Choosing an Alternative Water Intake Site for Solano County

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Abstract Solano County Water Agency, located in Northern California, pumps a majority of its water supply from the Sacramento and San Joaquin Delta. In recent years, the pumping head at Barker Slough has experienced poor water quality, detecting high concentrations of turbidity, dissolved organic and total organic carbon. In 2001, an alternative water intake cost-study began research to change the water intake site from Barker Slough to a location that contains lower contaminant concentrations. This study compared water quality data from 2001 to 2004 from proposed alternative intake sites (AIS), where water of improved quality could be pumped, against the Barker Slough. More recent water quality data are needed. The Department of Water Resources Hood station, located within 5 miles of the proposed intake sites, has been collecting water quality data continuously from the early 1990's to the present. This research will also ask whether the Hood data is a good surrogate for the alternative intake sites. From the start, two sites were eliminated from the study because neither improved water quality goal. In the comparison of the alternative intake sites with Hood, most of the parameters show a good comparison. For some of constituents, Hood is not a good predictor of AIS. The findings show there are alternative sites with better water quality, and the use of Hood as a surrogate will depend of the decision of the water agency.

Introduction

The Sacramento and San Joaquin Delta provide water to two-thirds of California and are an important spawning area for rare and threatened fish populations. As human population grows, so does the demand for water. However, the state's natural resources are limited and may not meet the predicted demand of an exponentially growing population (Lund *et al.* 2007). The summer of 2007 particularly did the judge have to rule on that, to illustrate the consequence of the lack of water, a federal judge ruled to reduce water deliveries from the State Water Project, from the Sacramento Delta to southern California and limiting water to the residents. As concerns increase, water stakeholders must allocate safe drinking water to the growing California population through best management practices (Lund *et al.* 2007). Currently to help with potential shortages, water agencies throughout California are studying the remaining amount of groundwater, snow melt, and other water run-offs in hopes of treating and making it available as alternative intake of water.

The Delta is facing inconsistent levels of contaminants with the current water supply and is becoming more limited because of the need to detected spawning sites for the endangered Delta smelt (Mount 2007). As a result, one of the stakeholders of the Delta, Solano County Water Agency (SCWA), has developed a preliminary study to seek an alternative intake of water to replace the source of water pumped out of Barker Slough (BSPP). The alternative location is necessary in order to avoid the limited amount of water that can be pumped during a certain time period, as well as protect the endangered Delta smelt species, an alternative water intake site is necessary. Another reason to seek alternate intake sources involves BSPP poor water quality; that have cases of high turbidity, total organic carbon, and dissolved oxygen (Department of Water Resources 2002), which require additional chemicals to be added to the water to treat the high dosage of unwanted contaminants, water plants are concerned, Thus, there are three main criteria for selecting alternative water in-take sites: natural obstacles, man-made obstacles (i.e. freeways or major development, which can create problems during construction of new pumping plant), and water quality issues. Using these criteria, SCWA identified five potential alternate intake sites (see Methods and Figure 1) (Bookman-Edmonston 2003). Nevertheless, since the SCWA study was conducted from 2001 to 2004 and issue of high levels of contaminants continue to arise, more recent research is needed to complete this alternative water intake study.

The objective of this study is to analyze the water quality constituents of the five proposed sites with the current intake at Barker Slough pumping plant (BSPP). In doing so, SCWA has identified a list of concerned water quality constituents to answer two questions for this study. Question one is, "From the proposed five sites along the Sacramento River, is there one site that is comparable or has better water quality than the existing water intake from Barker Slough Pumping Plant?" The null hypothesis is no AIS contain better water quality than BSPP. The water quality data collection for the five alternative sites ended in 2004, thus more recent data is necessary to assess the potential for these sites. Fortunately, the Department of Water Resources (DWR) Hood station, located within five to ten miles of the proposed sites, has been collecting water quality data continuously from the early 1990's to present. Therefore, the second research question addresses if the DWR Hood is a good surrogate of water quality data for the alternative intake sites? The second null hypothesis is that the Hood is not a good proxy for the AIS. Since question one addresses water quality, this question is not concerned with the actual one. Alternatively, by comparing specific water quality parameters at each site from 08/2001-02/2004, such as alkalinity, nitrate, total dissolved organic carbon, etc (refer to table 1 for all the consistent), I will determine whether the DWR Hood data can use legitimately be used as a surrogate for the alternative sites, thus saving the county time and money from additional monitoring costs. The ultimate goal of this alternative intake study is to gain a better understanding of a possible consistent and higher-quality drinking water location for the residents in Solano County.

