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USE OF CHLORINE DIOXIDE TO REMOVE FISH PATHOGENS FROM GARRISON DIVERSION WATER

prepared by:

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presented to:

Department of Civil Engineering
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in partial fulfillment of the requirements for the degree of "Master of Engineering"

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Dr. Ronald Apanian deserves thanks for the gentle persuasion he extended during my studies with the Department of Civil Engineering at the University of North Dakota.

My wife Phyllis deserves thanks for proof reading my paragraphs, and my children Heidi and Justin get a measure of appreciation for 'pushing' keyboard buttons while printing.

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ABSTRACT

This report considers the use of chlorine dioxide as an alternate disinfectant for the removal of biota from Garrison Diversion water. Laboratory testing has shown that chlorine may not be an acceptable disinfectant because it can produce carcinogens from side reactions with constituents found in natural surface waters.

This study used Lake Sakakawea water collected at the Snake Creek Pumping Station located on the eastern shore. Water samples were of direct filtration effluent from a laboratory scale filter column. Samples were gathered at several different turbidity levels. The "DPD" method, as published in "Standard Methods for the Analysis of Water and Wastewater," was used to measure the residuals of chlorine dioxide after dosing the samples and allowing a contact time of 10 minutes.

The data was graphed using a spreadsheet and tables were used to determine dosages required for the various turbidity levels treated. Aliquots of samples were plated and incubated to determine effects of disinfection. All procedures were followed as out-lined in "Standard Methods for the Analysis of Waters and Wastewaters."

Chlorine dioxide will produce a residual concentration of chlorine species in the dosed sample. This residual usually consists for the most part of unreacted chlorine dioxide, which is called a free residual. The results of this study indicate that chlorine dioxide is an effective means of removing

pathogenic bacteria and viruses from Garrison Diversion water when disinfection is carried out under the standard conditions used in the laboratory and with a 10 minute contact time.

The cost of the treatment has been estimated using conventional municipal drinking water process trains. Cost of treatment varies indirectly with treatment plant capacity. A treatment plant for domestic water supply is a good example of return to scale, to use a term from economics.

The cost of using chlorine dioxide as a disinfectant is on parity with other chemicals such as chlorine, chloramine and other chlorine-based dosing additives when used in a large treatment system such as Garrison Diversion would require.

More research is needed to determine the medical effects of such disinfectant byproducts as chlorite and chlorate. These byproducts are invariably present when dosing water with chlorine dioxide, though not always detectable.

1.0 INTRODUCTION

The use of an alternate disinfectant, chlorine dioxide, is described in this report. The primary differences between chlorine dioxide and chlorine (which is the most commonly used disinfectant in the U.S.) are (1) that chlorine dioxide is usually generated at the site of use and (2) it does not produce the types of by-products that are commonly produced by chlorine. Chlorine dioxide is not considered to be as strong of an oxidizer as chlorine, however it has been used effectively as a municipal water disinfectant for many years.

Chlorine has the ability to oxidize a wide variety of compounds and is considered to be a very effective chemical for disinfection of municipal water, treated sewage and sludges. Presently, chlorine is considered undesirable for use in some surface waters because it will combine with organic materials that are present. Some of the by-products produced from chlorination are suspected to be carcinogenic. One such by-product is chloroform. As a group, these chlorination by-products are referred to as trihalomethanes (THMs).

Research is presently being done to evaluate disinfection of large volumes of water that may be diverted from the Missouri River Basin into the Red River Basin via the Sheyenne River. The purpose of this study is to evaluate the use of chlorine dioxide to inactivate fish pathogens, when they exist, in the diverted Missouri River water.

This diversion would benefit North Dakota in a multitude of ways. For example, each of the communities along the Sheyenne River would benefit because they could support a larger population and attract industry. Grand Forks and Fargo would benefit from the increased flow in the Red River for similar reasons.

The diversion water is part of the pool impounded behind the Garrison Dam and is referred to as Garrison Diversion water. Garrison Dam is a structure on the Missouri River in North Dakota designed to impound high river stages. The dam can be used to control flooding or to raise the river stage for downstream transportation interests of the Missouri-Mississippi River system.

Almost all of the impounded water in the Missouri River Basin originates within the boundaries of the United States. Canada's interest in the diverted water relates to the effect the diversion might have on the rivers and lakes in Manitoba and Ontario provinces. Garrison Diversion water is believed to harbor biota that may degrade the Canadian habitat through injury to existing fish stocks and, or, allow competing 'rough-fish' species to enter the waters of northern Manitoba.

The United States and Canada jointly signed a treaty that restrains either country from activities that degrades water quality on either side of the international boundary. Thus, the Boundary Water Treaty of 1909 is cited as the benchmark that enjoins the United States from diverting Garrison Water to any point in which it will mingle with Hudson's Bay Drainage waters. It seems that if the Canadian fears of such contamination can be allayed, the spirit of cooperation will remain intact even with Garrison Diversion water crossing into the Canadian drainage basin.

2.0 BACKGROUND

Fish pathogens are organisms, such as bacteria and viruses, that will cause disease in individual fishes or in fishery stocks. There are many different diseases that effect fish, but one in particular, 'red-mouth', has been mentioned as a threat to the Hudsons Bay fisheries. Since the causative bacteria of red-mouth, Yersinia ruckeri, is known to be present in Missouri River, it is feared that this microorganism will migrate north through the Red River and become established in Canadian waters. Effected fish are not suitable for table use, and stunting of these fish means they will never approach trophy size.

Even though the Garrison Diversion project could possibly affect Canadian Fisheries, the benefits to North Dakota are so great that the completion of the project is still being sought. Increasing the water supply in eastern North Dakota is important to the agricultural and industrial economy of the region. Even without irrigation of field crops, increased water volumes will allow value-added operations to be used on the crops that are being produced. More potato processing plants could be brought on line, as an example. Grain processing installations, such as at the North Dakota State Mill in Grand Forks, could be expanded to increase flour and semolina production. Large volumes of water for processing, daily cleaning and fire control are necessary for increasing the industrial capacity and furnishing increased domestic supplies. Increased recreation capacity of all water sports would be realized.

2.1 Boundary Water Treaty

The Boundary Water Treaty of 1909 between the United States of America and Canada recognizes a shared responsibility of the signers toward maintaining the quality of a primary water source. The treaty contains wording to the effect that neither signee will support nor allow activities that will result in degradation of water quality on either side of the boundary (2).

