EXPERT PANEL FINAL REPORT

REVIEW OF PHASE 2 TREATABILITY STUDY AEROJET FACILITY RANCHO CORDOVA, CALIFORNIA

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AEROJET

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A. PROJECT DESCRIPTION

In 1997, Aerojet-General Corporation ("Aerojet") conducted pilot-scale studies to evaluate a biological reduction process to remove perchlorate ion from groundwater at their facility near Sacramento, California. Because this process appeared to be a cost effective treatment option for treating perchlorate contaminated groundwater, Aerojet completed a Phase I Treatability Study to further evaluate the effectiveness and reliability of the biological process. Based upon the results of the Phase 1 Treatability Study, Aerojet decided that the biological process, in conjunction with other appropriate treatment processes could produce water of potable quality from groundwaters contaminated with various chlorinated solvents in addition to perchlorate and other contaminants. Aerojet thus initiated a Phase II Treatability Study with the primary intent of demonstrating that water of potable quality could be produced with a treatment train utilizing the biological process for perchlorate ion removal.

Aerojet has undertaken these studies as part of a program to meet the groundwater remediation needs of the area known as the Baldwin Park Operable Unit (BPOU), located in the San Gabriel Valley of Southern California. In addition, these studies are anticipated to have potential application throughout the US in other groundwater treatment projects faced with perchlorate ion contamination in the presence of other organic contaminants, namely, chlorinated solvents. Aerojet has a lead role in remediating the groundwater in the BPOU and has proposed using a biological treatment process as the central control technology to meet the requirements of the US EPA for control of perchlorate ion. One of the goals of this project is to produce a treated water that can be used as a source of drinking water.

The groundwater to be treated by the application of the technologies evaluated in this study originates in impaired source areas. The groundwater continues of number of inorganic and organic contaminants, including perchlorate ion, TCE, 1,4-dioxane, and n-nitrosodiethyl amine (NDMA) at levels exceeding regulatory guidance or standards. If the treated water is to be used for drinking water purposes, the California Department of Health Services (DHS) must first accept the technologies and then permit a site-specific treatment facility before water treated by the technologies. DHS has outlined the procedures for obtaining such a permit in a policy memorandum prepared in 1997, entitled "Policy Memo 97-005: Policy Guidance for Direct Domestic Use of Extremely Impaired Sources." This will require the demonstration of the efficacy of the proposed treatment system to insure the removal of all contaminants to safe levels, and a demonstration that the treatment processes can meet reliability criteria and satisfy all present and anticipated public health requirements.

During the past several years at its facilities near Sacramento, Aerojet has been testing and operating a biological treatment process for the removal of perchlorate with subsequent discharge of the treated water to surface and ground waters. The biological treatment process has been operated with other processes to control additional contaminants found at the Aerojet site including NDMA, certain chlorinated solvents, such as trichloroethylene, and other synthetic organic chemicals such as 1,4-dioxane. However, the DHS has not yet permitted the treatment train which consists of biological treatment, air stripping, filtration, advanced oxidation using ultraviolet light with hydrogen peroxide (UV/OX), granular media filtration, granular activated carbon (GAC) adsorption, and chlorine disinfection. However, individual approvals for these unit processes have been issued.

B. PARTICIPANTS

Aerojet intends to present specific project configurations in the San Gabriel Valley and in the eastern Sacramento area for DHS approval. To assure that the pilot test program and subsequent reporting of the results is properly conducted and independently evaluated, Aerojet established a review Panel of recognized experts, and invited the participation of Dr. Michael McGuire, as an independent reviewer, as well as attendance and comments of DHS. Dr. Rick Sakaji and Mr. Gary Yamamoto represented DHS. The panel members are: Dr. Robert Clark, Dr. Michael Kavanaugh, Dr. Perry McCarty, and Dr. R. Rhodes Trussell. Mr. Jerome B. Gilbert was facilitator and editor. Mr. Travis E. Meyer, P.E., and Dr. John Catts guided the treatment development program. Mr. Don Vanderkar, P.E. oversaw the expert Panel program for Aerojet.

C. OBJECTIVES OF EXPERT PANEL

The objectives of the Panel were to provide independent advice on:

- The adequacy of the treatability studies to demonstrate the removal of all contaminants to safe levels in a reliable manner.
- The adequacy of the protocols, data gathering, monitoring, and process operations and the application of appropriate scientific and technical principles to the assessment of the treatment processes to meet project objectives.
- Reliability and scale-up issues associated with the each of the various processes
- Other issues that may affect obtaining acceptance of the process from a public health standpoint as outlined in DHS memoranda.
- Factors that could affect the performance and efficiency during the application of the treatment train under consideration

D. EXPERT PANEL ACTIVITIES

The Panel began its work in May of 2000. Five meetings were held and the Panel members individually inspected the full-scale biological process and the demonstration scale treatment train designed to meet drinking water objectives. At each meeting, project leaders presented oral descriptions of the treatability study documents provided to EPA, accepted suggestions, and responded to questions of attendees. Most of the meetings were attended by all Panel members and DHS was represented at all but one meeting. Dr. McGuire attended several meetings. The Panel considered all of the treatment processes being tested but gave particular attention to the biological process including the development of a model that would predict the performance of the biological process under various loading conditions. This model was prepared by the project team with assistance from Dr. McCarty.

The primary document reviewed by the panel was the “Final Draft of the Phase 2 Treatability Study Report, Aerojet GET E/F Treatment Facility” (hereafter, referred to as the “Treatability Study Report”), dated April 2001 and prepared under the direction of John G. Catts, Ph.D., Principal Consultant, Harding ESE.

At the final Panel meeting on April 24, 2001 the members agreed to prepare this document by sharing authorship. Dr. McCarty prepared the initial draft of the review of the biological process, Dr. Kavanaugh drafted the review of the air stripping process and the treatment train, Dr. Clark drafted the review of the filtration processes, and Dr. Trussell drafted the review of the disinfection and oxidation processes as well as the treatment train. Mr. Gilbert provided coordination, scheduling, and meeting facilitation, and with the Panel members edited the summary and conclusion sections.

A. ACHIEVEMENT OF PROJECT OBJECTIVES

The objectives of the Phase 2 Treatability Study, as outlined in the subject report are as follows; demonstrate the effectiveness and reliability of the proposed treatment train to produce potable water pursuant to all applicable state and federal regulations; confirm the efficiency of each unit process in the treatment train for all chemicals of concern; optimize the parameters for each unit process; and collect data for the design and construction of a full-scale treatment facility. The treatment train was designed to remove both inorganic and organic contaminants present at the site at levels exceeding regulatory guidance values. The principal chemicals of concern include perchlorate, NDMA, 1,4-dioxane, TCE, PCE, and chloroform.

The Panel concludes that the Phase 2 treatability study provides a sound scientific and technical basis for consideration of the processes tested to produce water of potable quality from groundwater at the Rancho Cordova site contaminated with perchlorate ion, NDMA, and various VOCs. The basic foundation has been created for application of this treatment train to specific sites. The treatment train contains processes that provide multiple barriers for removal of perchlorate and specific organic contaminants, including the final polishing step of adsorption on GAC. In general, the Panel concludes that the concerns expressed by the Panel in Section 3 can be addressed in site-specific demonstrations necessary to gain an operating permit from DHS in conformance with Policy Memo 97-005.