METHODS

Identification Of System Under Study The five alternative intake sites located in Solano County are: Sacramento Ship Channel at Clarksburg (abbrev-Ship Clark), Sacramento Ship Channel at Courtland (Ship Court), Sacramento River at Courtland (SR Court), Sutter Slough near Courtland (Sutter), and Elk Slough near Courtland (Elk) (Fig 1). The DWR Hood station is located five to ten miles east of the potential sites (Fig 1).

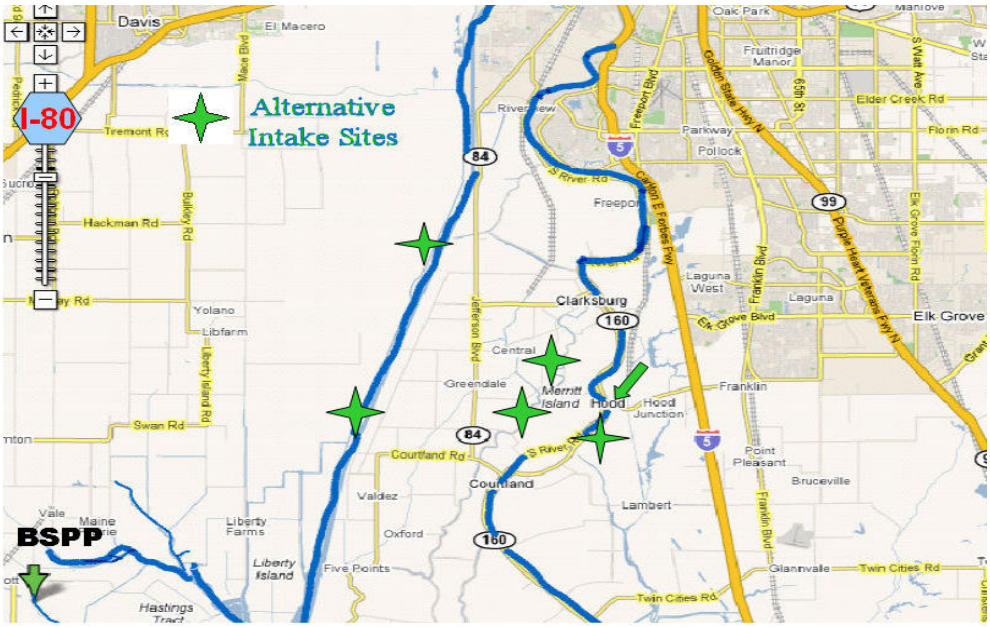

Figure 1: Map of the five AIS, BSPP, and Hood. The star represents the five alternatives intake sites, the arrow on the bottom left is Barker Slough Pumping Plant, and the second arrow by the I-5 is Hood. This shows how close the Hood station is to the other alternative intake sites.

Data Collection Water data values are analysis before it goes through treatment, therefore the Environmental Protection Agency (EPA) maximum contaminant levels will not be necessary for this study. The water quality data used for this study are gathered from sample collections by SCWA and an outside contractor, Nachtman Laboratory. The data also include information from the Department of Water Resources (DWR), California Data Exchange Center (CDEC) website under that station name of BKS and Hood. The water quality data collection is from 08/20/2001 thru 02/09/2004.

The majority of the gathered water quality lab sheets include the following constituents (more individual description is provided in Appendix A). These specific parameters are reviewed because they are the greatest concern to the local water treatment plant.

Dissolved Bromide	Field Water Temperature
Dissolved Nitrate	Total Alkalinity
Dissolved Phosphorous	Total Dissolved Organic Carbon
Field pH	Total Field Coliforms
Field Electrical Conductivity	Total Organic Carbon
Field Turbidity	Total Phosphorous

For the statistical analysis, not all water quality data are reviewed, due to sampling errors at locations where some parameters were not collected.