The Canadian government diplomatic transmittals cite the problem of foreign biota invading their cold water lakes and rivers. Biota is a term that encompasses all of the flora and fauna of a region. Their concern centers on the aquatic species relative to the biota. They believe the northern cold water fisheries are in biological balance and must not be disturbed by introduction of foreign species of any type (5). This does not allow for the fact that introductions might be made by bait species that visiting sportsman could carry with them and inadvertently introduce to northern lakes. Nor does this policy consider the possible transfer of biota by migratory animals. Such biota transfers may have already been taking place over a long period of time.

The Canadian officials believe that the transfer of biota between the watersheds of the Missouri River and the Red River, to which the Sheyenne River is tributary, is undesirable. They cite the risk of infection by disease, insurmountable competition between their native species and strains with those from the

Missouri River Basin and the likelihood of introduced algas causing 'blooms' on their northern lakes and rivers (5).

Canadian fisheries are valuable to both countries. Canadian commercial fisheries export fish to the United States. Sportsmen from both countries enjoy fishing the cold waters of North America. Manitoba and Ontario, both in the Hudson's Bay Drainage area, contain a significant portion of the northern cold water fisheries in North America. Loss of fish stocks would impact cross-border traffic adversely and displace part of the present work force of the commercial fisheries, fishing guides and the support staff presently in place in Manitoba and Ontario provinces. The Great Lakes, particularly Lake Michigan and Lake Superior, provide examples of what can be expected from introduction of exotic species. When such degradation occurs, it may take a long time to reestablish a biological balance.

2.2 Pick-Sloan Plan

The Lewis and Clark Expedition of 1805-06 delivered lengthy reports on geographical, geological and meteorological conditions of the northwestern portion of the Louisiana Purchase. The reports caused attention to be given toward internal improvements to this portion of the North American continent, and in particular, to this new United States Territory.

As noted in the diaries of Lewis and Clark, floods were often severe along the Missouri River. Low water levels in the rivers hampered internal transportation. Many plans were drawn up over time to address high water flows of the Mississippi-

Missouri River system. Flood damage was a recurring problem to those situated near the river system and its tributaries. High flows normally occurred in the early spring months as spring melt water and spring rain run-off entered the streams. Later in June, melt water from the snowpack in the Rocky Mountains of Montana would cause a high peak on the annual hydrograph. The Missouri River held the potential for at least two damaging floods each year. After the floods passed, the downstream transportation interests would often complain of water too low to float fully loaded commercial craft. Since a large amount of commerce is carried on along the Missouri River, each river community might well be expending resources to fight floods or 'waiting out' extended slack water periods while the hinterland was in drought (6).

Clearly, the Missouri River would have to be managed. It was during the national defense effort of World War II that the value of an unhindered transportation system in the nation's midsection was fully recognized. With both coasts vulnerable to enemy attack, increased attention was paid to developing the more secure interior of the country to furnish defense. Development of the industrial capacity of the interior was needed. The United States Army Corps of Engineers was called upon by the administration to get a feasible management plan before the United States Congress that legal action might be taken (1).

The Pick-Sloan Plan was developed as a management tool to be applied to the Missouri River. It was to address the transportation needs, mitigate flood damage and argument domestic and municipal water supplies. As such, the plan was made up from feasible parts of the many management plans. Those plans that had been drawn-up and studied over the years addressed special problems on the rivers (3). The plan that was needed would cover all the contingencies to make the river an efficient artery throughout the drainage region.

World War II had shown the need for a dependable Midwest agricultural production, processing and transportation system. The lessons of efficiency toward national defense were not lost on the United States lawmakers. The Pick-Sloan Plan was ratified through an Act of United States Congress in 1944 as part of the Flood Control Act.

The Pick-Sloan Plan would dam the Missouri River in Montana, North Dakota and South Dakota. The dams would each impound a large volume of water. Management of these dams would limit the river stage to control flooding throughout the length of the Missouri River. This management plan would address the complaints of flooding and that of the low water flows, while making water available for use on the drought-plagued "High Plains" of the US Midwest. Such a water supply was needed to supplement the low volumes and poor quality available. In North Dakota, water that was available in quantity to the farms, ranches and village communities might be of coal vein aquifers. The strong dark color caused this water to be unusable for many domestic purposes.

Capital costs of the initial structures called for in the Pick-Sloan Plan, such as the rolled earth dams, powerhouses and the affiliated control equipment, would require underwriting by the United States Treasury to obtain construction funding.

To address the costs of operation and maintenance of this river management system the Pick-Sloan Plan integrated electric power generation. Base flow of the river would be met by releasing water through penstocks to operate turbines connected to generators. The power demand was present all along the river and into the hinterlands. The power would be sold to raise funds. Water sales would generate funds to pay for infrastructure needed to divert and deliver water from the dammed impoundments (9).

The problems of the dry 'High Plains' of the US Midwest would be mitigated through diversion of part of the impounded water. North Dakota expects diversion of water from the Garrison Dam. This dam held the notoriety of being the largest in the world of its type, a rolled earth structure, at the time it was designed and built. Its pool surface is about 250 mi^2, and the depth of the pool is in excess of 100 feet at the dam structure. Drawdown of the pool level has occurred when downstream demand has been great, but there never has been a danger of draining the pool and stopping the turbines.

North Dakota has a major population base in the eastern portion of the state. The two largest communities in this portion of the state, Grand Forks and Fargo, use the Red River of the North and its tributaries as their municipal water source. Every community in eastern North Dakota is dependent on river flow for a major portion of their water supplies. Presently, these communities need supplemental volumes added to their water supply. The supplemental water is available from the impoundment, Lake Sakakawea, a large water body behind Garrison Dam (7).

The delivery system proposed for supplementary water is by canal to the Sheyenne River bed. The supplementary water supply would be made available to the communities along this river since they do harbor families that were displaced by the Garrison Dam and its pool. These communities also qualify due to the general intent of the Pick-Sloan Plan. The whole length of the Sheyenne River Valley will benefit from diversion water by virtue of enhanced municipal water supplies, clean recreation water and suitable supplies for garden and agricultural crop irrigation. Other river beds and channels are to be used in the water diversion portion of the Pick-Sloan Plan if they are conveniently located and have sufficient capacity. The Sheyenne River bed is unique in that it is conveniently located to carry water in the capacity needed to the eastern portion of the state. Its route is long and can serve a large population base in an area that needs supplemental water to continue development. River control structures are planned to maximize the efficiency of water flow along its length (4, 7, 10).