B. ADEQUACY OF STUDY TO CONFIRM TECHNICAL FEASIBILITY OF BIOLOGICAL PROCESS FOR PERCHLORATE REMOVAL

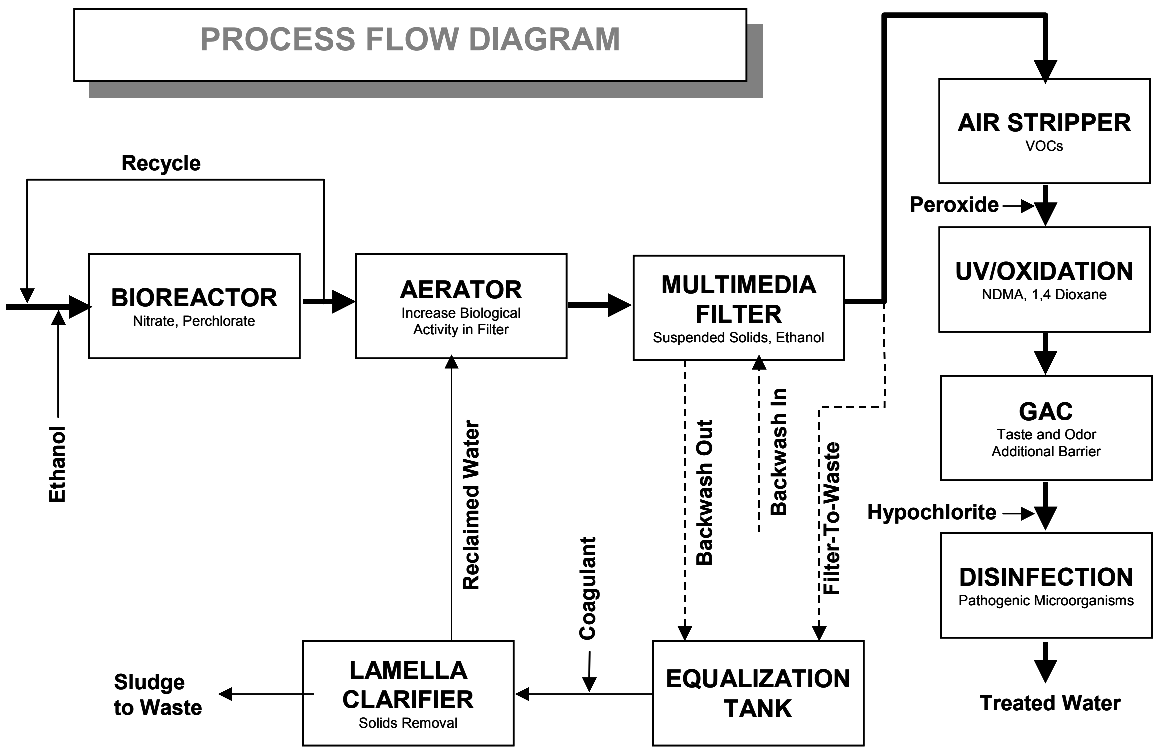
The most significant and innovative treatment feature of this study is the use of a biological process to reduce perchlorate to chloride ion. Biological treatment processes are not commonly used in drinking water treatment systems in the U.S., and special consideration must be given to process control and other operating issues affecting the reliability of the biological process. The Panel believes that the biological process tested can operate reliably and with acceptable stability when treating water of relatively constant composition and not containing contaminants that are toxic to the microorganisms involved.

A variety of factors should be considered when adapting this biological process to a site-specific location. These factors are discussed in detail in the section evaluating the stability and effectiveness of the biological process which address, among other issues, the need for process monitoring and control parameters that increase the reliability of the process. In addition, any site-specific application of the process, or of the treatment train tested in this treatability study, would require an engineering assessment of the overall design of the water system. This would include an assessment of raw water and finished water storage needs, an analysis of interconnections between alternative sources of finished water, and site specific contingency plans to minimize any water quality impacts of process or equipment failures in the treatment, storage or distribution system.

C. ADEQUACY OF STUDY TO DEMONSTRATE TECHNICAL FEASIBILITY OF THE TREATMENT TRAIN TO PRODUCE WATER OF POTABLE QUALITY FROM INDIVIDUAL SITES

Figure 1 includes a schematic of the treatment train tested during the study. As shown, the treatment train includes a sequence of processes to control the principal chemicals of concern, namely, perchlorate, NDMA, 1,4-dioxane, TCE, PCE and other chlorinated solvents.

FIGURE 1



The following is a brief summary of the effectiveness of each process to remove targeted chemicals.

Biological Process for Perchlorate Removal: The biological process, consisting of an upflow fluidized bed of granular activated carbon, operated as an anoxic fixed film reactor, with ethanol as the carbon feed source, was effective at removing perchlorate ion to below detection limits. Provided that the ethanol feed rate was maintained in an optimum operating range, and the flow and water quality were relatively constant, the system performed very reliably. With appropriate process control and monitoring features, a full-scale system has a high probability of meeting requirements for producing potable water from a source containing elevated levels of perchlorate.

Granular Media Filtration: The multimedia filter has been reliable and was able to meet all required effluent targets for turbidity. Because this is a well-demonstrated technology, there are few uncertainties regarding the ability of this process to produce water that would meet typical potable treatment requirements, provided that the headloss used in the design does not exceed that employed during the pilot studies. A design based on the longer filter runs would require pilot scale confirmation to ensure that turbidity breakthrough will not occur Typical future challenges that should easily be controlled by the filter include periodic spikes from the biological process and the corresponding response of filter controls and/or operators to mitigate the impact of the spikes. Redundancy in the final design should be considered.

Air Stripping: The air stripping system using a low profile five-tray air stripping device was very effective at decreasing both TCE and chloroform and all other VOCs that were present at low concentrations. Although the reliability of a full-scale packed tower system cannot be determined quantitatively from the current tray tower system, no scale-up problems are likely based on extensive experience in the water treatment industry with numerous water treatment applications of packed tower air strippers to remove chlorinated solvents. At scale up, appropriate ranges of water temperature, optimal air to water ratios as well as off gas treatment should be considered.

Advanced Oxidation: The advanced oxidation system consisting of UV/hydrogen peroxide (UV/OX) met NDMA and 1,4-dioxane targets with the air stripper in operation. The report indicates that scaling on the UV lamps will not be a problem at the Sacramento site and that the process can provide reliable performance. Scale up should include proper baffling at the entrance and exit as well as within the unit.

Granular Activated Carbon: Liquid phase GAC will function both as an adsorber and as a biological process depending on the circumstances. If an upstream process fails, GAC provides an additional barrier for VOC removal. GAC also provides control of taste and odor producing compounds, a reduction in assimilable organic carbon (AOC) and DBP precursors. Scale-up issues include how to move carbon through the system for regeneration. There are benefits of using available modeling tools to assist in scale up decisions.

Chlorine Disinfection: The disinfection requirements in the study protocols have been met for this process train, provided a chlorination system is designed for the effluent that can reliably achieve the appropriate concentration/time values for all microbial contaminants of concern.

D. MEETING THE REQUIREMENTS OF DHS TECH MEMO 97-005

In November 1997, the California Department of Health Services (DHS) published Policy Memorandum 97-005 which provides guidance for a permit applicant intent on producing potable water for domestic use from extremely impaired sources. The groundwater at the Aerojet Facility, as well as groundwater in the San Gabriel Basin meet one or more of the criteria established to define an extremely impaired source. For example, perchlorate levels observed at the Aerojet site have reached 2.6 mg/L which significantly exceeds the California action level or preliminary health goal for perchlorate of 18 µg/L. In addition, the groundwater at the Aerojet Facility contains a mixture of contaminants of health concern. In comparing the pilot study results reviewed by this Panel, it is apparent that Aerojet's test program provides some of the information and documentation that would be required to obtain a permit from the DHS to use the groundwater at the Aerojet facility as a source of potable water supply. Nonetheless, the scope of the treatability study does not satisfy all of the requirements specified in the DHS Policy Memo 97-005.