Techniques of Analysis For statistical analysis, the gathered data was organized and analyzed on Microsoft Excel® using a t-test, with two-tails of unequal variances. The t-test determine whether each of the AIS are comparable to or better than Barker Slough water quality. Each constituent needs to be less than or equal in water quality to the BSPP to be considered as a possible alternative intake site. This is analyzed with the t-test, P-value < 0.05, then it is considered whether the sites are comparable and contain a lower concentration of contaminants than Barker Slough. The second part of the statistic analysis looks at the raw mean for the water parameters at each site, and compares each site against each other. Using the mean, the research objectives are supported with an overall lower mean concentration of contaminant. In contrast, if any of the results showed a higher level of concentration contaminants, then it was considered hazardous and eliminated from the study. The AIS with the least amount of contaminant concentration will be proposed as the best alternative.

With respect to whether the Department of Water Resources, Hood data is a good surrogate for the AIS, the same t-test, two-tails with unequal variances as question one applies. From the T-test comparison of AIS with Hood, the desire P-value needs to be > 0.05, in order to consider Hood as a good surrogate. If the P-value is not > 0.05, then the comparisons between the sites are not considered to be significantly the same and Hood is not a good representation of the AIS. Like question 1, the mean of each water quality constituents are compared with each other; the results will emphasize whether the AIS are predictable to Hood. The desire mean in this case, needs to be similar, with lower variances between the Hood and the alternative intake sites.

Results

Comparison of Alternative Sites to BSPP Results such as the Total Phosphorous and Bromide are not used because there are only 2-5 sample sizes. This is relative to dissolved organic carbon and the other list of parameters with ~20 samples (refer to Table 1). The Sacramento Ship Channel at Clarksburg and Courtland are eliminated from this study because they do not meet initial selection criteria, the sites present man-made obstacles and do not meet improve water supply relative to Barker Slough goal Bookman-Edmonston 2003). For the rest of the AIS: Sacramento Courtland, Sutter Slough, and Elk Slough have results with statistical significant P-value < 0.001 for all the constituents (i.e. Alkalinity, pH, Electrical Conductivity, Turbidity, Dissolved Organic Carbon, and Total Organic Carbon) except for temperature with P > 0.5 (Figure 1). With P-value < 0.05, the AIS have better water quality compared to Barker Slough.

Table 1: Summary of P-values from T-test: Two Sample Assuming Unequal Variances

Despite the table presents p-values for Ship Clarksburg and Ship Courtland, these two sites are eliminated because it did not meet original research goals. While the other three sites: Sac Courtland, Sutter and Elk Slough, all three shows p-value < alpha of 0.05 for majority of the constituents. Even though temperature does not show p-value < 0.05, it is not an issue for treatment plants. Overall, the three sites present a high potential for replacing BSPP.

	Total Alkalinity	Field Electrical Conductivity	Dissolved Nitrate	Field pH	Field Turbidity	Dissolved Organic Carbon	Total Organic Carbon	Temperature Degree C
Desired Level	Lower	Lower	Lower	Between 7-8	Lower	Lower	Lower	
BSPP								
Ship Clarksburg	<0.001	<0.001	0.01	<0.001	<0.01	0.01	0.16	0.51
Ship Courtland	0.15	0.08	< 0.001	<0.01	0.09	ND	0.05	0.81
Sac Courtland	<0.001	<0.001	< 0.001	<0.001	<0.001	ND	<0.001	0.86
Sutter Slough	<0.001	<0.001	< 0.001	<0.001	<0.001	<0.001	<0.001	0.80
Elk Slough	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.69

*ND-Data are not producable due to limited samples collected.

