  | 0.00         | 43.80        | 209.07        | 0.22            | 0.01            | 6.529         | 37.04  | 7.50       |      | 7.4    | 2.80          | 280.00         | 0.32      | 32       | 0.16 | 0.13  | 0.33    | 3.3      |        | 0.001 |
| 26        | 154 | 13.01.2000 | 304.30 | 0.30  | 244.20  | 43.40   | 16.70 | 0.00         | 20.33        | 232.36        | 0.12            | 0.01            | 3.849         | 16.35  | 8.00       |      | 7.4    | 3.90          | 390.00         | 0.07      | 7        | 0.17 | 0.14  | 0.29    | 2.9      |        | 0.001 |
| 27        | 158 | 17.01.2000 | 132.60 | 0.13  | 59.30   | 53.20   | 20.10 | 0.00         | 52.28        | 203.48        | 5.06            | 0.32            | 26.82         | 20.09  | 7.00       |      | 7.4    | 2.80          | 280.00         | 2.2       | 220      | 0.19 | 0.16  |         | 2.2      |        | 0.036 |
| 28        | 161 | 20.01.2000 | 141.60 | 0.14  | 102.10  | 26.20   | 13.30 | 0.00         | 31.90        | 217.62        | 0.14            | 0.01            | 4.595         | 27.15  | 7.00       |      | 7.4    | 3.60          | 360.00         | 0.12      | 12       | 0.22 | 0.18  |         |          |        | 0.001 |
| 29        | 165 | 24.01.2000 | 138.30 | 0.14  | 92.10   | 32.90   | 13.30 | 0.00         | 65.95        | 200.68        | 0.11            | 0.01            | 4.63          | 61.21  | 5.50       |      | 7.5    | 3.10          | 310.00         | 0.11      | 11       | 0.24 | 0.20  | 0.24    | 2.4      |        | 0.001 |
| 30        | 168 | 27.01.2000 | 150.30 | 0.15  | 105.70  | 31.80   | 12.80 | 0.00         | 19.71        | 239.95        | 0.13            | 0.01            | 4.5           | 15.08  | 9.50       |      | 7.5    | 2.80          | 280.00         | 0.1       | 10       |      | 0.00  |         |          |        | 0.001 |
| 31        | 172 | 31.01.2000 | 65.89  | 0.07  | 14.59   | 36.80   | 14.50 | 0.00         | 26.56        | 239.90        | 0.08            | 0.00            | 3.94          | 22.53  | 11.00      |      | 7.6    | 2.80          | 280.00         | 0.04      | 4        | 0.02 | 0.02  | 0.33    | 3.2      |        | 0.001 |
| 32        | 179 | 07.02.2000 | 50.06  | 0.05  | 13.20   | 19.91   | 16.95 | 0.00         | 31.86        | 228.17        | 0.10            | 0.01            | 4.61          | 27.14  | 8.00       |      | 7.60   | 2.40          | 240.00         | 0.10      | 10       | 0.04 | 0.03  |         |          |        | 0.001 |
| 33        | 182 | 10.02.2000 | 44.17  | 0.04  | 8.37    | 22.93   | 12.87 | 0.00         | 25.14        | 236.79        | 0.31            | 0.02            | 6.813         | 18.00  | 10.00      |      | 7.60   | 3.10          | 310.00         | 0.37      | 37       | 0.09 | 0.07  | 0.29    | 2.8      |        | 0.001 |
| 34        | 186 | 14.02.2000 | 45.88  | 0.05  | 19.34   | 17.58   | 8.96  | 0.00         | 48.57        | 218.06        | 0.12            | 0.01            | 5.041         | 43.40  | 8.30       |      | 7.60   | 2.70          | 270.00         | 0.10      | 10       | 0.13 | 0.11  |         |          |        | 0.001 |
| 35        | 189 | 17.02.2000 | 51.62  | 0.05  | 13.91   | 26.57   | 11.14 | 0.00         | 41.31        | 225.70        | 0.06            | 0.00            | 3.637         | 37.61  | 9.00       |      | 7.60   | 2.80          | 280.00         | 0.03      | 3        | 0.10 | 0.08  | 0.29    | 2.8      |        | 0.001 |
| 36        | 193 | 21.02.2000 | 47.40  | 0.05  | 16.15   | 20.29   | 10.96 | 0.00         | 150.44       | 204.87        | 0.01            | 0.00            | 1.748         | 148.69 | 9.00       |      | 7.6    | 2.10          | 210.00         | 0.001     | 0.1      | 0.09 | 0.07  | 0.15    | 1.5      |        | 0.001 |
| 37        | 196 | 24.02.2000 | 35.87  | 0.04  | 11.43   | 17.61   | 6.83  | 0.00         | 53.41        | 226.42        | 0.01            | 0.00            | 1.492         | 51.91  | 9.20       |      | 7.6    | 2.40          | 240.00         | 0.001     | 0.1      | 0.02 | 0.01  | 0.24    | 2.4      |        | 0.001 |
| 38        | 200 | 28.02.2000 | 45.40  | 0.05  | 15.05   | 20.54   | 9.81  | 0.00         | 123.47       | 204.58        | 0.01            | 0.00            | 1.53          | 121.93 | 7.00       |      | 7.6    | 1.90          | 190.00         | 0.001     | 0.1      | 0.06 | 0.05  | 0.24    | 2.4      |        | 0.001 |
| 39        | 203 | 02.03.2000 | 43.65  | 0.04  | 10.58   | 22.24   | 10.83 | 0.00         | 44.38        | 212.90        | 0.13            | 0.01            | 5.745         | 38.50  | 7.20       |      | 7.5    | 2.00          | 200.00         | 0.21      | 21       | 0.05 | 0.04  |         |          |        | 0.001 |
| 40        | 207 | 06.03.2000 | 38.74  | 0.04  | 10.48   | 19.16   | 9.10  | 0.00         | 103.16       |               |                 |                 |               |        |            |      |        |               |                |           |          |      |       |         |          |        |       |

