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Klamath Hydroelectric Project

Reservoir Oxygenation Feasibility Evaluation Report

Copco and Iron Gate Reservoirs

Mobley Engineering

WolffWare™

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April 2008

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Introduction

As a part of their FERC license application process, PacifiCorp has been requested to evaluate the feasibility of maintaining dissolved oxygen (DO) levels in Iron Gate and Copco Reservoirs. In 2005, a team put together by Mobley Engineering Inc. (MEI) provided an evaluation of oxygenating Iron Gate Reservoir specifically to improve reservoir releases. In 2007, MEI was asked to evaluate placing oxygen in Iron Gate and Copco Reservoirs to obtain the desired DO levels. In preparing this report, MEI, WolffWare, and Reservoir Environmental Management (REMI) worked with Watercourse, CH2MHill, and PacifiCorp staff to develop an approach for evaluating oxygenation of the reservoirs and to develop a conceptual design to achieve those goals. The oxygen capacity and placement requirements were evaluated for each reservoir using CE-QUAL-W2 models. The costs and physical requirements for the oxygen supply facilities and diffuser system piping were evaluated using site-specific conditions, gas supply vendor information, and experience from other oxygen diffuser system installations.

Copco and Iron Gate CE-QUAL-W2 Models

Background

CE-QUAL-W2 models were used to investigate the feasibility of maintaining enhanced DO levels throughout Copco and Iron Gate Reservoirs. CE-QUAL-W2 is a laterally averaged two-dimensional model with resolution in the vertical and longitudinal direction. The model provides detailed results which include DO concentrations at any desired location versus time throughout the reservoir. A modified version of CE-QUAL-W2, provided by Loginetics Inc., which has the capability to include oxygen diffuser operation, was used for this study. A key advantage with this approach is that any number of diffusers, with any desired oxygen flow rate, can be located throughout the reservoir. The model results then provide a quantitative evaluation of the potential improvement that diffusers can provide.

CE-QUAL-W2 models of both Copco and Iron Gate existed from a previous PacifiCorp study. These models were used from the 2001 calibration year with minor modifications to be better suited for use in this study. These modifications are detailed in Appendix A and summarized below.

1. The sediment oxygen demand (SOD) was increased from 1.5 to 2.25 g O_2/m^2/day for Copco and from 1.1 to 2.25 g O_2/m^2/day for Iron Gate. This was deemed necessary because experience with other diffuser installations has shown an increased SOD when diffusers are operated in a reservoir and cause some mixing and higher DO levels near the bottom.
2. The inlet concentrations were modeled as either constant values or as a constant value with a step change. The constant values were based on median values from measured inflow data while the step changes for the peak loading case were based on maximum measured concentrations. This approach is desirable for evaluating the feasibility of different diffuser systems because alternate conditions are easily modeled and the results are more easily interpreted.
3. The oxygen flow rates were held constant for the entire oxygenation period or were held constant with a step change to handle peak loads. This approximation was consistent with the scope of this study. Over 100 model iterations were required to determine the location and flow rates for the diffusers with this simplified approach. Varying the oxygen rate for several different diffusers would have required a significant increase in the number of runs. The oxygen flow rates were set high enough to ensure that the target DO was achieved for the majority of the time and therefore are representative of the maximum daily flow required for the entire oxygenation period. A considerable reduction in oxygen could be achieved by continually varying the oxygen flow rate to handle the time-varying loads and time-varying inflows.

Base Case Summary

From the calibration and initial setup runs of the W2 model, it was clear that incoming organic loadings and temperature stratification would have a primary effect on the DO in both of the reservoirs. **Figure 1** presents both the residence time and the DO concentrations for Copco Reservoir, for two different dates, May 1st and August 1st. The concentrations are based on the model with the median loading and with no oxygen added to the reservoir.

Figure 1 shows that the water collects in the hypolimnion during the summer while the incoming flows move over the thermocline, through the metalimnion, and into the hydroturbine withdrawal which is located at elevation 786.7 m. During the latter part of the summer, the residence time in the hypolimnion can exceed a few months, while the residence time in the metalimnion is on the order of two weeks. The epilimnetic water has a residence time slightly longer than the metalimnion, with a higher DO concentration due to surface reaeration and algal DO production.