From the methods, if the P is not < 0.05, then comparison of the mean concentration will see if the AIS contain better water quality. Looking at the combined mean constituent in table 2 for each of the sites; Alkalinity, Electrical Conductivity, Field Turbidity, Dissolved Organic Carbon, and Total Organic Carbon have the lower contaminant concentration. With exception,

pH shows lower levels in the alternative intake sites, but the ±0.1 does not create a large issue during treatment, it is not considered too acidic or basic. Dissolved Nitrate shows an increase in the AIS; the original level of Nitrate in Barker Slough is only constituent to be at a better level. This is different from the results of P-values. Despite P-values< 0.05 showing significance, the raw mean concentration presents otherwise and concluding that BSP has a more desirable level of nitrate. Overall, from the three AIS, they present positive solutions for changing the current source at BSPP. The table reemphasis that the both the Ship Channel at Clarksburg and Courtland have higher concentration of contaminants than the rest of the AIS.

Table 2: Summary of mean values of BSPP, the 5 AIS, and DWR Hood.

Samples were collected from (08/2001-02/2004) and the majority of the total collection size is 50, but for the Ships Channels they are more limited (<10 samples). For all the constituents, water treatment plant desires a lower concentration. The Ship Channel at Clarksburg and Courtland site are not considered because they both have higher concentration of undesired contaminants. Dissolved Nitrate is the only constituent that does not show AIS with the better water quality. BSPP is used to analyze question 1 and Hood is used to analyze question 2. Comparison to BSPP, Sac Courtland, Sutter and Elk Slough all present lower concentration of the contaminants. For Hood, looking at individual constituents separately, some shows that it matches well with very lower differences; however for two of the constituents (e.g. Nitrate and Turbidity) means are not comparable.

	Total Alkalinity	Field Electrical Conductivity	Dissolved Nitrate	Field pH	Field Turbidity	Dissolved Organic Carbon	Total Organic Carbon	Temperature Degree C
Desired Level	Lower	Lower	Lower	Between 7-8	Lower	Lower	Lower	
BSPP	86.79	261.96	0.28	7.55	56.92	4.88	6.08	16.61
Ship Clarksburg	150.40	1229.20	2.16	8.36	33.36	2.36	4.13	18.56
Ship Courtland	96.38	510.50	4.92	7.82	116.05	2.14	4.25	17.41
Sac Courtland	63.45	157.55	2.02	7.08	28.47	0.13	2.56	16.88
Sutter Slough	64.33	168.40	2.76	7.26	15.05	2.21	2.72	17.03
Elk Slough	65.88	168.74	2.28	7.13	24.29	2.17	2.52	17.21
Hood	65.83	171.32	0.62	7.53	15.74	2.20	2.42	16.88

Comparison of Alternative Sites to Hood Station Data

To determine if Department of Water Resources (DWR) Hood data is a good surrogate for the AIS, the desired P-values are > 0.05. For the three AIS's, Sacramento River at Courtland, Sutter and Elk Slough have P > 0.05 for alkalinity, electrical conductivity, dissolved organic

carbon, total organic carbon, and temperature. This excluded dissolved nitrate, pH and Turbidity, because the P-value < 0.05; this is not desired for the research's objective.

Table 3: Summary of P-values from T-test: Two Sample Assuming Unequal Variances

The p-values are only present for Sacramento at Courtland, Sutter Slough, and Elk Slough. The three sites have total alkalinity, electrical conductivity, dissolved organic carbon, total organic carbon, and temperature with the desired p-value > 0.05. This shows that the data are not significantly different. However, this also shows that Hood is not a good representation of water quality constituents: dissolved nitrate, pH, and turbidity.

	Total Alkalinity	Field Electrical Conductivity	Dissolved Nitrate	Dissolved Organic Carbon	Field pH	Total Organic Carbon	Temperature Degree C	Field Turbidity
Desired Level	Lower	Lower	Lower	Higher	Between 7-8	Lower		Lower
Hood								
Sac Courtland	0.47	0.24	<0.001	ND	<0.001	0.75	0.99	0.04
Sutter Slough	0.69	0.82	0.01	0.98	<0.001	0.53	0.82	0.04
Elk Slough	0.99	0.82	<0.001	0.91	<0.001	0.81	0.69	0.04
Ship Clarksburg	NOT USED because of poor water qualities from question 1.							
Ship Courtland	NOT USED because of poor water qualities from question 1.							

*ND-Data are not producable due to limited samples collected.

