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This manuscript has been submitted to the
Water Authority of Jordan and
Ministry of Planning, Jordan.

FINAL REPORT ON THE USE OF EAST GHOR CANAL WATER AS A RAW WATER SOURCE FOR TREATMENT PLANT TO SUPPLY DOMESTIC WATER TO AMMAN

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by

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May, 1985

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A. INTRODUCTION

I was invited to Jordan by the Minister of Planning and the President of the Water Authority to provide advice on the potential trihalomethane (THM) problem resulting from chlorinating East Ghor Canal water at the new Amman water treatment plant. References 1 to 8 comprise a list of some of the papers I have published in the THM area. A summary of my itinerary and observations made during my stay in Jordan from March 12 to 19th, 1985 are given in my preliminary report which is attached here as Appendix 1. In addition to my limited laboratory experiments and my visual observations of the East Ghor Canal, I collected a series of seven samples from the canal at 10 km intervals which were brought back to Canada. In this final report, I will describe the results of experiments I conducted on these samples at the Canada Centre for Inland Waters (CCIW).

B. THE TRIHALOMETHANE PROBLEM

(a) THM Potential Measurements

A series of chlorination experiments were conducted on canal water from Deir Alla. The water was chlorinated with an excess chlorine dose of 25 ppm and the THM production measured as a function of reaction time. These experiments were conducted at 20°C and at 35°C to simulate seasonal temperature changes in the canal water.

After quenching the residual chlorine with sodium thiosulfate, the 30 mL samples were extracted with 10 mL of pentane and the pentane extracts analyzed on a Varian 3700 gas chromatograph equipped with an electron capture detector. The column used was 2 m long x 4 mm ID, and was packed with 10% Squalane on Chromosorb P (80/100) mesh. The determination temperatures were as follows: column 90°C, injector 120°C and detector 300°C. The results of these experiments are shown in Table 1.

The data in Table 1 indicates that the THM potential of the canal water at Deir Alla is very high. The eight-day THM potention is 820 ppb at 20°C and 1900 ppb at 35°C. Fortunately these THM levels will not be reached during the normal water treatment process because of lower chlorine doses and shorter reaction times.

Table 2 shows the changes in the 48 hr - THM potential from the canal source to Deir Alla. The THM potential roughly doubles along the canal. This result is in good agreement with my earlier observations (Appendix 1, p. A3) showing the organic carbon concentration of the water approximately doubled from 1.4 to 2.6 mg/L along the canal. Most of the input of THM precursors to the canal must occur over the last 30 km, since there is little change in the THM potential between the source and the station half-way (30 km) along the 60 km canal.

(b) THM Production During Water Treatment

The short-term chlorine demand of the canal water from Deir Alla was found to be 3 ppm at 20°C and 3.5 ppm at 35°C. Therefore, the following treatment scheme was used to simulate the water treatment process:

Step 1 Prechlorination of Filtered Water (3 or 3.5 ppm chlorine) Reaction time = 2 hrs.

Step 2 Alum Coagulation (0,5 or 10 ppm Alum) Stirring Time = 1 hr.

Step 3 Filtration (medium porosity filter).

Step 4 Postchlorination (2 ppm chlorine).

Step 5 Water Storage and Distribution (Time = 2 days)

Because of the limited sample volume, we did not attempt to optimize the alum coagulation step but simply used typical alum doses to roughly estimate THM precursor removal by this process. After two days storage, the chlorine residual at 20°C was 0.4 ppm at 20°C and zero at 35°C, so somewhat higher chlorine doses than 2 ppm will be required in practice for postchlorination.

The THM data for this experiment are shown in Table 3. It is immediately apparent that the THM's produced by the water treatment process simulation are much lower than the THM potentials in Table 1. Prechlorination, postchlorination and storage for two days without alum coagulation produced the highest THM concentrations, 220 ppb at 20°C and 390 ppb at 35°C (Column 2, Table 3). The addition of 10 ppm alum reduced these values by about 50% to 87 ppb at 20°C and 180 ppb at 35°C. It may be possible to further reduce these values by a better optimization of the coagulant dose. Also a small improvement may be obtained by addition of the potassium permangamate (see reference 9).