The oxygen demands in the hypolimnion, which are produced by both the sediments and by the organic loading, reduce the DO concentration to zero. Although the residence time for the water withdrawn through the turbines is much shorter, the oxygen demands and mixing which may occur are sufficient to reduce the DO by approximately 5 mg/L as compared to the inflow DO concentrations.

Figure 2 presents the residence time and the DO concentrations for Iron Gate Reservoir, for the same dates shown in Figure 1, May 1st and August 1st. The concentrations are based on the model with the median loading and with no oxygen added to the reservoir. Similar behavior is shown in this figure as demonstrated in Copco Reservoir. As the summer progresses, the region of anoxic water extends to just a few meters below the centerline of the turbine withdrawal (elevation 700.7 m). The incoming water flows through the reservoir in a layer of water which extends approximately 8 m in height and is centered at the turbine withdrawal elevation. Even though the residence time is short in this withdrawal layer, the oxygen demands are significant enough to reduce the DO concentration by approximately 5 mg/L as compared to the inflow concentration.

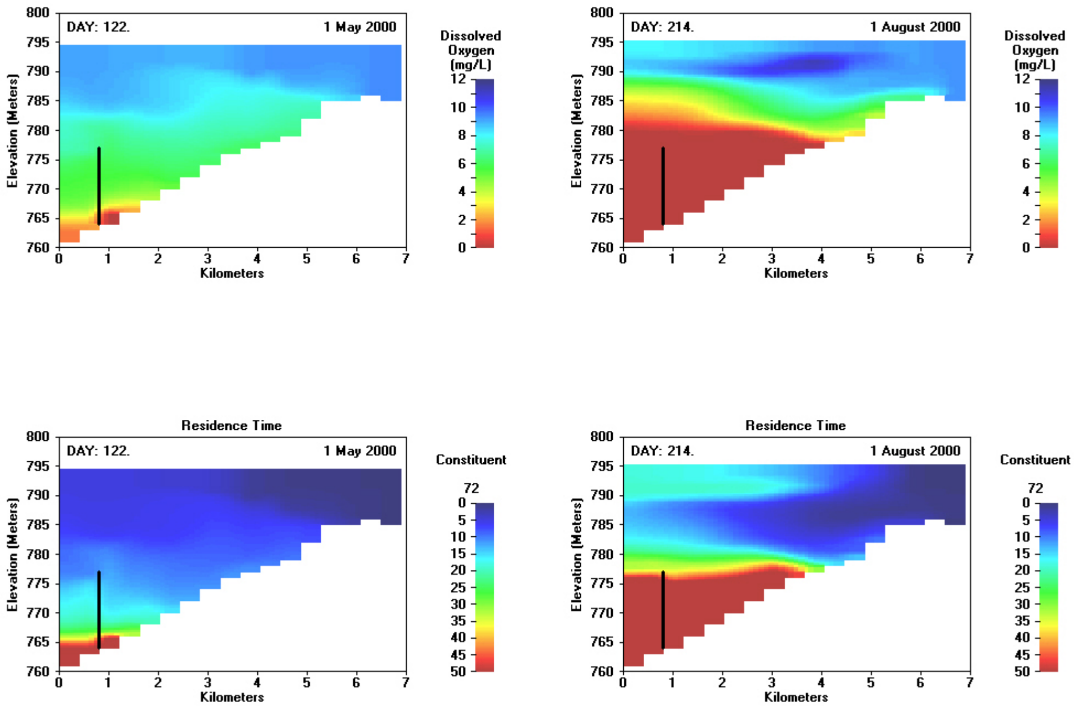

Figure 1: Copco Reservoir, Median Loading, Without Oxygen

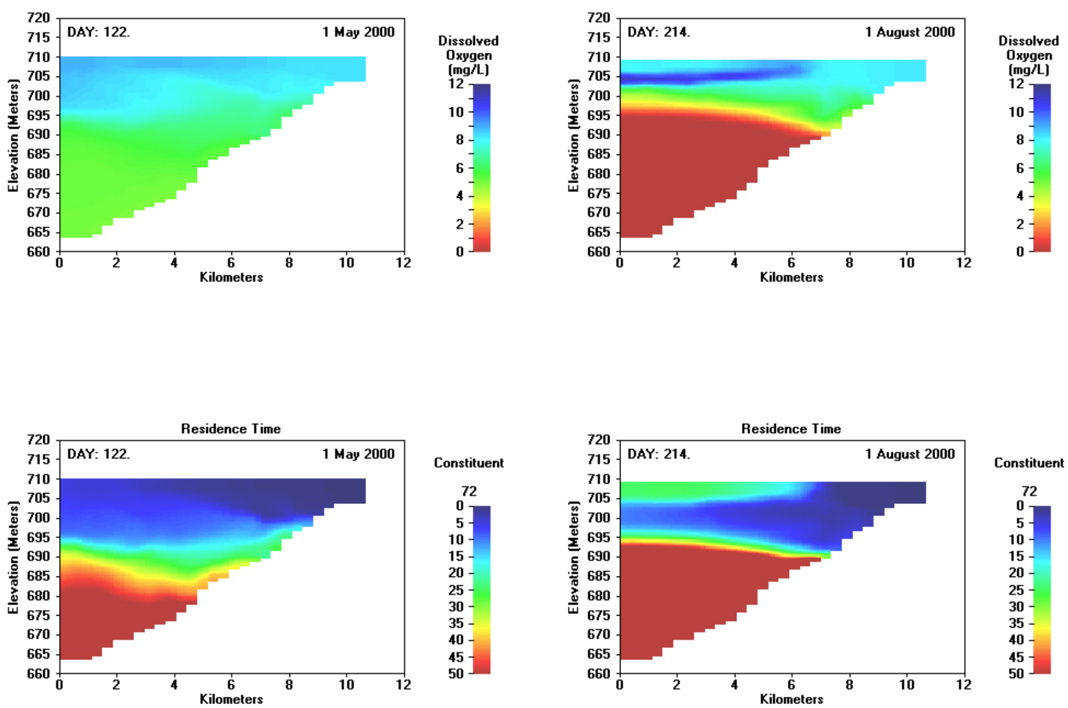

Figure 2: Iron Gate Reservoir, Median Loading, Without Oxygen

Diffuser Placement

By reviewing the residence time and DO concentrations in Figures 1 and 2, and by evaluating several iterations of diffuser placement, the diffuser layouts in Figures 3 and 4 were achieved. The diffuser layout and the respective flow rates for each section depend on the reservoir hydrodynamics as presented in Figures 1 and 2.