The key elements in the DHS Policy include the following: a) completion of a source water assessment, b) full characterization of the water quality in the aquifer of interest as well as an assessment of the time variability of contaminants of concern under the pumping scenarios must be completed, c) an assessment of source protection to determine the source or sources of contamination that caused the groundwater to be severely impaired, d) establishing specifications for an effective treatment and monitoring program for the contaminated groundwater, e) completion of an evaluation of human health risks in the context of the potential failure or failures of the proposed treatment train, and f) a discussion of alternatives to the use of the extremely impaired source must be discussed. Finally, the DHS policy requires that the project meet the California Environmental Quality Act (CEQA), that a permit be submitted, and that a public hearing be conducted to identify and address concerns of consumers who would be served by the water.

The report submitted to the Panel for review addresses primarily item d above, namely, establishing the treatment and monitoring program for the contaminated water. Should Aerojet decide to pursue a DHS permit in the future, the results of this demonstration project would be an essential component of that report. The following comments therefore summarize the Panel's opinions on the likelihood that the results of the current study would satisfy DHS requirements for a treatment train and monitoring program to treat the groundwater at the Rancho Cordova site and subsequently provide the treated water for potable use.

Specific issues that would need to be addressed to meet DHS requirements specified in the Policy Memorandum 97-005 include 1) matching the effectiveness of the treatment processes with the degree of risk associated with the contaminants present, 2) inclusion of sufficient engineering reliability features to meet more demanding reliability requirements for treating an impaired source, and 3) assuring that treatment processes are optimized to produce water with the lowest concentrations of contaminants that can be feasibly attained.

It is the Panel's opinion that the Aerojet's treatability study has addressed each of these three issues thoroughly for the specific water quality conditions at the Rancho Cordova site. The chemicals of concern are removed to levels well below their respective drinking water action levels or standards. Sufficient process redundancy has been incorporated into the treatment train. There are three treatment barriers for all VOCs of concern (air stripping, UV/oxidation and liquid phase GAC), two barriers for perchlorate (biological process, liquid phase GAC), and one barrier for NDMA (UV). Finally, the process train and individual processes have been subjected to a number of optimization studies, which have shown that the treated water has the lowest concentrations of the chemicals of concern that can be feasibly and reasonably attained.

With respect to the issue of control and monitoring of the treatment processes, the Panel has raised a number of concerns regarding the reliability of the biological process to control perchlorate ion should the water quality conditions change. The pilot studies have clearly shown that the biological process can be operated in a highly reliable manner provided that the feed rate of the ethanol can be maintained at an optimum level to ensure effective perchlorate reduction without the formation of sulfides. Additional monitoring devices and strategies are apparently being developed by Aerojet consultants. Final permit application to the DHS would presumably include an extensive discussion of the process control strategies for the complete treatment train. The Panel believes that it is likely that such monitoring technologies and strategies would be sufficient to meet the DHS's requirements for this element of the permit application for treating waters of similar water quality.

E. RECOMMENDATIONS ON DISSEMINATION OF STUDY FINDINGS

The information gathered as part of this program could be of significant value to the drinking water industry as a whole. While no two water systems are identical, the unit processes could be adapted to fit a wide range of situations with a similar mix of contaminants. Therefore, the water industry in California and elsewhere could benefit by learning about Aerojet's experiences. There are various ways to achieve this objective. They include: offering articles for publication in the American Water Works Association Journal; participating in the Associations specialty conferences particularly on water quality; joining the Association's Research Foundation in it's technology transfer symposia and publications; offering articles for peer review and publications in other journals such as the Journal of Science and Technology of the International Water Association (IWA). Other potential journals include Journal of Environmental Engineering, and Water Research. The California Section of the AWWA and the Association of California Water Agencies have water quality committees and regularly sponsor programs on contaminant removal. The Panel believes that the lessons learned in this study could be of considerable benefit in addition to serving a regulatory function, and they should be made available to water professionals and other interested groups.

A. BIOLOGICAL PROCESS FOR PERCHLORATE REMOVAL

The fluidized-bed granular activated carbon (GAC) fixed-film bioreactor that was evaluated at the Aerojet facility near Sacramento, California, is a unique process for removal of perchlorate. This 22 foot tall, 14 feet diameter reactor is the only process in the treatment train studied that is capable of perchlorate removal, and thus must be operated reliably for the system to perform as required in the treatment of perchlorate-contaminated water. The bioreactor also removes oxygen and nitrate, chemicals that must be removed first before perchlorate removal can be accomplished. These three chemicals serve as electron acceptors in bacterial energy metabolism and require that an electron donor be added to serve as the food source for bacterial growth and maintenance. Ethanol was added at the Aerojet facility for this purpose. Sufficient ethanol must be added to effect removal of all three electron acceptors to obtain good perchlorate removal, but care must be taken not to overdose ethanol. This will result in sulfide formation and excess total organic carbon will be present in the effluent, adversely affecting downstream treatment processes and effluent quality. Thus, a critical operational need is to insure that ethanol additions are neither too little nor too great.

1. Effectiveness

The bioreactor began operation in October 1, 1999 after seeding with about 6,000 pounds of biomass-coated GAC from another site bioreactor. In order to maintain adequate fluidization of the GAC with 33 percent bed expansion to a total height of 12 feet, a flowrate through the reactor of 1,800 gpm was needed, resulting in an empty-bed detention time for the whole reactor of 14 min. As the biofilm developed, bed expansion increased up to 67 percent or 15 feet. Biofilm removal was used to maintain bed height at this level. The reactor flowrate of 1,800 gpm consisted of forward flow of untreated groundwater and recycle flow from the reactor effluent. Following startup, the forward flow was increased from about 240 gpm initially to about 1,400 gpm during the most recent reporting period from September 13, 2001, through December 13, 2001.

The groundwater treated had a dissolved oxygen concentration of about 5.5 mg/l, a nitrate-nitrogen concentration of about 1.4 mg/l, and a perchlorate concentration of about 2.6 mg/l. By the end of October 1999, perchlorate was being removed by the reactor to below an action level of 18 µg/l, at which time the forward flow rate was 500 gpm. Effluent perchlorate levels remained below the action level with the forward flowrate varying between 500 and 880 gpm, until April 19, 2000, when ethanol dosage was reduced in order to find an optimum level for operation. The reduction in ethanol feed resulted in an increase in effluent perchlorate up to several hundred µg/l, illustrating the negative effect of under feeding ethanol. Following return to previous ethanol levels, the perchlorate decreased again to well below the 18 µg/l action level, and generally below a detection limit of 4 µg/l, even with increase in forward flow up to 1,440 gpm. Thus, the bioreactor has been demonstrated to be capable of satisfactory perchlorate removal, providing ethanol dosage is closely controlled.

2. Process Reliability

The large-scale Aerojet bioreactor operated reliably for over one and one-half years with flow rates from about 0.5 to 2.0 mgd. This suggests that biological processes can operate reliably when treating water of relatively constant composition and containing no materials that are toxic to the microorganisms involved.

Because of the importance of correct ethanol dosage to effect satisfactory perchlorate removal, and the danger of over dosing, maintaining the correct ethanol feed is essential. This was aided at the Sacramento site as the concentrations of the chemicals of concern in the groundwater mix entering the reactor were of constant composition over time. Without this, maintaining the correct ethanol feed would be very difficult. The correct ethanol feed is a function of the concentration of the three electron acceptors - dissolved oxygen, nitrate nitrogen, and perchlorate. If these three parameters cannot be maintained constant over time, then the concentrations would need to be continuously monitored in a reliable manner, and the ethanol feed would need to be adjusted continuously as well. Unless reliable analytical instrumentation were available for this purpose, a controlled composition feed source as used at Sacramento would be mandatory for successful operation.