It should be pointed out that these THM concentrations were obtained from samples collected in March - one of the wetter months in Jordan. During the dry summer months, there may be an increase in the concentration of organic THM precursors in the water. This coupled with the high water temperature may result in THM concentrations well above the 180 ppb found above. Further studies on the seasonal variations in THM precursor concentration will be required before the range of THM levels in the finished drinking water can be predicted.

(c) Bromide Concentration and Production of Brominated THM's

While I was in Jordan colorimetric measurements of bromide concentration were conducted at the Water Authority Laboratory. At that time, we estimated the bromide level in the water to be 1 ppm.

The bromide concentration of my second set of samples from the canal was determined at CCIW using a bromide ion-selective electrode. Standard solutions were made using 80 ppm chloride background electrolyte to match the chloride level in the canal water. This was necessary because the electrode's response to chloride is about 1/100 of its response to bromide. As an additional precaution, the method of standard additions was employed. The bromide concentrations in the seven canal samples was virtually constant ranging from 0.67 ppm to 0.78 ppm with a mean of 0.73 ppm. This supports the conclusion made in my preliminary report (Appendix 1, p. A3) that the bromide sources are ubiquitous to the area and cannot be controlled.

Tables 1 to 3 show that the majority of the THM's produced by chlorination of the canal water contain bromine. At 20°C brominated THM's comprise about 70 mole % (78 wt %) of the THM's at the high chlorine dose (Table 1) and an even larger percentage, 80 mole % (85 wt %) at the lower chlorine dose (Table 3). Interestingly, at the high chlorine dose, after eight days reaction time, 0.3 ppm of the bromide had been incorporated into THM's. Thus about 40% of the original inorganic bromide present in the water was converted to organic bromine under these reaction conditions.

(d) Human Health Implications of THM Results

In order to compare the drinking water THM concentrations with guidelines, we must first try to approximate what will be the likely THM concentrations in Amman's drinking water. Since health guidelines are based on THM carcinogenic potential (not acute toxicity) some type of mean value over the year, not the highest concentration, must be determined. If the canal's water quality in March, 1985 was typical of the entire year, we would crudely estimate the annual THM to be the average of the winter value, 87 ppb, and the summer value, 180 ppb, or about 130 ppb. If the organic content of the water doubled over the summer months, then the THM summer mean value could increase to about 360 ppb and give an annual mean of about 220 ppb. Optimization of the water treatment process would probably reduce these estimated means to between 100 ppb (same water quality) and 200 ppb (changing water quality). From these crude estimates, the mean THM concentration in drinking water produced by efficiently treating East Ghor Canal water would likely be in the 100 to 200 ppb range.

The recommended maximum concentration for total THM's in Canada is 350 ppb. This guideline is based strictly on health considerations (see enclosed document, Appendix 2, reference 10). The United States recommended level for total THM's is 100 ppb. This value is based not only on health considerations but on the technical achievability of the level. In other words, what THM level could reasonably be achieved with current technology (reference 11). Finally, the World Health Organization (WHO) has set a guideline of 30 ppb for chloroform alone which they admit in this document is very conservative (reference 12). Amman's water will likely be well below the Canadian guideline and marginally above the United States and WHO guidelines.

As mentioned in my preliminary report (Appendix 1, p. A8), there is still doubt as to the carcinogenic potential of the brominated THM's. However, based on current knowledge and the guidelines above, I do not believe that the THM's in drinking water from the new treatment plant will be a serious problem. Several cities in the southern United States produce similar quality drinking water with brominated THM's predominating with no apparent adverse effects (reference 13).

C. WATER QUALITY IN THE EAST GHOR CANAL

The concentrations of many chemical constituents do not change appreciably over the canal's length. The range and mean values for several parameters from my March survey are shown in Table 4. These values are closely comparable with historical canal data from the Water Authority Laboratory for the same time of year.