3.0 RESEARCH THEORY

Efforts have been made by the State of North Dakota and by the United States government to remain in compliance with the Boundary Waters Treaty of 1909 as well as with the changing interpretation regarding diversion of water. As a part of this effort, research has been carried on to find efficient methods to remove water-borne materials such as algae, live fish, fish eggs, and fish pathogens from Garrison Diversion before it enters Canadian Waters. Fish pathogens are the most difficult to deal with since bacteria and virus are difficult to remove from water. The laboratory study discussed in this paper focuses on the use of chlorine dioxide as a disinfectant to inactivate bacterial and viral threats to fish.

The larger-sized contaminant items of interest are removable by sand filtration. Sand filtration to produce potable water is common. Laboratory study on the use of "Direct Filtration" with filter aids shows high efficiency in removing turbidity from Garrison Diversion source water from Lake Sakakawea. Filtration tests performed at the University of North Dakota have shown that the turbidity of Lake Sakakawea water can be readily reduced to levels of 0.5, 0.75 and 0.90 NTU by direct filtration. However, direct filtration did not consistently remove significant numbers of bacteria and viruses from the water (28). Efficient inactivation of the bacteria and viruses in the water will require some type of disinfection process.

The laboratory studies carried on at the University of North Dakota were designed to gain design data for a chlorine dioxide disinfection system. The main design considerations were to determine the chlorine dioxide demand, the necessary disinfectant concentration (C) and contact time (T) for the system. The product of the disinfectant concentration and the contact time is referred to as the CT value. Based on this parameter, a contact basin can be designed for the system. To minimize the size of the basin, it is important that the mixing take place through a short diffusion path because intimate contact of the water and disinfectant is required for efficient operation. Thus, it is important to be able to predict the instant when blending has occurred.

Disinfection of water involves inactivation of the most persistent species of aquatic microorganisms. These are usually the most threatening to human health. Studies have shown the disinfecting chemical's effectiveness can be modelled using a mathematical product of its concentration, usually in mg/L, and the number of minutes the microorganisms are exposed to its oxidizing activity (i.e., the CT value). Some other important parameters for the disinfection process include pH and water temperature.

Chlorine dioxide is generated in a reactor using strong acid and some precursor of chlorine, such as sodium chlorate. It evolves as a gas. When cleaned of impurities, the gas stream is directed into water. It is handled as an 11% by weight solution.

Chlorine dioxide has been extensively studied in the laboratory. It has been found that its oxidizing activity for inactivation of microorganisms is dependent on water temperature. The other common disinfectants are pH dependent to a high degree as well as temperature dependent. This makes chlorine dioxide more effective at high pH than chlorine. This is because chlorine will form a less effective disinfectant, hypochlorite ion (OCl^-), at high pH values. As a water disinfectant, hypochlorite ion is not as effective as hypochlorous acid (HOCl), the form present at lower pH. In normal surface waters, the pH range is 8 to 9 (11).

Chlorine dioxide, as a water disinfectant, is sometimes described as 'short-lived'. This is in reference to remaining concentrations of the chloro-species. The residual level is easily removed by aeration. Aeration can occur unintentionally. Pumping of water will entrain air. Air enters pumped water as a fugitive through the pump packing or seals and along flange gaskets. It will be purged by automatic valving at high points in the pipeline as a mixture of air and chlorine dioxide gas. At high dissolved concentrations in water, chlorine dioxide outgases. This will begin at about 5 mg/L, STP. However dosage is never at this level of concentration for most waters. Chlorine dioxide is also light sensitive and will be removed by photo-activity.

3.1 Disinfectant Removal

In some cases it is necessary to remove all traces of chlorine dioxide and the reduced forms of this compound, chlorite and chlorate. There is a danger that chlorite will cause methemoglobin in mammals, a form of anemia. Humans infants will be the most visible target of this contaminant. Methemoglobin causes a bursting of the red cells in the blood and interferes with the oxygen transport. Infants are the most vulnerable to this medical condition. More medical research is needed to determine dangerous side effects chloro-species concentrations pose to the public health. Biological studies are also required to find the degree of danger chlorate poses to aquatic species.

3.2 Mixing

Tables have been developed and published to indicate the contact time and disinfectant concentration for common disinfectants that are be required to cause inactivation of bacteria and viruses for given water parameters such as temperature and pH. The derived data can be found in the literature in CT tables (15).

Since chlorine dioxide is temperature sensitive, CT versus temperature tables have also been constructed to indicate the efficiency of this disinfectant as a function of temperature. Generally the water pH must be between 8 and 11 for effective use of chlorine dioxide. Mixing the filtered water with chlorine dioxide must be performed in a manner that achieves a quick blend with minimal turbulence. This factor may preclude adding the disinfectant in a pump intake. Mixing turbulence of the disinfectant in pipe flow is not easily measured. A high

Reynolds Number (N_{Re}) generally indicates that high fluid turbulence occurs during flow.

Mechanical mixing of water is commonly done with an electrically powered impeller mounted in a specially designed tank (10). A measure of the mixing efficiency of a system is the specific energy (G), which is a measure of the mixing power applied to a solution. More research is needed in the area of disinfection of water with chlorine dioxide. The research can productively be directed toward removal of by-products as well as toward efficient blending of the produced water with the liquid disinfectants.

Chlorine dioxide is used in drinking water disinfection treatment because it will oxidize dissolved organic molecules. It is effective in low concentration. It is readily available. A survey by the American Water Works Association conducted in 1987 reported 22 of 907 water supplies were using chlorine dioxide, at least in part, for municipal water supply disinfection (21). Chlorine dioxide has a distinct advantage over chlorine because it does not react with acetone, ammonia or methane to form trihalomethanes. Thus, it remains in the water as a strong oxidizing molecule targeting other organic materials.