In order to arrive at a satisfactory design of a bioreactor to treat a groundwater with different chemical characteristics than that at Sacramento, a numerical model of the bioreactor process is desirable. This should include, to the extent possible, known physical, chemical, and biological factors affecting biofilm kinetics and reactor operation. Such a model was developed for this purpose by the Aerojet contractors and appears to perform satisfactorily for predicting the change in electron acceptor concentrations throughout the reactor and required ethanol dosage as documented in the April report. The model also correctly indicated the impact on effluent perchlorate concentrations of under dosing the system with ethanol. It thus appears to be a useful design tool for evaluating process effectiveness for waters of different water quality, and perhaps of bioreactors with different GAC composition and reactors with other height to diameter ratios. Empirical data were not readily available for several of the biological parameters of importance, and so values were estimated from theoretical equations or best-fit parameter estimation. While this is satisfactory for preliminary design calculations, the uncertainties in these estimates need to be considered before final design and construction of a new facility. Because of the limited experience with this process, and the limited operational experience available at other locations, extra safety may need to be built into a new system, and pilot-scale studies on untested groundwaters would be desirable.

As indicated above, control of ethanol dosage is a critical operational parameter. For high reliability in process operation, monitoring of influent and effluent chemical constituents is needed. The relative importance of various possible analytical monitoring approaches to control operation is dependent upon the constancy of the water quality of the groundwater to be treated and the disposition of the treatment water. If treated water storage were included in a design, then absolute system reliability would not be as crucial as when treated water is to be directly added into a public drinking water supply system.

Various possible control approaches were evaluated for the Sacramento bioreactor. These included effluent sulfide and dissolved oxygen concentrations and ORP, and bed height. None of these proved to be suitable by themselves. In order to insure system reliability a better monitoring system will be required, especially if a reactor is to receive water of varying quality or if treated water is to be used directly for potable reuse. Possible analytical procedures for consideration are on-line influent and effluent nitrate and TOC analyses, along with DO and bed height monitoring. TOC measurements would help indicate possible over dosing of ethanol, and nitrate measurements would help indicate whether under dosing is occurring. Three options should be considered to overcome concerns regarding optimal control of the ethanol dose. First, the system could be operated in a manner that minimizes changes in flow rates or chemical composition, as was accomplished in this study. Second, if variability in flow and composition cannot be assured, then water could be stored to allow analysis before placing the water in the distribution system. Finally, further tests could be conducted to develop a reliable ethanol control system that would allow feed-forward control of the ethanol dose based on measured changes in composition and flow. The reason for the choice of a given option should be a component of any proposal to the DHS regarding the use of the treatment train for producing potable water from the Rancho Cordova groundwater.

3. Process Stability

The Aerojet bioreactor operation was stable over the one and one-half years of operation. As long as ethanol dose was maintained correctly, undesirable excursions of nitrate and perchlorate did not occur. Reactor performance returned to normal quickly following shut down periods of a few days resulting from power failures. The system responded rapidly to increases in forward flow rate and resulting increased loadings up to the limit of the flow rates tested of 1,400 gpm. However, when ethanol dosage decreased below an optimum level, effluent perchlorate concentrations immediately increased, indicating the need for reliable ethanol dosing and monitoring controls that sound alarms when this is not occurring. Effluent perchlorate concentrations dropped rapidly to desired levels once ethanol feed was returned to the proper level. Indications from the Aerojet study indicated that the biological process can operate with good stability.

4. Scale up Concerns

The Aerojet bioreactor used in this study was essentially a full-scale unit treating up to two million gallons per day reliably and with good stability. For larger flow rates it would be desirable to have multiple treatment systems to provide for shut down and maintenance of units without complete stoppage of a system. Multiple units would also be beneficial for transfer of biomass seed in case of failure of a single unit. A small increase in size probably could be achieved with little concern about scale up problems as well, providing proper flow distribution could be achieved and system height remained the same. Change in system height could have an impact on flow rates required for fluidization, detention time, and recycle rate, all of which would need proper evaluation on effectiveness and performance. Use of a different biocarrier (GAC) than used in the pilot study could also have major impacts on design and thus would require careful evaluation. A knowledge of fluidization requirements and use of a biofilm model such as developed for this study would be important if significant changes in design criteria were used for a new bioreactor as would differences in the quality of water to be treated.

Microorganisms that develop in one location on one particular water supply will likely be different than those that develop at another location with a water supply of different character. For this reason, the reaction kinetics may be different for a reactor that is built at a new location. Since there is so little history of operation of fluidized bed reactors for treatment of perchlorate, there is no guarantee that operation elsewhere will result in the same level of performance as in the Aerojet pilot study. Preliminary to design of a treatment system elsewhere, a good sensitivity analysis on the kinetic parameters in the reactor biofilm model should be undertaken to help guide towards a conservative design that is likely to perform reliably and as intended. A pilot scale study would then be desirable to confirm that performance at the new location will be adequate. A pilot reactor would also be useful to provide a seed culture for a possible full-scale reactor built subsequently.

An additional problem not solved well in the pilot study was cleaning of biomass from the activated carbon as growth becomes excessive. The periodic cleaning with the system available created problems of excess biological solids to the subsequent filter beds which impacted effluent quality. More continuous removal of excess biomass would be desirable to avoid such perturbations on downstream processes. The Aerojet report on system operation suggests various possible approaches to handle this problem. These and perhaps other approaches need evaluation for future design.

5. Other Factors

Biological processes result in the production of soluble microbial organic products that will become part of the treated water. The concentration of these materials is a function of the biomass production rate and indirectly, the concentration of electron donor (ethanol) applied to the water treated. While little is known of the exact composition of this material, it is produced by all biological degradation processes and so is present and part of the normal TOC found in essentially all surface and groundwaters. Since normal TOC has not been found to be of concern in the past, except for its formation potential of disinfection byproducts, there would appear to be no reason for concern here. This material is at least partially biodegradable, and likely to be removed in downstream processes such as the filter and a liquid phase granular activated carbon system.

The bacteria that effect reduction of nitrate and perchlorate in the treatment system tend to be the normal soil bacteria that are involved in the natural nitrogen cycle, and thus common in all agricultural soils. The bioreactor effluent will contain many of these organisms as reflected by heterotrophic plate counts, but then they are also removed by each of the subsequent treatment processes of filtration, UV/H_2O_2 oxidation, activated carbon adsorption, and disinfection.

Bacteria require nutrients in addition to substrate for growth. Included are the macro nutrients, nitrogen and phosphorus, but there are several trace nutrients such as sulfur and iron that are also required. Nitrogen and phosphorus requirements can readily be determined from bacterial growth analysis as carried out for the Aerojet bioreactor. Most natural waters contain sufficient trace elements and so it is generally assumed that the needed ones will be present. However, this is not always the case. Poor performance of a bioreactor at some other site could reflect a deficiency in a needed trace element. A small-scale study to insure this is not the case may be beneficial. Generally, trace element addition would not be costly if required since amounts needed are quite small.