The historical water quality data does show that the canal water becomes more saline during the dry summer months. However, the very high total dissolved solids concentrations shown in Table A1 (Appendix 1) were found only at Deir Alla and not at upstream sites in the canal. This probably indicates backflow of water from the more polluted and saline Zarqa River to Deir Alla during the dry season. Some remedial measures may have to be taken to assure that this does not occur when the canal water is being pumped to the treatment plant.

Some parameters do change along the course of the canal, and these show some deterioration in water quality is occurring. The organic carbon level approximately doubles from 1.4 to 2.6 mg/L (Appendix 1, p. A3) as does the concentration of THM precursors (see Table 2). The suspended solids concentration also dramatically increases from 100 to 200 mg/L (this survey) and from 140 to 400 mg/L (earlier survey, Appendix 1, p. A3). At treatment plant design capacity of 32 million gallons per day, between 25 and 50 metric tons of soil per day will have to be removed from the water. It may prove cost effective to reduce soil erosion into the canal by constructing ditches along appropriate canal reaches.

As mentioned in my preliminary report (Appendix 1, p. A4), the bacterial quality of the water deteriorates drastically along the canal. This could seriously jeopardize the safety of the drinking water from the treatment plant. Because of the long storage time involved in transportation of the samples to Canada (≈2 days), and the inherent instability of bacterial populations, we performed the coliphage test rather than the standard fecal coliform test on the samples. Coliphage are more stable and, therefore, more likely to survive for this period than coliforms. Measurements on fresh samples at CCIW have shown that coliphage counts are normally between 1/7 to 1/8 fecal coliform counts. Using the coliphage test, we estimated that the fecal coliform populations were about 100 counts/100 mL at the start of the canal and about 1000 to 2000 counts/100 mL at Deir Alla. This data and the earlier data from the Water Authority Laboratory clearly shows severe bacterial contamination along the canal. Surveys should be conducted to identify sources, and action taken to control and stop inputs of sewage into the canal.

D. FINAL RECOMMENDATIONS

1. Microbiological

(a) An extensive microbiological survey should be conducted along the East Ghor Canal to locate and eliminate sources of fecal contamination (for further details see Appendix 1, p. A10).

(b) Once the treatment plant is operational, regular monitoring of bacteria counts and chlorine residuals should be conducted at the plant and throughout the distribution system.

2. THM's

(a) Even though this report shows there probably is not any pressing THM problem, because this conclusion was based on limited sampling, more work should be done to measure the seasonal variability of THM potential of East Ghor Canal water at Deir Alla.

(b) Once the treatment plant is operational, the actual THM concentrations produced by the treatment plant should be measured on a regular basis to obtain a good annual mean THM value.

(c) Experimentation should be undertaken to optimize THM removal by the treatment process.

Note: Microbiological quality of the water should not be compromised to reduce THM's.

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TABLE 1. THM Potential (μg/L or ppb) of East Ghor Canal Water at Deir Alla (Chlorine Dose, 25 ppm)

Reaction Time →	T = 20°C						
Compound	2 hrs	4 hrs	6 hrs	1 day	2 days	3 days	8 days
$CHCl_3$	29	33	43	53	72	87	330
$CHBrCl_2$	20	25	44	97	170	200	370
$CHBr_2Cl$	23	31	34	63	73	83	97
$CHBr_3$	7	10	9	14	15	12	22
Total THM	79	99	130	230	330	380	820
Reaction Time →	**T = 35°C**						
Compound	**2 hrs**	**4 hrs**	**6 hrs**	**1 day**	**2 days**	**3 days**	**8 days**
$CHCl_3$	37	49	76	200	220	680	1300
$CHBrCl_2$	56	95	140	310	320	410	430
$CHBr_2Cl$	41	53	69	91	100	94	100
$CHBr_3$	12	14	15	19	16	14	21
Total THM	150	210	300	620	660	1200	1900

TABLE 2. Changes in THM Potential (ppb) of Water Along the East Ghor Canal from the Source to Deir Alla (DA). (Chlorine Dose 25 ppm, Reaction Time 2 days).