A major disadvantage of chlorine dioxide is that some of its breakdown products are toxic. The toxicity of chlorite (ClO^{-2}) has been established in the laboratory. The LD_{50} of sodium chlorite is listed as 140 mg/kg of body weight. At this dosage, one-half of the target population did not survive. If all the chlorine dioxide dosage in water treatment reduces to chlorite, the LD_{50} is about 105 mg ClO_2/kg body weight (7).

EPA suggests a chlorine dioxide dose that will limit the total oxidant level (TOL) to 1.0 mg/l (15). At this level of chlorite there is no danger of exceeding the LD_{50} established for rats. This data pertains to drinking water disinfection. The use of chlorine dioxide for fish pathogen inactivation will have to meet the in-stream standard for released water as published by the EPA. Chlorinated products are corrosive to gill membrane at low concentration. Trimming of excess chlorite will be required if the treated water effluent fails to meet the standard. Aquatic organisms below fish in the food chain are effected by chlorine dioxide reaction molecules. It has been shown that using sulphur dioxide to destroy chlorine dioxide and chlorite residual in water will leave chlorate, a reduced species of chlorine dioxide, and expose benthic organisms to possible risk that, so far, has not been assessed (11).

The in-stream standard will preclude the maintenance of high residuals of chlorine dioxide, chlorite and chlorate. All the disinfection will have to be accomplished in the contact basin. This will require adherence to all suggested design parameters outlined by EPA and the North Dakota Health Department (23). At the present time there is no problem meeting them.

3.3 T_{10}

The T_{10} is a symbol used in design to indicate the time frame that a contact basin has for retaining 90% of the flow-through volume. Thus, the symbol is used as an indication of how well the design is able to meet the CT of EPA criteria.

4.0 RESEARCH METHODS

To obtain samples of filtered water for the disinfection tests, a laboratory scale filter column was installed at Snake Creek Pumping Station located near Garrison, ND, on the eastern shore of Lake Sakakawea. Samples of unfiltered (raw) and filtered water were collected in 20 liter polyethylene containers. These samples were transported to the laboratory of the University of North Dakota, Grand Forks. The samples were kept refrigerated until tested. All samples were re-constituted by shaking for several minutes prior to use. The laboratory testing method used to measure chlorine dioxide concentration in water was the DPD Titrametric Method (tentative) contained in "Standard Methods, 1985."

Tests were performed on the water samples to generate data for the design of a chlorine dioxide disinfection system. These tests measured the chlorine dioxide demand of the water. The chlorine dioxide demand indicates the amount of chlorine dioxide that must be applied before a free residual is established. This determination is important because effective inactivation of bacteria and viruses requires a free residual. Chlorine dioxide demand can be caused by the presence of reduced inorganic elements such as iron or manganese, organic compounds, or ammonia in the water. A residual indicates the above ions and species have been contacted and chemically reduced.

To measure the demand of the lake water samples, various amounts of chlorine dioxide were added to the water and allowed to react for 10 or 20 minutes. At the end of the reaction time, the concentration of free chlorine dioxide remaining in the water was measured and the difference between the applied chlorine dioxide concentration and the residual chlorine dioxide concentration was taken as the demand of the water.

5.0 RESEARCH RESULTS AND DISCUSSION

Four different water samples obtained from direct filtration tests performed on Lake Sakakawea water were evaluated for chlorine dioxide demand. Tables 1 through 4 show the results of laboratory tests done to measure ClO_2 demand. The data from the tests is graphed in Figures 1 through 4. Table 1 contains demand data collected for the raw (unfiltered) Lake Sakakawea water. All analyses were carried out using 10 minutes of contact time with chlorine dioxide, in the dark. Based on the results of the data contained in Table 1 the average chlorine dioxide demand was 0.96 mg/l as ClO_2. Table 2 contains demand data collected for filtered Lake Sakakawea water having a residual turbidity of 0.5 NTU. The average chlorine dioxide demand of this sample was 0.8 mg/l as ClO_2. Table 3 contains demand data collected for filtered Lake Sakakawea water having a residual turbidity of 0.75 NTU. The average chlorine dioxide demand for this sample was 0.86 mg/l as ClO_2. Table 4 contains demand data for filtered Lake Sakakawea water having a residual turbidity of 0.9 NTU. The average chlorine dioxide demand for this sample was 1.47 mg/l as ClO_2, chlorine dioxide.

The results of the chlorine dioxide tests indicate that the demand of the water tended to decrease as the level of filtration increased. (An increased level of filtration was indicated by a reduced residual turbidity.) Thus it can be concluded that prefiltration of Lake Sakakawea water increased the disinfection efficiency of chlorine dioxide treatment by reducing the disinfectant demand of the water.

TABLE 1

RESULTS OF CHLORINE DIOXIDE DEMAND TESTS PERFORMED ON THE UNFILTERED LAKE SAKAKAWEA WATER

Sample #	Dose ($mg/l\ ClO_2$)	Residual ($mg/l\ ClO_2$)	Demand ($mg/l\ ClO_2$)
1	0.875	0.0*	0.875
2	1.225	0.8	0.425
3	1.4	1.03	0.37
4	1.575	0.8	0.775
5	1.75	0.65	1.1
6	2.1	0.85	1.25
7	2.625	1.4	1.225
8	3.063	1.45	1.613
9	3.5	2.2	1.3

* Since there was no residual for this sample, the demand of the water was not fully satisfied.

TABLE 2

RESULTS OF CHLORINE DIOXIDE DEMAND TESTS PERFORMED ON THE FILTERED LAKE SAKAKAWEA WATER HAVING A TURBIDITY OF 0.5 NTU

Sample #	Dose mg/l ClO_2	Residual mg/l ClO_2	Demand mg/l ClO_2
1	1.25	0.45	0.8
2	1.5	0.65	0.85
3	1.88	0.95	0.93
4	2.13	1.5	0.63
5	2.63	3.350	---*
6	3.13	3.75	---*

* Indicates the demand was not defined, since the residual was greater than the dose.

TABLE 3

RESULTS OF CHLORINE DIOXIDE DEMAND TESTS PERFORMED ON THE FILTERED LAKE SAKAKAWEA WATER HAVING A TURBIDITY OF 0.75 NTU

Sample #	Dose mg/l ClO_2	Residual mg/l ClO_2	Demand mg/l ClO_2
1	0.25	0.0	0.25*
2	0.5	0.0	0.5*
3	0.75	0.25	0.5
4	1.0	0.25	0.75
5	1.25	0.25	1.0
6	1.5	0.5	1.0
7	1.75	0.75	1.0
8	2.0	1.25	0.75
9	2.25	1.25	1.0

* Since there was no residual for this sample, the demand of the water was not fully satisfied.