B. GRANULAR MEDIA FILTRATION

The multimedia filter is located between the bioreactor and the UV/OX system. The filter vessel is an 8-foot wide by 9 foot long steel tank and the filter bed includes layers of anthracite, silica sand, and garnet sand, with a total media depth of 2.6 feet. It operates in a constant-rate mode, at a rate of 350 gpm and with a liquid loading rate of approximately 4.9 gpm/ft^2. Its primary function is to remove suspended solids consisting of waste biomass and GAC fines present in the effluent from the bioreactor but it serves other important functions as well. For example, removal of the suspended solids will maximize the efficiency of the UV/OX system since suspended solids interfere with its performance. The multimedia filter also provides a substrate for the biological degradation of residual ethanol and metabolic breakdown products not fully removed in the bioreactor. Ethanol or ethanol breakdown products would increase the required dosage of hydrogen peroxide in the UV/OX system. In addition removal of suspended solids will prevent clogging of the Liquid Phase Granular Activated Carbon (LPGAC) system and will minimize the chlorine dosage required for disinfection.

1. Effectiveness

It is useful to examine two sets of parameters when evaluating the effectiveness of the multimedia filter. One set of parameters includes the surface loading rate, polymer dosage, filter cycle ratio, and filter backwashing procedures. These parameters can be modified to affect the performance of the filter. The second set of parameters are head loss through the filter, influent and effluent concentrations of turbidity, total and dissolved organic carbon, particle counts, ethanol (and breakdown products), suspended solids, virus and bacteria removal, and DO concentration. If, for example, the surface loading rate were increased we would expect to see lower removals of turbidity, dissolved organic carbon, particles, etc, in the effluent stream, shorter run times to head loss or removal efficiency limits or both.

Turbidimeters and particle counting instruments are located on both influent and effluent lines providing real time quantification and characterization of the removal of solids through the filter.. The filtration system also includes the capability to add polymer upstream of the filter as a filter aid. Based on the data presented in the Aerojet report the multimedia filter has been reliable and able to meet all expected effluent targets and to produce water that would meet typical potable treatment plant requirements. (The turbidity effluent levels have been low (below 0.3 NTU) and very consistent except for periods when the bioreactor's educator operation resulted in high influent turbidity spikes. Despite these excursions the filter has consistently produced low turbidity water. It is expected that the Liquid Phase Granular Activated Carbon (LPGAC) unit located downstream of the multimedia filter will also dampen variations in turbidity, and that low turbidity waters (i.e., <0.3 NTU in 95 % of the samples taken) will be produced consistently. Early in December of 2000, for a period of 3-4 days the turbidity from the bioreactor spiked but returned to normal levels. Polymer was added but the filter runs were dramatically reduced due to increase rate of headloss. Therefore the polymer addition was stopped because the turbidity criterion was being met without its addition.

The multimedia filtration backwash system includes a backwash pump, backwash storage tanks, and air scour. This system operates at a water flow rate of 20 gpm/ft^2 and an airflow rate of 3 standard cubic feet per minute per square foot ($scfm/ft^2$). Backwash is initiated based on head loss through the filter bed, effluent turbidity, or elapsed time. When backwash is activated the valve on the multimedia filter influent pipe is closed and solids trapped in the filter media are transported by the backwash water into the reclamation system. Nonchlorinated water from the pilot scale system is used as backwash water which allows the microbial population in the filter bed to remain viable. Spent backwash water is routed to the reclamation system for processing and a filter-to-waste cycle is implemented immediately following each backwash cycle. After start-up for a short period of time filter effluent is routed to the reclamation system. The backwash cycle was originally set at 6 minutes following the air scour cycle. This was shortened to 5 minutes which allowed some of the biological particles to remain in the bed, which in turn minimized the post-turbidity spike. Filter run times varied between 7 and 12 hours.

As mentioned previously one of the objectives of the multimedia filter was to encourage biological removal of ethanol or other biodegradable organic compounds in the filter. To facilitate this process oxygen is added to the bioreactor effluent upstream of the filter in a post-aeration tank using fine bubble diffusers which increases the DO concentration from 0 mg/1 to approximately 5 mg/l. Addition of oxygen creates aerobic conditions in the filter bed to facilitate growth of the biomass resulting in the consumption of ethanol and its breakdown products that may be present in the bioreactor effluent. It was found that ethanol and its breakdown products were below the detectable limits in both the influent and effluent (186 μg/l). Most of the DOC samples were below the detection limit of 500 μg/l and TOC results showed a reduction of 100 μg/l. DO was reduced through the filter by approximately 0.87 mg/l. Both the DO and the TOC results indicate that there is biological activity taking place in the filter.

There were some problems with particle removal especially in the 2-5 micron particle size range which coincides with the effective size of *Cryptosporidium*. This should not be a problem since the Aerojet system is proposed for treating ground waters, not under the influence of surface water. If the treatment system were used to treat impaired surface waters then particle removal might become an issue. As can be seen in Figures 44 and 45 there was a period when particle removal was about 50% in the 2-5 micron range although after a period of operation particle removal improved and remained stable through the rest of the testing period. However, there seemed to be no problems at all with microbial penetration of the system.

2. Reliability

As mentioned previously turbidimeters and particle counting instruments are located on both influent and effluent lines of the multimedia filter providing real time quantification and characterization of suspended solids. This would seem to provide the minimum data set that should be used to monitor the performance of the filter. In addition head loss through the filter is monitored which should provide another measure of performance.

Of concern are periodic spikes from the biological filters and whether they are reflected in the filter effluent. It would be reasonable to question how fast the operators can react to these spikes and how effective they can be in mitigating their impact. An important issue in terms of the full-scale system will be the need for redundancy. This is not addressed in the Aerojet report but will probably be raised by the California Department of Health Services.

3. Scale up Concerns

There are several issues to be considered if the system is scaled-up. In a full-scale application filters operated in parallel might be required in order to provide redundancy and to insure consistency of performance. If the system were considered for application to an impaired surface waters it might be productive to study the possibility of optimizing the use of coagulants which in turn should increase the removal of particles in the 2-5 micron range. At full scale the investigators have estimated that a maximum head loss of 120 inches of water would most likely result in filter run times of between 16 and 17 hours.

One issue of concern is the scale of the pilot test. A flow of 300 gpm translates into approximately 0.5 million gallons per day which is the size of many small systems. Because of the scale of operation, it is difficult to examine operating conditions other then those for which the system was tested. This has both advantages and disadvantages. It is close to the scale at which the actual system may operate but the size of the system eliminates the opportunity to study its behavior under different conditions. Pilot testing is usually considered to be more then an attempt to see how the system operates under nearly full-scale conditions. For example, pilot testing might entail a detailed examination of the use of coagulants or coagulant aids, the effect of varying filter loading rates, filter cycle ratio and back washing strategies. However to conduct this type of program might require the development of small bench scale units. There is no indication that any of the operating conditions were systematically modified to stress the filter to the point of failure and then readjusted to identify the strategies that would bring the system back into a stable operating condition. This might be considered to be a study weakness. However, filtration should scale fairly easily and the system certainly seems to work very well under the current set of testing conditions. Because granular media filters are standard technology in the water industry, no scale up issues are likely if such a filter were included in a full-scale system used to produce water of potable quality.

C. AIR STRIPPING SYSTEM FOR VOC REMOVAL

An air stripping system was recently installed (October 2000) by Aerojet General Corporation at the Rancho Cordova Facility for the treatability study to remove volatile organic chemicals (VOCs) prior to the UV/hydrogen peroxide advanced oxidation process. It was observed prior to that date, that the UV/oxidation system was not effectively removing chloroform and TCE to acceptable levels. Furthermore, the energy and chemical requirements in the UV/oxidation system were higher due to the presence of TCE. As a consequence, it was determined that an air stripping process would be a cost-effective way of reducing VOCs prior to the UV/oxidation system, whose primary treatment objective was removal of 1,4-dioxane and NDMA. The following is a brief summary of the air stripping system with a focus on various factors that must be evaluated to determine the adequacy of the treatment train to provide potable water from a severely impaired source.