Compound	Deir Alla	DA + 30 km	Source (DA + 60 km)
		T = 20°C	
$CHCl_3$	72	48	43
$CHBrCl_2$	170	57	41
$CHBr_2Cl$	73	53	46
$CHBr_3$	15	16	14
Total THM	330	170	140
		T = 35°C	
$CHCl_3$	220	110	120
$CHBrCl_2$	320	110	120
$CHBr_2Cl$	100	82	80
$CHBr_3$	16	22	20
Total THM	660	320	340

TABLE 3. THM Concentrtions Produced by Simulated Water Treatment of East Ghor Canal Water at Deir Alla (ppb).

Compound	THM's after Prechlorination Step 1*	THM's after Steps 1,2,3, 4,5* (Alum Dose = 0 ppm)	THM's after Steps 1,2,3, 4,5* (Alum Dose = 5 ppm)	THM's after Steps,1,2,3, 4,5* (Alum Dose = 10 ppm)
		T = 20°C		
$CHCl_3$	8	22	25	16
$CHBrCl_2$	9	61	29	20
$CHBr_2Cl$	21	84	40	28
$CHBr_3$	25	54	30	23
Total THM	63	220	120	87
		T = 35°C		
$CHCl_3$	8	71	47	31
$CHBrCl_2$	16	120	61	50
$CHBr_2Cl$	43	120	58	57
$CHBr_3$	43	75	41	43
Total THM	110	390	210	180

*See text page - for treatment steps.

TABLE 4. Chemical Constituents of the East Ghor Canal from Source to Deir Alla (mg/L)

Constituent	Range	Mean
Calcium	45.0 - 49.2	46.5
Magnesium	24.4 - 25.0	24.7
Sodium	60.4 - 69.3	66.8
Potassium	4.53 - 4.71	4.63
Nitrate + Nitrite	2.46 - 2.88	2.72
Sulfate	37.4 - 40.6	39.6
Chloride	79.7 - 82.5	81.2
Bromide	0.67 - 0.78	0.73
Silica	17.5 - 19.6	18.7
Total Dissolved Solids	420 - 460	440
Suspended Sediment	80 - 190	130
Turbidity (JTU)	18 - 74	39
pH	8.39 - 8.47	8.44

APPENDIX 1

PRELIMINARY REPORT

ON THE USE OF EAST GHOR CANAL WATER

AS A RAW WATER SOURCE FOR TREATMENT PLANT

TO SUPPLY DOMESTIC WATER TO AMMAN

BY

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SUBMITTED

TO THE

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MARCH 19, 1985

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ACTIVITIES IN JORDAN

March 13:

1) Meeting with Water Authority of Jordan (WAJ) and Ministry of Planning officials.

2) Visit to WAJ Laboratory.

3) Sampling of the East Ghor Canal from Deir Alla to Yarmouk River.

March 14:

4) Determination of suspended solids, dissolved organic carbon, bromide, chloride, pH and electrical conductivity of samples from the canal at Water Authority Laboratory.

March 16:

5) Meeting with Dr. M. J. Bino and Dr. I. Darwish of the Royal Scientific Society (RSS).

6) Examination of historical water quality data on the East Ghor Canal and Wadis flowing into the canal.

March 17:

7) Meeting with Dr. Omar Joudeh to discuss work progress.

8) Meeting with Dr. E. Salameh of the University of Jordan to discuss his report on the East Ghor Canal.

9) Discussion with Engr. A. Khatib regarding difficulties encountered in obtaining analytical results from the WAJ Laboratory.

10) Preliminary report writing.

March 18:

11) Briefing H.E. Dr. Abdullah Nsour, Minister of Planning, on progress of investigation.

12) Final sampling of Ghor Canal to obtain samples to take back to Canada for further analysis.

March 19:

13) Final meeting and report submission.

14) Return to Canada with Canal water samples to perform further testing.