TABLE 4

RESULTS OF CHLORINE DIOXIDE DEMAND TESTS PERFORMED ON THE FILTERED LAKE SAKAKAWEA WATER HAVING A TURBIDITY OF 0.9 NTU

Sample #	Dose mg/l ClO_2	Residual mg/l ClO_2	Demand mg/l ClO_2
1	0.25	0.0	0.25*
2	0.5	0.0	0.5*
3	0.75	0.0	0.75*
4	1.0	0.0	1.0*
5	1.25	0.0	1.25*
6	1.5	0.25	1.25
7	1.75	0.5	1.5
8	2.0	1.0	1.0
9	2.25	0.5	1.75
10	2.5	0.65	1.85

* Since there was no residual for this sample, the demand of the water was not fully satisfied.

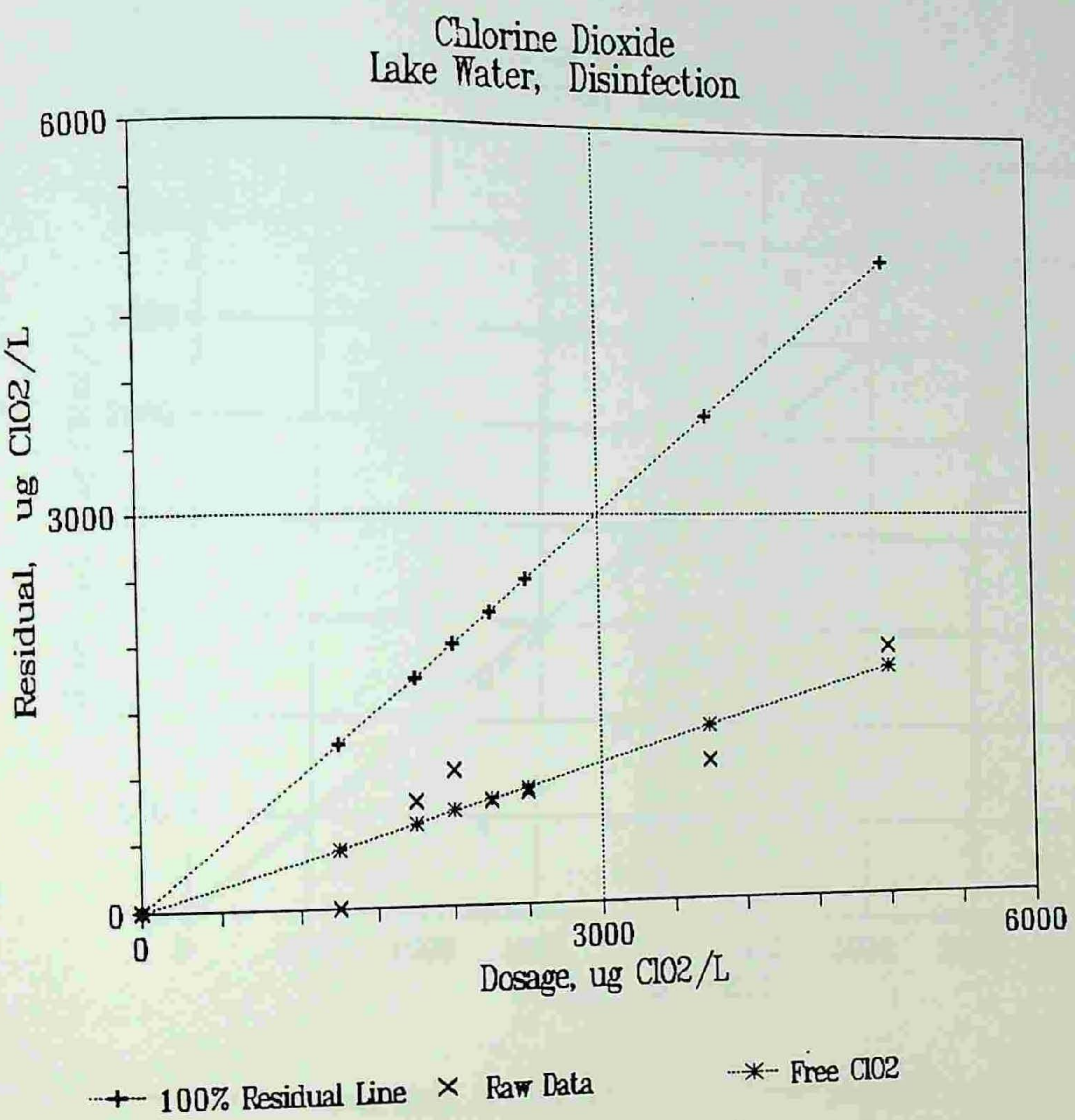

Figure 1. Graph of ClO_2 residual versus ClO_2 dose for raw Lake Sakakawea water.