For Copco Reservoir, the placement of the diffusers shown in **Figure 3** can be described with respect to three different regions:

1. The Entrance Region: This region is located as far upstream from the dam as possible while the depth is still sufficient to ensure that reasonable oxygen transfer efficiency is achieved. This region requires large oxygen flow rates because the inflow moves through this region and continually replenishes the organic loads while removing the oxygenated water. Diffuser 1 is located in the entrance region.
2. The Metalimnion: This region is immediately downstream of the entrance region and is affected by the organic loads continually being replenished with the inflows and the oxygenated water which is also removed with the inflows. DO is also consumed by SOD in this region in the shallower sections of the reservoir. Diffusers 2 and 5, shown in Figure 3, are placed in this region. As the summer progresses, a portion of diffuser 2 will be contained in the hypolimnion. Diffuser 5 is placed far enough upstream where the reservoir is shallower to facilitate ease of diffuser construction and installation. Because these diffusers are located over one kilometer upstream from the dam, it is important to achieve large enough DO concentrations to ensure that the DO concentration does not fall below the target level before the water exits the reservoir.
3. The Hypolimnion: This region contains the water that is not replenished during the summer. The oxygen is depleted with both organic loading and SOD. Because the oxygen is not removed with water flowing through the region, smaller oxygen flow rates are required. Diffusers 3 and 4 are located in this region.