1. Effectiveness

The air stripping system was tested between October 2000 and December 2000 with samples taken approximately every two weeks to determine the effectiveness and reliability of the air stripping process. Of the nine samples collected, VOCs of concerns, primarily chloroform and TCE were removed at an efficiency rate above 99%. For example, TCE removal average 99.88% treating a TCE influent level ranging from 900 and 1,100 µg/L. The average effluent concentration was 1.34 µg/L with a range from 0.85 to 2.9 µg/L in the effluent from the air stripping. Subsequent treatment processes including the UV/oxidation process and the liquid phase GAC removed these VOCs below detection limits (detection limits for VOCs are generally approximately 0.5 µg/L or less depending on the chemical). Thus the air stripping system was very effective at decreasing both TCE and chloroform. All other VOCs that were present at relatively low concentration (e.g., cis-1,2-dichlorethene at levels of approximately 15 to 25 μg/L) were also effectively removed.

2. Reliability

As noted, the nine samples collected during the test period clearly show that the air stripping process is highly reliable. VOC removal efficiencies were consistently above 99%. The exact definition of reliability in the context of the proposed treatment system has not been quantitatively determined. However, in this case, data are available to specify the level of reliability that could be achieved for any given air stripper design. Models of the air stripping process are readily available and reliability criteria, once established, can be used to guide the design of any air stripping process used in the final treatment design. A set of only nine samples is too small of a sample set to confirm a specific reliability for the air stripper used in the treatability study. However, as discussed below, the observations in the tray tower air stripping system are not applicable to a packed tower aeration system and consequently the issue of reliability for a full-scale system could not be determined quantitatively in this treatability study.

3. Process Stability

Process stability defines the ability of a process to maintain its target effectiveness as certain independent variables change in value. Independent variables of importance for an air stripping system would include the influent concentration of the VOCs of concern, the water temperature, and flow rates. With respect to influent concentrations, the air stripping system is easily removing more than 99% of the VOCs of concern. Should the TCE concentration increase to 2,000 μg/L, TCE levels would still be below 5 μg/L which is the current MCL for TCE. Subsequent treatment processes as noted would further reduce TCE to below the MCL and possibly below detection limits.

The proposed treatment system is expected to treat a groundwater where temperature generally remains constant throughout the year. However, when the temperature decreases, the stripping of any VOC would become more difficult. This can be easily handled through appropriate design safety factors in the final system design. With respect to flow rates, the ultimate design of the air stripping system should include sufficient flexibility to control alternative flow rates with respect to both air and water.

4. Scale up Concerns

It is presumed that the pilot investigations being conducted at Rancho Cordova will serve as the basis for a full-scale design that could potentially be either installed at Rancho Cordova or could be installed at the San Gabriel Valley Baldwin Park Operable Unit. In either case, it is anticipated that the flow rate in the treatment system could be many hundreds if not thousands of gallons per minute (gpm), compared to the 150 gpm tested in the pilot plant. As a consequence, a scale up issue with respect to the air stripping system is that a tray aeration system would not be suitable for very high volume flows due to process flow and cost limitations. Consequently, a packed tower aeration system would be required for the full-scale system.

The results of the current treatability study would not be directly applicable to a full-scale system. For example, the air to water ratio used in the tray aeration system at the Rancho Cordova Facility was 67.3 on a volume-to-volume basis. This translates into a stripping factor of 77. Typical packed tower design call for a stripping factor between 3 and 5 to provide minimum packing volumes with adequate removal efficiencies. Additional safety factors are usually applied to increase the height of the packing such that the treatment process provides the necessary reliability and process stability desired. Clearly, a stripping factor of 77 in a packed tower system would be excessively costly and not an optimum design. For a stripping factor of 5, the appropriate air to water ratio on a volume to volume basis would be approximately 22 at a water temperature of 20^{o} C for removal of TCE. The use of a lower air to water ratio is clearly desired in a packed tower system, both because of the cost of the blower, cost of the pumping due to the increase in pressure drop and because of the need for off-gas treatment for the air stream from the air stripper. The TCE influent concentration currently is approximately 1 mg/L. Thus, the air stripping tower would be discharging roughly 8.3 pounds of TCE per day for every million gallons of water treated. In California, typically off-gas treatment is required if the quantity of VOCs emitted exceeds one pound per day.

Other scale up issues would include the potential need for equipment redundancies in the event of possible equipment outages and failures. Trade-offs between redundant equipment and plant water storage to meet demands would be a key factor in the overall design of the treatment system.

Finally, the packed tower aeration process is well established as a demonstrated technology. Analytical models are available to use as the basis for system design. Safety factors can be applied to tower design to provide the necessary level of system reliability. Typically, with packed towers, it is not appropriate to assume that removal efficiencies will consistently exceed 99%. Small non-ideal flows such as conduit flow along the walls of the tower could lead to short-circuiting and decrease overall removal efficiencies. Proper tower design can minimize these effects, however.

5. Other Factors

As noted in the treatability study Report, additional factors need to be considered for an air stripper such as chemical feeds system to minimize chemical precipitation in the packing which may reduce removal efficiency. However, because air stripping in a packed tower is a well-established technology, no barriers are likely with respect to the effectiveness of the system to meet potable drinking water objectives. Numerous air strippers are currently in operation at water treatment systems throughout the country removing a variety of VOCs, with subsequent potable use of the treated water.

Nonetheless, the factors discussed in this review would need to be considered in the final design of a treatment train that included air stripping towers for VOC control.

D. UV/HYDROGEN PEROXIDE (UV/OX) FOR CONTROL OF NDMA AND 1,4-DIOXANE

Advanced oxidation via a UV/OX system was also included in the process train tested at the Rancho Cordova facility. This technology was included as the primary treatment barrier for the contaminants, NDMA and 1,4-dioxane. Originally the technology was also intended to address the volatile organic compounds (VOCs) chloroform, TCE, cis-1,2-DCE and 1,1-DCE, but the concentrations of TCE and chloroform were so high at the Rancho Cordova site that air stripping was required for cost-effective treatment. Once the air stripping system was installed, it effectively removed the latter compounds as well.

Testing was conducted in a custom-designed 100 gpm pilot unit made by the Trojan Technologies. Low pressure ultraviolet light (LP UV) was used because it's effectiveness in NDMA removal is not influenced by nitrate interference as is the medium pressure ultraviolet light (MP UV) used in the original Rancho Cordova facility. The tests were conducted with two banks of 16 lamps each followed with an additional 8 lamp bank as well.

1. Effectiveness

Early tests showed the UV/ H_x process to be successful in meeting removal targets for NDMA and 1,4-dioxane, but falling short of its removal targets for TCE and chloroform. TCE removal was not sufficient because the influent was at very high levels (greater than 1 mg/L) and chloroform was too high because the process is not particularly effective in removing chloroform. Attempts to improve removal of TCE by increasing H_2O_2 dose had adverse impacts on NDMA removal. The addition of an air stripper ahead of the UV/ OX unit solved this problem by eliminating both TCE and chloroform. With the air stripper in operation, the UV/ OX process was easily able to meet the NDMA and 1,4-dioxane removal targets of 20 ppt and 3 ppb, respectively.

2. Process Reliability

Ideally the effluent levels of 1,4-dioxane and NDMA should be continuously monitored, but this is not practical with today's technology. On the other hand if measures could be taken to ensure that proper amounts of UV light and H_2O_2 are being applied, adequate removals of 1,4-dioxane and NDMA would be assured.