# FSM Model

$$\text{TTHM} = 5 \text{ TOC}^{0.2}$$

$$(\text{Cl}_2\text{Appl}-7.6 \text{ NH}_3\text{-N})^1$$

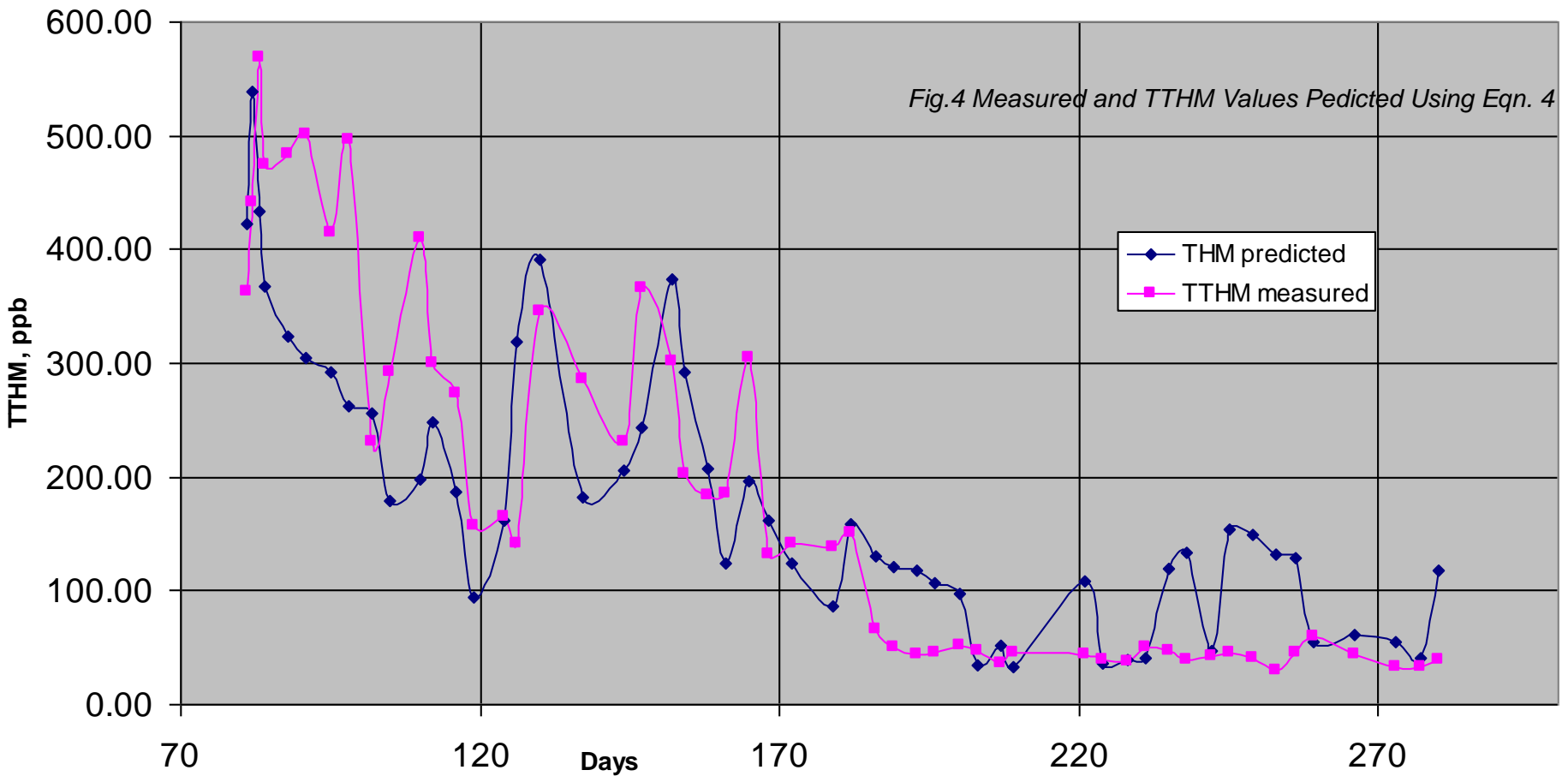
$$t^{0.7}$$

$$(1+\text{Br})^3$$

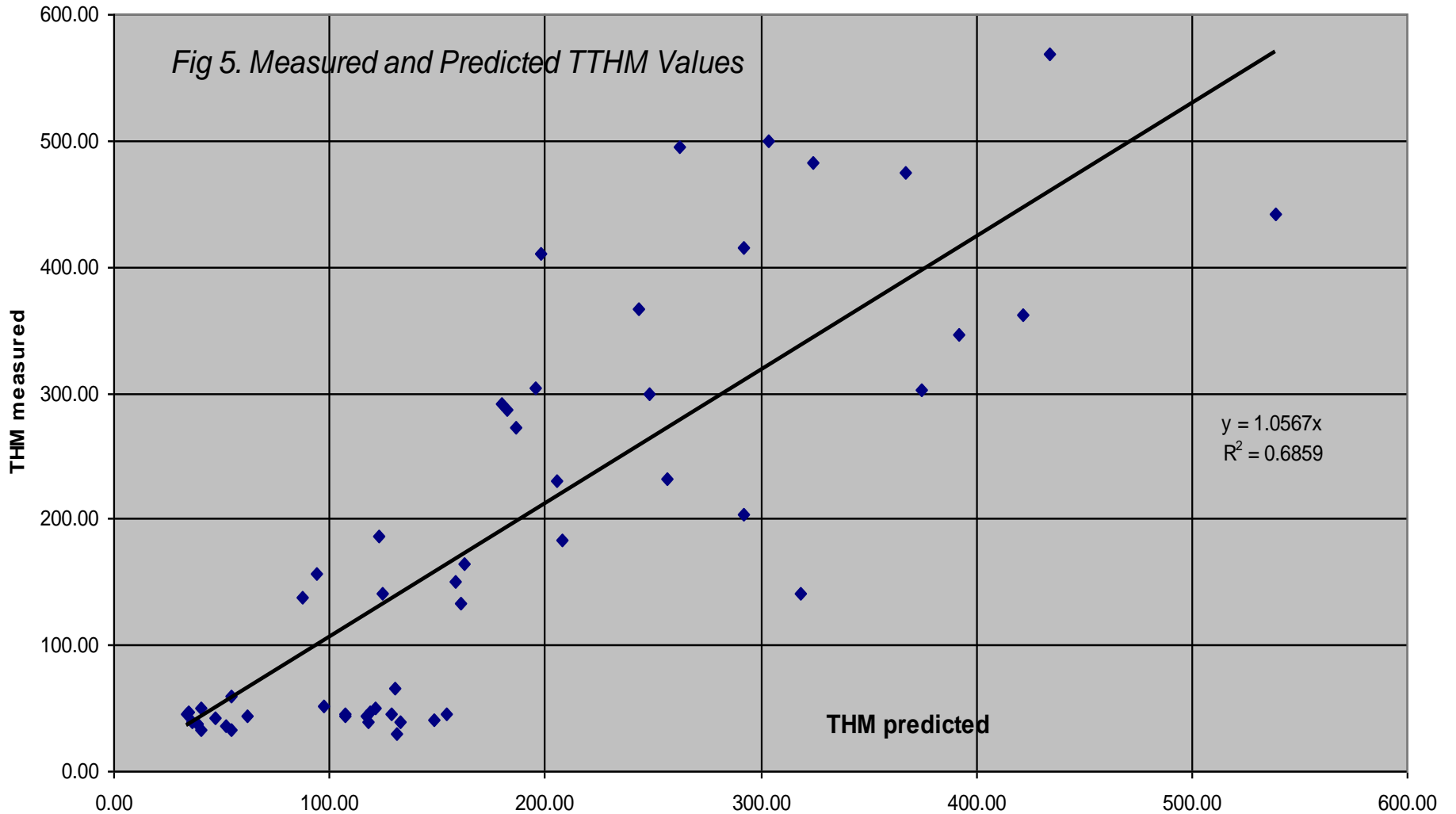
$$(\text{pH}-2.6)^{0.8}$$

$$T^{0.1}$$

# FSM Model



# FSM Model



# RESULTS: 1

–Pre Cl<sub>2</sub> = 4 ppm



–TTHM = 460 ppb

–Pre Cl<sub>2</sub> = 0 ppm (O<sub>3</sub> = 1 ppm)



–TTHM = 230 ppb

## RESULTS:2

TOC=1.6 mg/L



THM= 230 ppb

TOC = 1 mg/L



THM less 50 ppb



## RESULTS 3 : FSM Model

$$\text{TTHM} = 5 \text{TOC}^{0.2} (\text{Cl}_2 \text{Appl} - 7.6 \text{NH}_3\text{-N})^1 t^{0.7} (1 + \text{Br})^3 (\text{pH} - 2.6)^{0.8} T^{0.1}$$

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