Figure 4 presents the diffuser layout for Iron Gate Reservoir. Diffuser 1 is located in the entrance region, Diffuser 2 is located in the metalimnion, and Diffuser 3 is located in the hypolimnion. Because of the lower organic loading and because of the more uniform reservoir geometry, fewer diffusers are required for this reservoir.

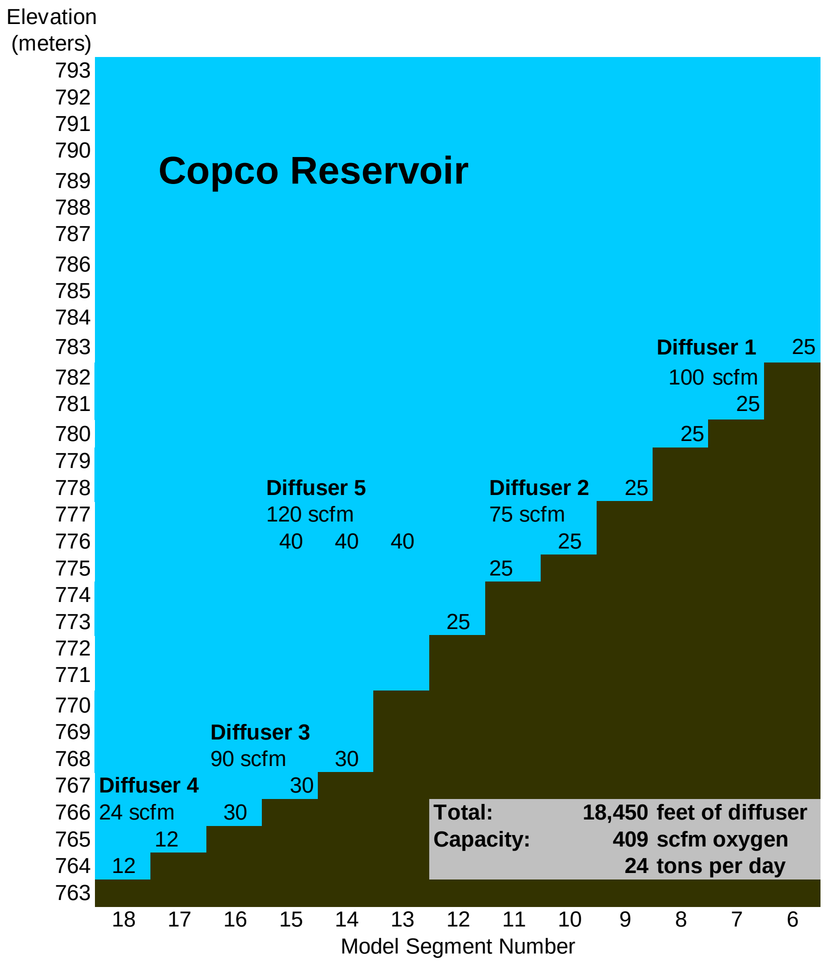

Figure 3: Copco Model Diffuser Location and Flow Rates for Median Load, DO Target of 7 mg/L