OBSERVATIONS FROM CURRENT ANALYSES

The analyses required to assess the trihalomethane (THM) problem could not be performed in the WAJ Laboratory because of the lack of the appropriate standards. The equipment and technical support required to perform these analyses was available. A few simple tests were successfully completed and the results are as follows:

a) The suspended solids concentration gradually increased by a factor of three (~140 to 440 Mg/L) from the Yarmouk River inlet to Deir Alla suggesting significant inputs to the canal from Wadis and/or soil erosion along the canal banks.

b) The dissolved organic carbon (DOC) levels approximately doubled from 1.4 to 2.6 Mg/L over the course of the canal from the Yarmouk River to Deir Alla. This increase in DOC could provide much more precursor material that could react with chlorine to produce THM's.

c) The concentration of bromide along the canal was largely constant at ~ 1 ppm. This fairly high bromide level likely results from natural weathering processes in the Yarmouk River and Canal watersheds and probably cannot be controlled. This bromide level is sufficient to lead to a high predominance of bromine containing THM's rather than chloroform when this water is chlorinated.

d) No significant changes in pH, chloride or electrical conductivity were observed along the canal.

OBSERVATIONS FROM HISTORICAL WATER QUALITY DATA

The limited data base of water quality observations in the East Ghor Canal is somewhat surprising considering the millions of dollars being spent on a water treatment plant for the canal water. Also it does not appear that any studies have been conducted on the treatability of this water.

Since 1974 about 42 observations have been made from each of four sites along the canal and some data has been collected from Wadis entering the canal. These samples have been analyzed for many of the standard water quality parameters such as: total dissolved solids, pH, calcium, magnesium, sodium, potassium, chloride, sulfate, carbonate, bicarbonate and nitrate. Some samples have been analyzed for trace metals and other constituents. Only one or two observations of the microbiological quality of the water from each site along the canal have been made. This almost complete lack of microbiological data is shocking since microbiological purity is the first and most important requirement for using water for drinking purposes. When I asked why there were so few observation, I received the reply, "It is well known that the East Ghor Canal is grossly contaminated with fecal pollution".

a) Changes in Water Quality along the Canal.

A preliminary scan of the data does not indicate any gross changes in standard water quality parameters along the canal, although there may be an increase in total dissolved solids. The one microbiological survey conducted showed a greater than tenfold increase in fecal contamination (from 240 to greater than 2400 counts/100 ml) from the Yarmouk River to Deir Alla. Although water treatment with chlorine should destroy the bacteria and viruses,with a contaminated source there is the possibility of the presence of pathogenic protozoa that are resistant to chlorine. The treatment process may be partially effective in removing these protozoa but the only way to assure their absence is protection of the source water from fecal contamination. This is probably not possible for the East Ghor Canal.

b) <u>Water Quality at Deir Alla.</u>

The water at Deir Alla is of questionable quality for drinking particularly in the dry summer season, when compared with the World Health Organization Guidelines (See Table 1).

All these guidelines with the exception of nitrate, are related to aesthetics rather than health. This means there will likely be taste problems with water from the canal during the dry season. It should be noted that most of these parameters will not be changed significantly by the water treatment. In addition, the bacterial quality of the water is poor. THM guidelines will also be exceeded for the water but this will be discussed in detail separately.

Table 1

COMPARISON OF DEIR ALLA WATER QUALITY TO WHO GUIDELINES

PARAMETER	WHO GUIDELINE (MG/L)	OBSERVED CONCENTRATION RANGE (MG/L)	MEAN CONCENTRATION (MG/L)
Nitrate	10	5 - 42	15
Chloride	250	51 - 690	160
Total Dissolved Solide	1000	280 - 2250	690
Sodium	200	26 - 440	110
Sulfate	400	18 - 600	130

OBSERVATION FROM VISUAL INSPECTION OF CANAL

The canal is a completely unprotected water source with intensive human and animal activities around it. The following contamination may occur along the canal:

a) Sewage discharges from villages and private homes.

b) Detergents from clothes washing in and around canal.

c) Gasoline and oil seepage into the canal from gasoline stations in close proximity.

d) Low levels of pesticides from general usage and the potential of major spills because of transport of pesticide containers along the canal road.

e) Fertilizer inputs (plus phosphates from sewage) which could lead to algal blooms which pose severe taste and odour problems as well as the potential direct toxicity from blue-green algal toxins.

Except for limited bacterialogical data the above problems have not been substantiated by scientific observations. Studies should be conducted to see whether or not these problems do in fact exist.