For the means between Hood and the three AIS, all measurements of water quality except nitrate, turbidity, and dissolved organic oxygen suggest and conclude Hood is a good surrogate. The Ship Channels are discarded because of its limited sample size and because it does not meet the original water quality improvement goal. The water quality constituents (i.e. Alkalinity, Field Electrical Conductivity, Field pH, Dissolved Organic Carbon, Total Organic Carbon and Temperature) for Hood falls within ± 0.1- 10 differences between the three selected AIS (Table 2). Although Hood is unable to predict nitrate, water treatment plants consider this manageable. The main concern in Hood is the turbidity level; according to the results in table 2, it is unable to predict for the alternative intake sites.

Discussion

For question 1, the results showed that the majority of the P-values are < 0.05, this answered that the AIS's have healthier water quality and less concentration of contaminants. Temperature for the three AIS's does not have P-value < 0.05; overall it shows that AIS have a higher temperature concentration, but this is treatable in the treatment plant, so this does not

eliminate the results that the AIS contain lower contaminants. Nitrate was mentioned to have significant P-value < 0.05, but with different results of lower contaminant concentration. Based on the objectives, the mean values for nitrate is more important to determine that AIS show better water quality.

For question 2, results show Hood is a good surrogate for the alternative intake sites, P > 0.05 for all constituents except pH, nitrate, and turbidity. This validates that Hood does a good job in predicting the water quality for the three alternative sites.

Acceptability of the Alternative Intake Site For the Sacramento River at Courtland site, dissolved organic carbon was not detected because of sampling errors. Despite dissolved organic carbon not being detected, with all other P-values <0.05 including Alkalinity, Field Electrical Conductivity, Nitrate, pH, Turbidity Dissolved Organic Carbon, Total Organic Carbon, and Temperature, the Sacramento River at Courtland has better water quality. On table 2, the mean average for Sacramento River at Courtland reemphasizes better water quality relative to the poor water measurements in Barker Slough. In cases of electrical conductivity, turbidity, dissolved organic carbon, and total organic carbon, Sacramento River at Courtland is lower in concentration by 100% compared to BSPP.

Sutter Slough shows similar results with all P-value < 0.05; it answers the first objective of having less concentration of contaminants compared to BSPP. For the average mean concentration (Table 2), all water quality constituents show Sutter has a lower contaminant concentration. This further demonstrates that improved water quality is present along the Sacramento River.

Elk Slough followed the same pattern as Sacramento River at Courtland and Sutter Slough. The P-values being < 0.05, proves that Elk has healthier water compared to Barker Slough. The lower average mean concentration of water quality parameter for Elk further verifies the objective for question one.

Overall ranking of the three AIS, (1) Sacramento at Courtland, (2) Elk Slough, (3) Sutter Slough with improved water quality with respect to 1=Best and 3=Less Desired.

Hood Water Quality Data as Surrogate for the Alternative Intake Sites Hood data is a good representation for most of the water constituent concerns (Table 2). In contrast to DWR, Hood is not a good predictor for pH, nitrate, and turbidity.

Water quality at Sac River at Courtland shows that for all the parameters, P-value being > 0.05, denote there is no significant difference between BSPP with Hood. Hood is a good surrogate according to the P-values and mean concentration of each constituent. According to table 2, when comparing BSPP with Sac River at Courtland, there is only a difference of 2 mg/L for the majority of the parameters. With the concentration of dissolved organic carbon, Hood does not show a good surrogate. To monitor the level of DOC more accurately, since Hood is a poor proxy, then actual site collections are required, similar to parameter, turbidity.

In Sutter Slough, following Sac River at Courtland, the P-values are > 0.05. This shows that Hood is a good surrogate and additional collections are not needed at this site. From mean averages of Sutter and BSPP in table 2, there is a very small difference in concentration. Hood is able to predict the water quality of Sutter with high significant confidence.

Finally, for Elk data also proves Hood as a good representation. Finally, for Elk, the pattern of Hood being a good representation of this site is also true. According the P-value on table 3, Hood can be used as a proxy for future analysis. Looking at table 2 for AIS, Elk Slough mean concentration of contaminants have very small difference compared against BSPP.