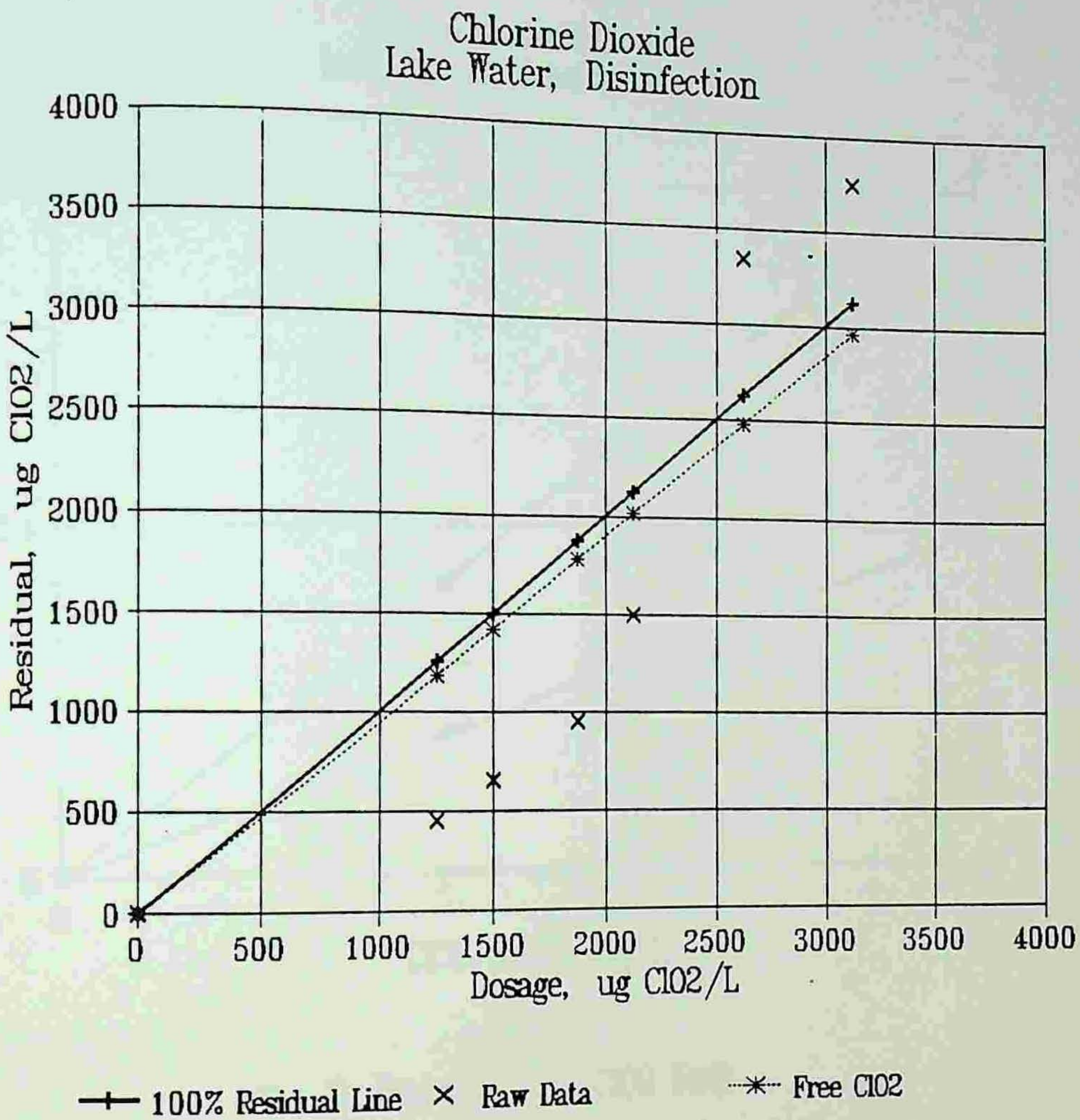

Figure 2. Graph of ClO_2 residual versus ClO_2 dose for filtered Lake Sakakawea water with a residual turbidity of 0.5 NTU.

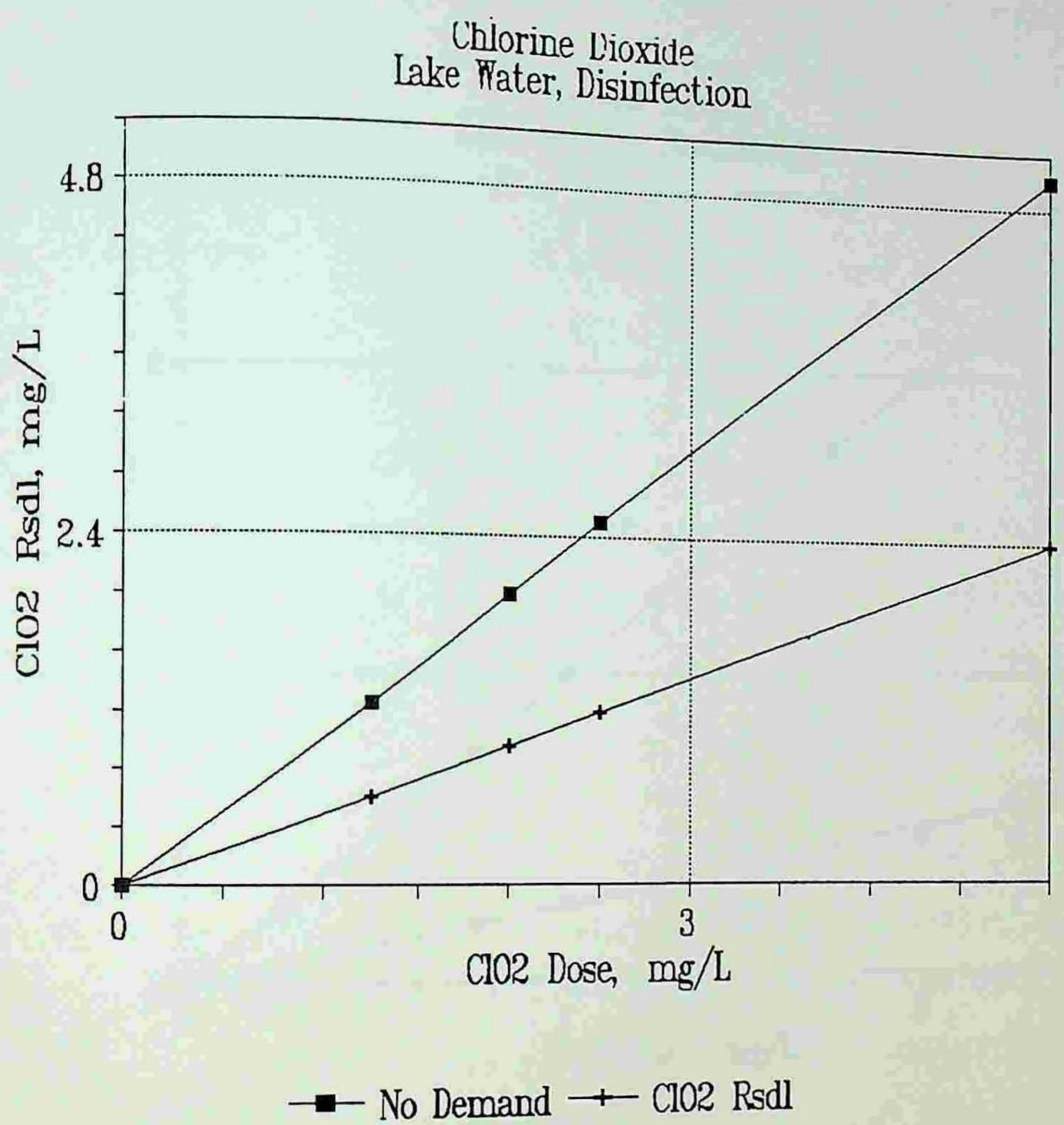

Figure 3. Graph of ClO_2 residual versus ClO_2 dose for filtered Lake Sakakawea water with a residual turbidity of 0.75 NTU.