If the H_2O_2 feed should fail the result would be better removal of NDMA, but a substantial reduction in the removal of 1,4-dioxane. The H_2O_2 feed must be reliable, so regular confirmation of H_2O_2 levels by operational staff is needed, but continuous monitoring is desirable if suitable equipment for this can be found.

The reliability of the system for providing the UV light deserves some further investigation. Testing with the specific water quality of interest is especially important as lamp fouling rate is a function of water quality. The study demonstrated that there will not be a problem of scaling of quartz sleeves at the Rancho Cordova site. However, similar pilot demonstrations would be needed for application at other sites.

3. Process Stability

It may be possible to monitor the level of UV light being applied directly using UV sensors. Fairly reliable sensors are available for low-pressure UV systems. It is also possible to include interlocks in the instrumentation that would shut the unit down in the case of sudden lamp failure. Finally a regular, staggered lamp replacement program of conservative design would make an important contribution to system reliability.

Based on the Aerojet study it appears that, with the considerations described above, the UV/ H_2O_2 process can provide reliable performance.

4. Scale up Concerns

With this process, scale-up concerns mostly center on the hydrodynamics of the unit, that is, assessment of the potential for short circuiting. As long as the required removals of compounds targeted by this treatment stage are modest, some short circuiting can be tolerated and ordinary precautions can be applied.

For example, suppose that the target effluent level for NDMA is 20 ng/L (parts per trillion, or ppt) and the influent NDMA is at 100 ng/L. The required removal is then 80%. If the designer uses a safety factor of two, the unit will be designed to accomplish a removal of 90%. If 5% of the flow is bypassed completely around the unit, while the NDMA in the flow through the unit is reduced by 90%, the effluent level will be about 14.5 ng/L, which is still acceptable. On the other hand, suppose the influent NDMA is 1,000 ng/L. In this case the unit would be designed for a removal of 99%. If 5% of the flow bypasses the unit the combined effluent concentration would be just short of 60 ng/L which is unacceptable.

Thus the attention devoted to the design and control of the reactor hydrodynamics e depends on the removal efficiency required. As a rule of thumb, if the required removal were one order of magnitude or less, ordinary precautions, such as proper baffling at the entrance, exit and within the unit would probably be adequate. If a two-order reduction were required, better design with less short circuiting would be required. For greater removals coupled computational fluid dynamics (CFD)-reaction modeling might be necessary for each reactor, whenever the scale or design configuration is changed.

5. Other Factors

Whenever a powerful oxidation process is used, oxidation by-products will develop. The Aerojet study focused on this issue, addressing most concerns presently understood to be at issue. On the other hand, it would be prudent for an operator of a plant using such an oxidation process to produce drinking water to maintain a continued interest in emerging knowledge about oxidation by-products.

E. LIQUID PHASE GAC FOR POLISHING, TASTE AND ODOR CONTROL

The liquid phase granular activated carbon (LPGAC) contactor is located in the treatment train between the UV/OX system and the disinfection unit. The unit consists of a cylindrical carbon steel pressure vessel 5 feet in diameter, 8 feet in height and containing 2,500 pounds of carbon. It treats 100 gpm (100 percent) of the UV/OX effluent at a liquid loading rate of 5 gpm/ft^2 resulting in an EBCT of 6 minutes. The vessel has dished heads, is skid-mounted, has a pressure relief valve and a drain and equipped with sample ports at the 20-, 50- and 75- percent elevations on the vessel. After start up and prior to September 2000 the LPGAC unit begin to experience chloroform breakthrough. The breakthrough event was brought under control by replacing the GAC in the unit and then, in October, installing an air stripper prior to the UV/OX system. The LPGAC system was originally designed to remove VOCs, VOC breakdown products, and any other organic compounds remaining in the UV/OX system effluent. However, since the installation of the air stripper it has served primarily as a secondary barrier for VOCs and perchlorate removal. It also serves as a polishing step for the treatment train, providing some physical and biological removal of the remaining natural organic matter as well as taste and odor control.

1. Effectiveness

Control parameters for the LPGAC system include pressure drop across the GAC bed and contaminant breakthrough profile. If the concentration in the effluent exceeds a specified level then the GAC is either reactivated or replaced, which in effect determines the GAC bed life. If the pressure drop across the contactor becomes excessive, it should be backwashed to remove trapped solids and eliminate media compaction. Throughout the pilot study, the pressure drop has been less than 2 psi and backwash has not been required. The unit was put into operation in April 2000 during the Phase 2 treatment system start-up and analytical samples were collected at sample ports 12 through 16. Prior to October 3, the LPGAC contactor followed the UV/OX unit in the treatment train without an air-stripping process. During this period chloroform concentrations were observed to increase over time in the effluent, although TCE breakthrough did not occur. The gradual increase in chloroform concentration over time and the continuous removal of TCE indicates that adsorption was taking place in the column.

2. Reliability

It seems possible that, in the future, the LPGAC unit will function either as an adsorber or as a biological process depending on the circumstances. However if an upstream process fails, having the LPGAC unit in place is consistent with a multiple barrier philosophy. The unit is effective for control of taste, odor, assimilable organic carbon (AOC), and disinfection byproduct (DBP) precursors.

The GAC contactor will also provide a potential secondary barrier for perchlorate should the bioreactor fail or under-perform, although the capacity of GAC for perchlorate removal is apparently low, indicating that if perchlorate removal on GAC became necessary, careful control would be required to assure that perchlorate levels in the treated water did not exceed standards. The presence of LPGAC should also minimize problems with biological regrowth in the distribution system. Finally, the GAC contactor acts as a polishing unit by controlling taste and odor and removing some of the disinfection by-product precursors before the treated water is disinfected.

The LPGAC unit provides an added degree of reliability. It provides a barrier to VOCs and SOCs, helps control taste and odor and, controls products created in the UV/OX system. The addition of hydrogen peroxide resulted in a major increase in total THM Formation Potential. This was somewhat reduced by the UV/OX unit itself but completely removed in the LPGAC unit.

In order to assess the potential for biological re-growth within a water distribution systems two parameters were routinely monitored throughout the Phase 2 Treatability Study: AOC and biodegradable organic carbon (BDOC). No conclusive trends were evident from the BDOC data. However the ability of the LPGAC unit to remove AOC is evident from the data presented in the Treatability Study Report). In general, AOC concentrations increase after UV/OX and then decrease after LPGAC. For example on 5/10/00, AOC concentrations in the influent water after UV/OX, and after LPGAC were 42, 92, and 58 µg/L respectively. On 5/23/00, AOC concentrations in the untreated water, after UV/OX, and after LPGAC were 72, 249, and 105 µg /L. Some of these values were even higher at other sampling locations in the treatment train. These data indicate that AOC concentrations increase in magnitude by a factor of 2 to 3 due to production in the treatment processes prior to and including UV/OX. The LPGAC unit with an EBCT of 6 minutes was able to reduce the AOC to values close to the untreated water values.

The LPGAC did experience periodic flushing of heterotrophic plate count organisms. However this behavior is consistent with the behavior of GAC systems in general. There are no documented cases of pathogens amplifying on GAC if the influent water is pathogen free. Since the effluent is disinfected, the threat of pathogen intrusion should be nonexistent.

Using an LPGAC unit seems to have many benefits including improving taste and odor, controlling AOC and the byproducts of biological reduction of perchlorate and the oxidation of VOCs and SOCs. It also provides a barrier against upstream process failure.