COMMENTS ON DR. E. SALAMEH'S REPORT AND THE TRIHALOMETHANE PROBLEM

Many of the general observations made by Dr. Salameh, are in agreement with my general comments above. His water quality measurements for standard parameters are in good agreement with those of the WAJ. I have no reason to doubt the accuracy of the THM data in Dr. Salameh's report, which ranged from 40 to 160 ppb for total THM's. The predominance of brominated THM's is expected because of the fairly high bromide concentrations in the water. These data were obtained for chlorination reaction times of 24 hours at ambient temperature = 20°C. The water treatment process of alum coagulation may be capable of reducing these values by about 50%. In summer time this reduction would be offset by the increased temperature of the water to 30 - 35°C, which would lead to about a 50% increase in THM yield. Thus the range of THM values in Dr. Salameh's report may indeed be close to what will eventually be produced by the plant. More investigations will be required on the effect of reaction temperature and time, and on the effect of the water treatment process before a final answer can be provided.

Given the current information, is a THM level of 40 to 160 ppb a health problem? The THM standard in the United States is 100 ppb for total THM's, whereas, Canada's standard is 350 ppb. If these standards are a true indication of health hazard then values in the range found in Dr. Salameh's report are probably not a problem. Testing of the brominating THM's with rats and mice has still not been completed so it is not known at this time whether they are more toxic and/or carcinogenic than chloroform. The brominated THM's are more mutagenic than chloroform in the Ames Test, but is hard to extrapolate this data to humans. If research shows that the brominated THM's are more carcinogenic than chloroform, because Amman's water will likely contain a high proportion of brominated THM's, a lowering of these standards

may be necessary in the future. At this time THM problem does not seem as serious as other problems mentioned in this report.

PRELIMINARY RECOMMENDATIONS

1) Because of the actual and potential water quality and possibly water quantity problems with the East Ghor Canal water, an alternate source should be seriously considered. The Mukheiba well or water from the Yarmouk River inlet is of much better quality and more suitable for drinking purposes. The additional cost of the pipeline to these locations would be recovered over a period of time by reduced treatment plant operating costs. Much lower amounts of chemicals would be required to treat this much purer water source. The final product drinking water would definitely be of superior quality.

2) If plans proceed to use, East Ghor Canal water detailed surveys should be conducted to identify and to eliminate major contaminant sources to the canal.

a) An extensive microbiological survey every one or two kilometers along the canal and in all inlets to find major sources of fecal contamination is required. I suggest that a person outside the WAJ Laboratory be responsible for developing the survey plan, for compiling the data and for following through with required cleanup action. A person from the WAJ Laboratory should collect the samples using the proper laboratory protocols. Analyses should be performed as quickly as possible using more dilutions to get above the 2400 + counts routinely recorded as a maximum value.

b) Similar detailed surveys for dissolved organic carbon and suspended solids would also be useful.

c) Measurements should be made to quantify the flows of the various inlets to the canal and in the canal itself so their significance can be evaluated using the analytical data.

d) Some analyses should be conducted on pesticide concentrations in the canal and wadis. I suggest that the WAJ contract this work to the RSS.

Surveys (a), (b) and (c) should be conducted periodically at least once a month. Although the WAJ Laboratory has the capability to perform the analyses for such surveys, more productivity and organization will be necessary to meet the increased analyses requirements.

3) Prohibit the transport of pesticides along the canal road and dumping of pesticides into the canal. Apparently 500 Jordanians are killed each year by careless use of these chemicals. A concerted education program on the hazards of the chemicals to users and to the canal water will be required.

4) Algal and p rotozoa studies in the canal to estimate populations and their significance to water quality. Elevated populations of these organisms will definitely lead to water treatment problems.

5) Detailed studies on the kinetics of THM formation of Deir Alla and other potential water sources (in Canada), Technology transfer of analyses and experimental methods for these determination to WAJ Laboratory.

<u>NOTE:</u>

A more complete and detailed plan for future proposed scientific studies will appear in final report.

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APPENDIX 2

Guidelines for Canadian Drinking Water Quality 1978

SUPPORTING DOCUMENTATION

Published by authority of the
Minister of National Health and Welfare