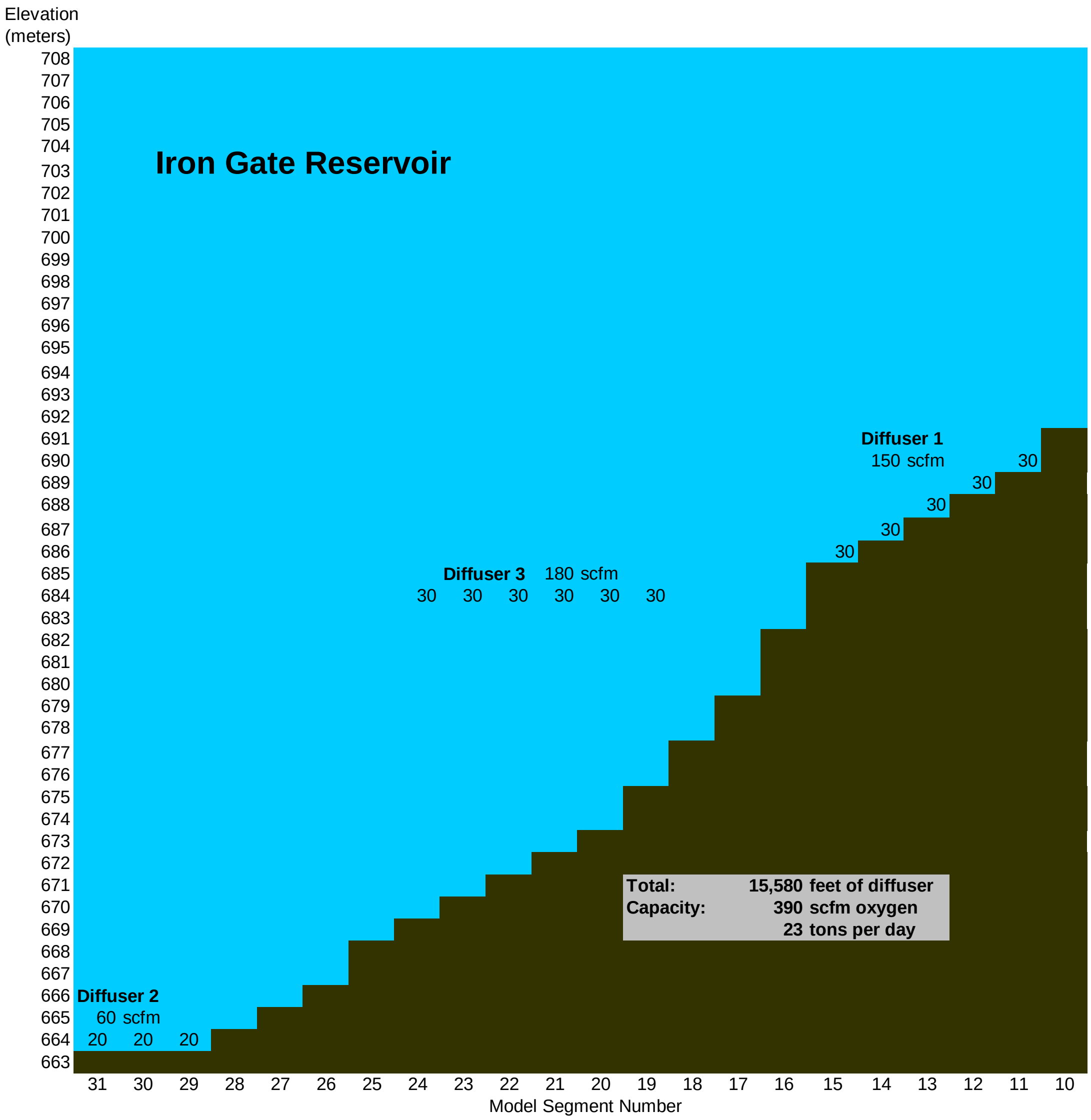

Figure 4: Iron Gate Model Diffuser Location and Flow Rates for Median Load, DO Target of 7 mg/L

Copco Oxygenation Results

Diffuser systems were evaluated for Copco Reservoir with four different cases: 1) median loading with a target of 7.0 mg/L; 2) median loading with a target of 5.0 mg/L; 3) peak loading with a target of 7.0 mg/L; and 4) peak loading with a target of 5.0 mg/L. For the median load case, the diffuser system began operating on 3/21/2001 and stopped on 10/27/2001. The beginning and ending dates were based on reviewing the model results for median loading with no oxygen, and operating the diffusers during the time when the DO in any region of the reservoir first dropped below 7 mg/L until the time in the fall when the reservoir had turned over and all regions in the reservoir exceeded 7 mg/L. The DO first dropped below 7 mg/L in the bottom layers of the forebay. For the peak loading case, the oxygen flow rates were increased in a step-wise manner during the time period of 7/14/2001 to 9/7/2001. This coincided with a time period of an observed peak loading event (Deas, 2007). It was necessary to operate the diffusers with the increased level of oxygen 15 days after the peak event ended to accommodate the increased organic loading that required approximately two weeks to flow through the reservoir.