3. Process Stability

Based on the data presented in the pilot study report the lpgac unit was able to meet its target effluent levels despite changes in the influent concentrations of various target compounds. After start-up the lpgac unit experienced chloroform breakthrough which was easily brought under control by replacing the gac in the unit. Chloroform onto the gac was maintained at a low level by installation of an air stripper in the treatment process chain ahead of the lpgac unit. Both total thm formation potential and aoc increased after the uv/ox unit but were easily controlled by the lpgac unit. The unit did experience periodic discharges of heterotrophic plate count organisms which is typical of gac systems. However, since the effluent is disinfected the threat of pathogens entering the system is virtually non-existent. The unit seems to have served as an excellent polishing step for the treated water. Based on the data reported from the pilot study the lpgac system operation was very stable during the pilot study.

4. Scale up Concerns

The flow rate of 100 gpm through the LPGAC vessel was selected to demonstrate its efficacy at a scale large enough to be confidently applied to a full-scale design. The hydraulic loading rate on the pilot GAC contactor is 5 gpm/ft^2. The parameters identified and evaluated to assess LPGAC operation were head loss and empty bed contact time and breakthrough profiles. Various modeling tools are available to help make scale-up decisions for the LPGAC unit. EPA's GAC models were run to predict a range of breakthrough behaviors that may be exhibited by GAC. Runs were based on some arbitrary assumptions including influent levels at 2 µg/L for both chloroform and TCE onto the GAC contactor. The model predicted that the initial chloroform breakthrough should occur in 41 days and that the 50% breakthrough should occur in 52 days. The initial breakthrough for TCE was predicted as occurring in 3.6 years and the 50% breakthrough in 4.2 years. These results indicate the wide range of breakthrough behaviors that may be exhibited by GAC, which may be rationalized using actual project characteristics. These models could be applied in developing the specific data necessary for DHS review under DHS policy 97-005."

F. DISINFECTION

Disinfection is an important element of this process train because biological processes are not common in the treatment of drinking water and it is prudent to ensure that no unusual microbial activity is introduced into the drinking water system. There are three unit processes used in the proposed process train that are widely recognized as effective in reducing the concentration of microbial contaminants: granular media filtration, UV/OX, and chlorination. In fact EPA has published formal credits for the removal of microbial contaminants that can be assigned to filtration and chlorination. Unfortunately there are no such standard credits available for UV/OX. As a result, attempting to get removal credits for this unit process, probably would require microbiological testing to establish the removals that it can accomplish. LPGAC is also likely to accomplish some removal of particulates, but it introduces it's own unique contribution to the microbial community.

1. Effectiveness

A simple way to consider the requirement for disinfection would be to evaluate whether the system meets the surface water treatment rule with the process stream in its entirety (ignoring UV/OX) and then ensure that the level of chlorination alone is adequate to control heterotrophic bacteria (HPV) in the LPGAC effluent. So long as free chlorine is used, the disinfection requirement is easy to meet.

If a plant were designed to meet the surface water rule, the overall removal credit required would be 3 logs for Giardia and 4 logs for viruses. The direct filtration step would provide credit for 2 logs reduction for Giardia and 1 log for viruses. In order to meet the requirements of the enhanced surface water treatment rule (2 log removal of cryptosporidium) the turbidity of the filter effluent must be kept less than 0.3 NTU, 95% of the time. This means that chlorination must accomplish 3 logs of virus removal and one additional log of giardia removal. According to EPA's tables the chlorine concentration times the contact time or, Ct required for 3 logs of virus removal (pH=8, T=10^{o}C) is 4 mg/L-min. In the same tables, and with the same conditions, the Ct required for a 1 log reduction in giardia is 53 mg/L-min. The time credit received in this regulation is the time required for 10% of the mass of a dye to pass through the disinfection unit. Pilot tests were conducted by Aerojet with chlorine at a level of 3 mg/L and a nominal contact time of 22 minutes. These tests demonstrated that HPC from the upstream LPGAC could easily be controlled and that the levels of regulated disinfection byproducts would be far below present and future regulatory limits.

It would appear that disinfection requirements can be met for this process train provided a chlorination system is designed for the effluent that can reliably achieve a Ct of approximately 53 mg/L-min or greater. Designing such a system is a relatively straightforward exercise.

2. Reliability

Where disinfection is concerned, the Aerojet process train would not appear to introduce any requirements beyond those normally encountered in the design of conventional water treatment facilities. Under these conditions, the requirements for process reliability (monitoring of turbidities, flow and disinfectant residuals) should also be the same as those that normally apply.

3. Scale up Concerns

Scale-up concerns for this process address primarily the hydrodynamics of the process, as was the case for the UV system. In this case, however, the EPA has established an objective criterion, namely that the contact time credited to the design will be the time required for 10% of the dye to pass through the unit. Once again, conventional methods being used to meet these requirements in water treatment plant design should be suitable for this process train as well.

G. SUMMARY – TREATMENT TRAIN

The treatment train tested in the Aerojet Phase 2 Treatability Study consisted of six unit processes, a fluidized bed GAC bioreactor, a multi-media granular filter, a tray air stripper, a UV/Oxidation process using hydrogen peroxide, a liquid phase granular activated carbon adsorption process, and final disinfection with free chlorine. Auxiliary processes included a biomass reclamation system for management of excess biosolids from the bioreactor. This combination of processes was operated over an extended period of time to demonstrate that the treatment train could produce water of potable quality from a severely impaired groundwater source at the Rancho Cordova site. As discussed in the previous sections, the Panel agrees that the Phase 2 treatability study has confirmed that this combination of treatment processes is capable of removing all target chemicals below all regulatory standards required to meet potable water requirements. Each of the treatment processes was demonstrated to meet desired removal efficiencies in a reliable manner. Process stability was also demonstrated, provided that the optimum ethanol dosage was maintained during operation of the bioreactor. All target chemicals were effectively removed.

An analysis of influent and effluent concentrations for all target chemicals as provided in the Phase 2 report shows that the treatment train is highly efficient at removing the principal compounds of concern, namely, perchlorate ion, NDMA, 1,4-dioxane, and a suite of chlorinated compounds, primarily TCE, and chloroform. In addition, the treatment train demonstrated that any treatment related chemicals, such as excess ethanol, oxidation by-products, hydrogen peroxide, cell exudates from the bioreactor, or treatment train generated microbes could be readily controlled to acceptable levels. In the case of chlorinated solvents, particularly TCE and chloroform, the treatment train provides three treatment barriers, namely, air stripping, UV/OX, and liquid phase GAC. For perchlorate ion, the primary treatment barrier is the bioreactor. Some additional removal capacity may be available in the liquid phase GAC, but more assessment of the capability of GAC for perchlorate control is needed, because of uncertainties about the removal capacity of GAC for perchlorate. For NDMA and 1,4-dioxane, the only effective treatment barrier is the UV/OX process, although some additional removal of 1,4-dioxane may occur in the GAC system. The lack of redundant treatment process for perchlorate and NDMA would need to be addressed in the risk analysis of the proposed treatment system in the context of a site-specific permit application.

Scale-up issues for each of the processes have been discussed above. Any site-specific design utilizing the tested treatment train would need to address a number of issues related to alternative equipment designs, location and interconnections between the processes, and the integration of the treatment train into the overall operations strategy for the water treatment system. For example, the need for, and use of sufficiently large treated water storage facilities would clearly impact the requirements for redundant treatment systems, or the need for fail-safe control systems.

In conclusion, the Panel is of the unanimous opinion that the Phase 2 Treatability Study has demonstrated that the selected treatment train is a viable treatment option to produce water of potable quality from a groundwater impacted with perchlorate, NDMA, 1,4-dioxane, and TCE and chloroform, as well as other chlorinated solvents defined as VOCs. Site-specific factors would need to be considered if this treatment train were proposed to be used in a plan to remediate a severely impaired water source and to use the treated water for potable purposes. These factors are discussed above, and are more specifically identified in Section 2 of this report.