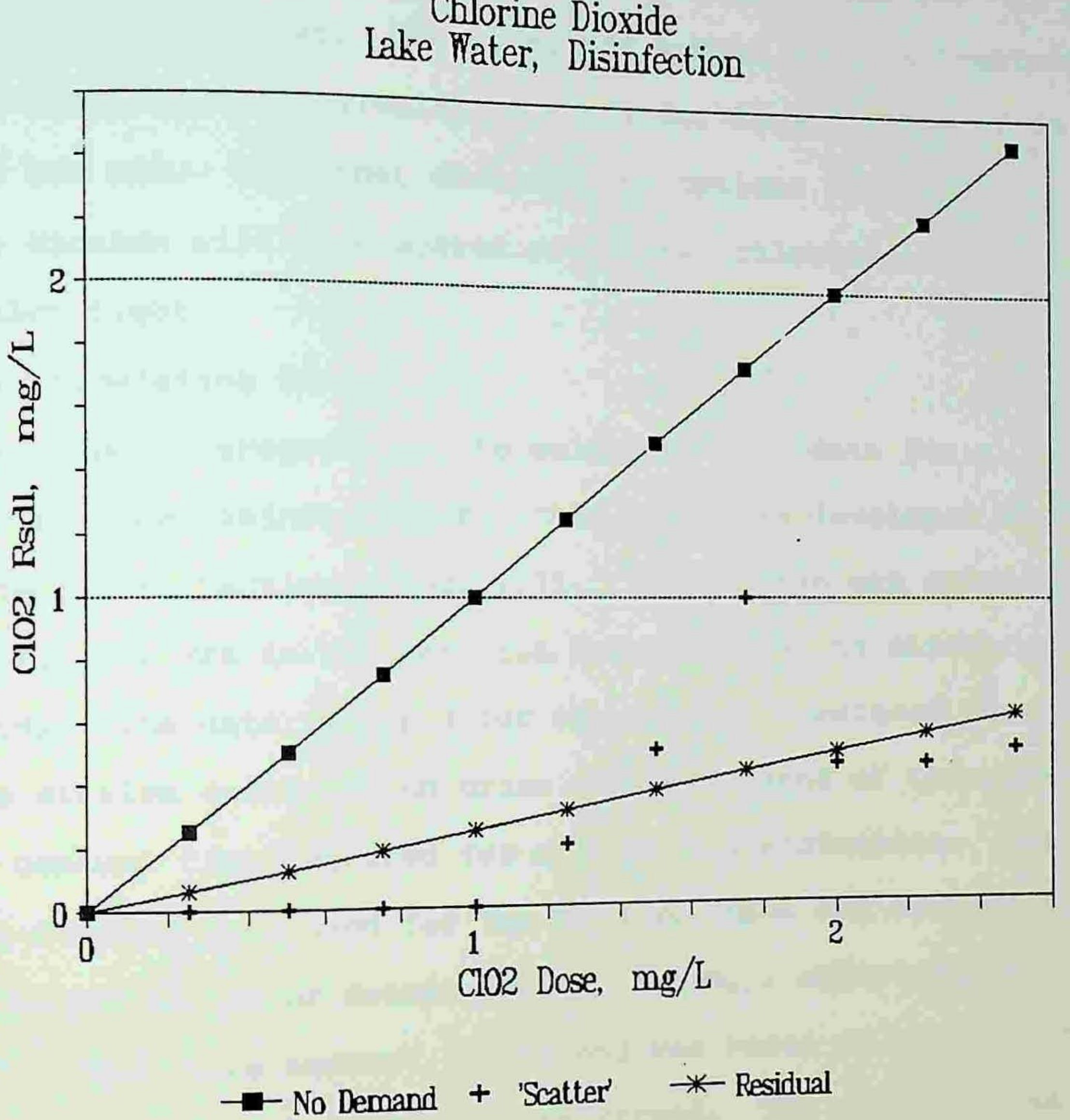

Figure 4. Graph of ClO_2 residual versus ClO_2 dose for filtered Lake Sakakawea water with a residual turbidity of 0.9 NTU.

6.0 DISINFECTION COST EVALUATION

Treatment costs for chlorine dioxide disinfection were evaluated and compared with other disinfection options for Garrison Diversion water. The effect of system size on treatment cost was determined by calculating costs for design flows of 30, 100, and 500 MGD. The other disinfection options to which chlorine dioxide will be compared are ozone, chlorine, and ultraviolet light.

6.1 Calculating Costs

The computer program used to calculate cost data for chlorine dioxide disinfection for this study was developed by the Environmental Protection Agency (13). The program was originally written for the EPA in FORTRAN, but was converted to BASIC for this study. The data required for the program included the chlorine dioxide dose, the chlorine dioxide demand of the water, and the contact time required for efficient disinfection. The chlorine dioxide dose used for the program input was assumed to be the sum of the water demand plus a 1.0 mg/l chlorine dioxide residual. The value assumed for demand was based on the results of the laboratory tests that were performed. The contact time for all of the systems, regardless of design flow, was assumed to be 10 minutes.

The output from the program is broken down into two categories, water production costs and operation and maintenance costs. Further, each of these categories is divided into the cost for the contact basin, the cost for the chlorine dioxide feed and the cost for the chlorine dioxide reactor. All of the various cost components were summarized in a total disinfection cost in units of cents per 1000 gallons of produced water. The cost data generated for each of the different size chlorine dioxide disinfection systems is summarized in Table 5.

Another feature of the disinfection computer program is that it sizes the contact basin in cubic feet for each plant capacity. The program outputs the construction cost of the required basin, the capitalized cost of the basin, as well as the operation and maintenance cost. The sizes of the contact basins determined for the three different design flows are listed in Table 6.