Hood is not a good predictor for pH, nitrate, and turbidity at each of the alternative intake sites. Out of these three, turbidity was one of the water quality parameters of greatest concern at the current pumping site. Thus, for future studies, in order to monitor these parameters more sample collections are needed at the three individual AIS. Even though turbidity needs actual site collection versus using Hood as a surrogate, this collection is for one parameter and thus not for the whole list of constituents, which will bring the overall cost down.

Similar to previous including the previous research completed by Bookman-Edmonston and Northwest Hydraulic Consultants (Bookman-Edmonston 2003) studies, these results further suggest Sutter Slough and Elk Slough are good replacements to the BSPP site. Bookman-Edmonston and Northwest Hydraulic Consultants' report also followed the consideration of Barker Slough water quality with high level of TOC and DOC, and turbidity. However, this research was different from previous study because the old analysis mainly looked at the cost-effective of potential pipeline construction of the alternative intake sites. A major difference between this study and past studies is that these results show an additional potential alternative at the Sacramento River at Courtland.

The finding of this research is a good approach in determining alternative water intake sites. The main limitations of this research arise from not collecting personal water quality samples, but relying on data collected by others; this creates a problem because it does no include or consider problems that may have occurred during the time of collection. Another main consideration not taken into account was the unequal sample sizes for the AIS, where certain parameters were eliminated because of incomplete sample sizes.

The results for this research will be submitted to Solano County Water Agency (SCWA). It can potentially influence changes in water intake from current intake at Barker Slough to one of the three AIS. If additional research is needed, extra money would not go completely into setting up sample sites at the AIS because of the conclusion that Hood is a good proxy. With exception of turbidity, actual samplings are desired for further and more accurate assessment. In this respect, future study can base AIS water quality using Hood samples. In answer upcoming water quality issues, Hood will be the proxy to compare current water quality at Barker Slough pumping plant.

In regards to current issues of degraded water treatment plant may increase water costs because of the additional chemicals added to treat high contaminant concentration and remove unwanted particles. The intensity level of contaminants is predicted to be an effect of human development, irrigation run-off, and the excessive use of pesticides in agriculture. Moreover, based on the current issue of growing populations, water agencies are constantly seeking for improved and increased water quality for drinking. More generally this research shows how a comparison of water quality from different sites can answer alternative water supply concerns. For Solano County Water Agency, they selected to look at different sites' water qualities. The goal is to find a location that will provide safe and clean drinking water with few chemicals added to kill bacteria; moving the location of the intake will also protect endangered species that spawn in current water source.

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Appendix

In this section, you can find a complete list of the water quality constituents and meaning/ effects it has in water.

- Total Alkalinity- Lower levels are desired. Is a measure of water's capacity to neutralize acid. Alkalinity results from the concentration of bicarbonates, carbonates, and hydroxides in the water; these ions also increase pH, which is a measure of the hydrogen ion concentration and indicates the degree of acidity or alkalinity.
- Dissolved Bromide- Occurs as a result of seawater intrusion and sea-spray-affected precipitation.
- Dissolved Nitrate: lower levels are more desired. High concentration in water can cause the Blue Baby Symptoms. Higher concentration can be due to agricultural runoff, industrial discharges, or municipal sewage.
- pH: Between the values of 7-8. Any higher or lower would be considered basic or acidic.
- Electrical Conductivity: Lower levels are more desired. It causes the water to be more salinity.
- Field Turbidity: Low levels are desired. Turbidity defines how clear the water is. Less turbidity means less concentration of small particles to be present in the water.
- Field Water Temperature: pH of 7 is the ideal case, but usually it is ± 1ºC.
- Total Dissolved Oxygen: A high concentration is more desire. Dissolved Oxygen
- Total Organic Carbon: Low concentration is desired. TOC is a measurement of carbon or organic in the water from agriculture run-off; this is unfavorable condition for aquatic life, because the organic content consumes the oxygen in the water that are needed for fish species.
- Total Phosphorous- one of the key elements necessary for growth of plants and animals and in lake ecosystem. When there are high levels of phosphorous present, it can have an increase on the growth of nutrients such as nitrate, phosphate, or organic waste. This is the case of eutophication.