The results of the cost analysis for chlorine dioxide disinfection are plotted in Figure 5. The results show that the cost of disinfection per 1000 gallons of water treated increased significantly as the design flow of system decreased from 500 MGD to 30 MGD. The increased cost efficiency of the disinfection system at higher design flows was due to the fact that the large cost component for the chlorine dioxide reactor was the same for all of the design flows.

TABLE 5

WATER PRODUCTION COSTS FOR CHLORINE DIOXIDE DISINFECTION

500 MGD System

Production U 5C0(MGD)	Cost(cents)/ 1000 gallons	Operations & Maintenance	Total Cost/ 1000 gallons
Contact Basin Ammortized	0.1417	0	0.1417
Cl2 feed	0.0044	0.17	0.1744
ClO2 Reactor	0	1.73	1.73
Total cost to disinfect/1000 gal			2.05 cents

Produced Water Cost, Cents per 1000 gallons

100 MGD System

Production U 100 MGD	Cost(cents)/ 1000 gallons	Operations & Maintenance	Total Cost/ 1000 gallons
Contact Basin Ammortized	.312	0	.180
Cl2 feed	.071	.241	.290
ClO2 Reactor	0	.864	1.730
Total cost to disinfect\1000 gal			2.193 cents

Produced Water Cost, Cents per 1000 gallons

30 MGD System

Production U 30 MGD	Cost(cents)/ 1000 gallons	Operations & Maintenance	Total Cost/ +1000 gallon
Contact Basin Ammortized	0.26	0	0.26
Cl2 feed	0.19	.25	.44
ClO2 Reactor	0	1.73	1.73
Total cost to disinfect\1000 gal			2.43 cents

TABLE 6

CONSTRUCTION AND CAPITALIZATION COST OF CHLORINE DIOXIDE CONTACT BASINS

Plant Size MGD	Contact Time Minutes	Contact Basin Ft3	Contact Basin Construction Cost $	Basin Capitalized Cost $ *
30	10	27880	156292	210992
100	10	92933	360894	487207
500	10	464665	1420611	1917824

*Capitalization is based on 7% interest rate. There is no salvage value. Use straight line depreciation.

Using capitalization to recover the costs of water treatment facilities has both negative and positive features. In new communities it is effective in returning project costs on a timely basis. For add-on systems the original customers pay an equal share for improvements they have no need of. Costs shown here are for new systems for new communities.

The disinfection installation is estimated to be about 15% of the cost of a complete water treatment plant.

The cost has been estimated using index values published by the United States Department of Labor encompassing the Producer Price Index and the Consumer Price Index(12). Other sources of information are given in the Appendix.

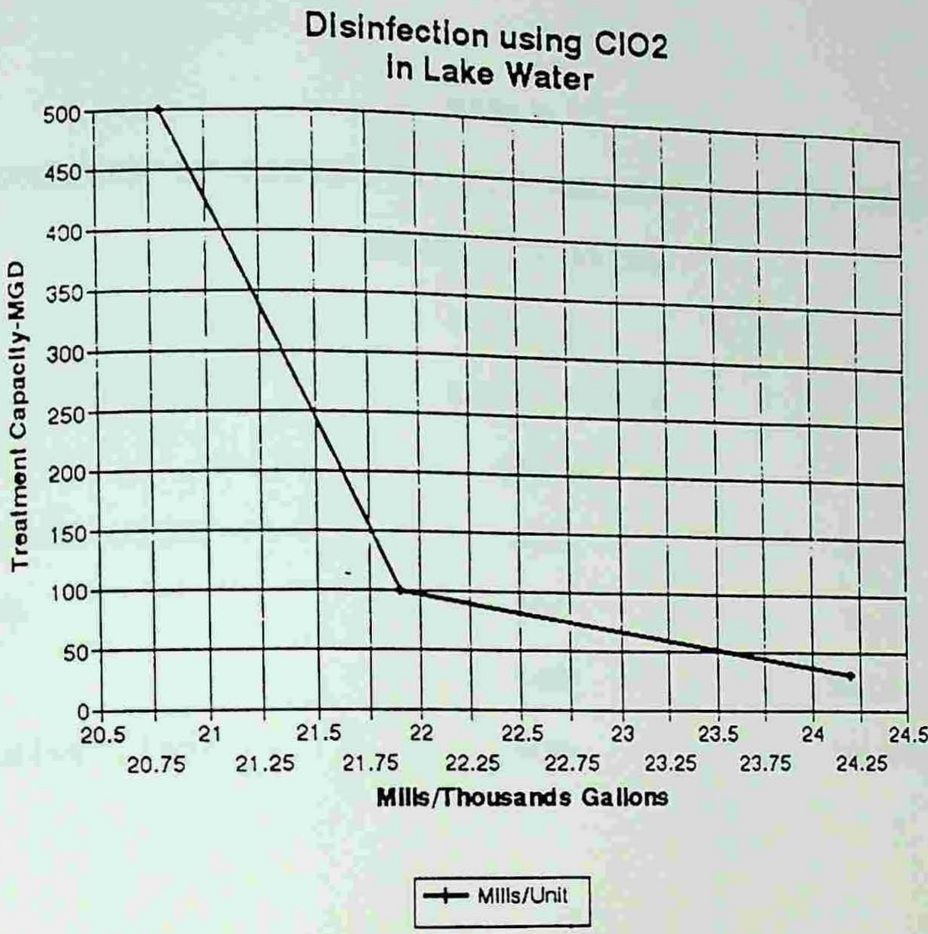

Figure 5. Water production costs versus design flow of system

TABLE 7

COMPARISON OF COSTS FOR DISINFECTION OPTIONS FOR GARRISON DIVERSION WATER

Disinfection Option	Design Flow (MGD)	Cost ($/yr)
Chlorine Dioxide	500	4,562,500
Chlorine	500	3,838,503
Ozone	500	14,462,014
Ultraviolet Light	500	20,783,544

7.0 Recommendations

More research work must be carried out to attempt to minimize the side effects of using chlorine dioxide as a primary disinfectant. This work might involve removal of the reaction products such as chlorite and chlorate. Chlorine dioxide could then be used safely even for sub-groups of the population that react adversely to the effects of the byproducts in domestic water supply as well as in medical applications.

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