Figure 5 presents the DO concentrations on two days, May 1st and August 1st, for the median loading case with a DO target of 7.0 mg/L. **Table 1** presents the total oxygen flow rate (25 tons/day) and the oxygen flow rate in each diffuser for this case. The target level of 7.0 mg/L is achieved throughout most of the reservoir on both days presented in Figure 5. Two regions in which the target was not achieved include the very bottom layers of the hypolimnion and in the entrance region. The bottom of forebay does not achieve the target DO, at least in the model simulations, because the diffusers are located 1.0 meter off the bottom. Some mixing may occur in an actual installation that would eliminate this thin layer of low DO. On August 1st the entrance region is also lower than the target. This occurs because the diffusers are located 1.6 km after the start of the reservoir. This diffuser location was chosen because the upper reaches of the reservoir are too shallow, and diffusers placed in this region would have extremely low oxygen transfer efficiency. In a shallow placement, the oxygen would exit through the water surface before being absorbed into the water.

Figure 5 also shows that the region directly in front of the turbine withdrawal (elevation 786.7) meets the target, but has a lower concentration than the surrounding water. This occurs because the oxygen supplied by the diffusers is diluted by the water flowing through this region and because the oxygen is depleted by the organic loads. For all of the cases evaluated in this study, the lowest DO in the oxygenated portion of the reservoir (i.e., above the bottommost layer of the hypolimnion and downstream of the first diffuser) generally occurred at the turbine withdrawal.

An additional feature demonstrated in Figure 5 is that the hypolimnion in the forebay is very high in DO. This is caused by setting the oxygen flow rates to a constant value. The flow rates are set high enough to ensure that the target is achieved most of the time. This enables the system to achieve the target when the DO demands are the highest, but maintains DO levels higher than necessary for much of the time period.

Figure 6 presents DO concentrations for May 1st and August 1st for the median load case with a target of 5 mg/L. The diffusers are in identical locations as the previous case with reduced flow rates, which are shown in Table 1. The total oxygen use was reduced from 25 to 20 tons per day. The DO distribution is similar to the oxygenation case with a target of 7.0 mg/L. However, with a target of 5.0 mg/L, the inflows meet the target because the inflow concentration exceeds 5.0 mg/L.

Figure 7 presents the DO concentrations for the peak loading case with a target of 5.0 and 7.0 mg/L on 8/14/2001. The daily oxygen flow rates were increased to 48 and 63 tons for each case, respectively. The figure shows that the target of 5 mg/L was achieved throughout the reservoir, with the exception of the lowest layer in the hypolimnion and the entrance to the turbine withdrawal. For this snapshot in time, the turbine withdrawal zone has dropped to 4.9 mg/L, but for most of the peak loading period the DO meets the target in this region. For the peak loading case with a target of 7.0 mg/L, the entrance region is consistently below the target. Although both cases generally meet the target, both show large changes in DO concentration in different regions of the reservoir. These changes could be reduced with adjustment of the oxygen flow rates.

Figures 8 and 9 summarize the predicted improvement in reservoir oxygen levels with diffuser operation. The plots present time series of the percent of the reservoir that meets the target DO for the base case condition and for conditions with diffusers in operation. The base case conditions were obtained from the W2 model as originally received with no modifications.

Figure 8 shows that for the median load case, a target of 7 mg/L is achieved by the oxygenation system throughout the reservoir for most of the year. The reservoir volume meeting the target drops to approximately 95% for a period in July and August. Some of the volume not meeting the target occurs upstream of the diffusers in a portion of the reservoir too shallow for efficient diffuser operation. An additional zone that periodically does not meet the target is in the turbine withdrawal zone. For the peak load case, the target is met throughout the reservoir most of the time with diffusers in operation. As in the median load case, a deviation occurs during July and August where the percentage of the reservoir volume meeting the target drops to 88%. The primary cause of this deviation is the water entering the reservoir which does not meet the target and is upstream of the diffusers. Figure 7 clearly shows this situation.

Figure 9 presents the results for the case with a DO target of 5 mg/L. The oxygenation systems for both the median and peak load case meet the target most of the time. As in the case with a DO target of 7 mg/L, deviations occur in the entrance region upstream of the diffuser and periodically in the volume immediately in front of the turbine withdrawal.

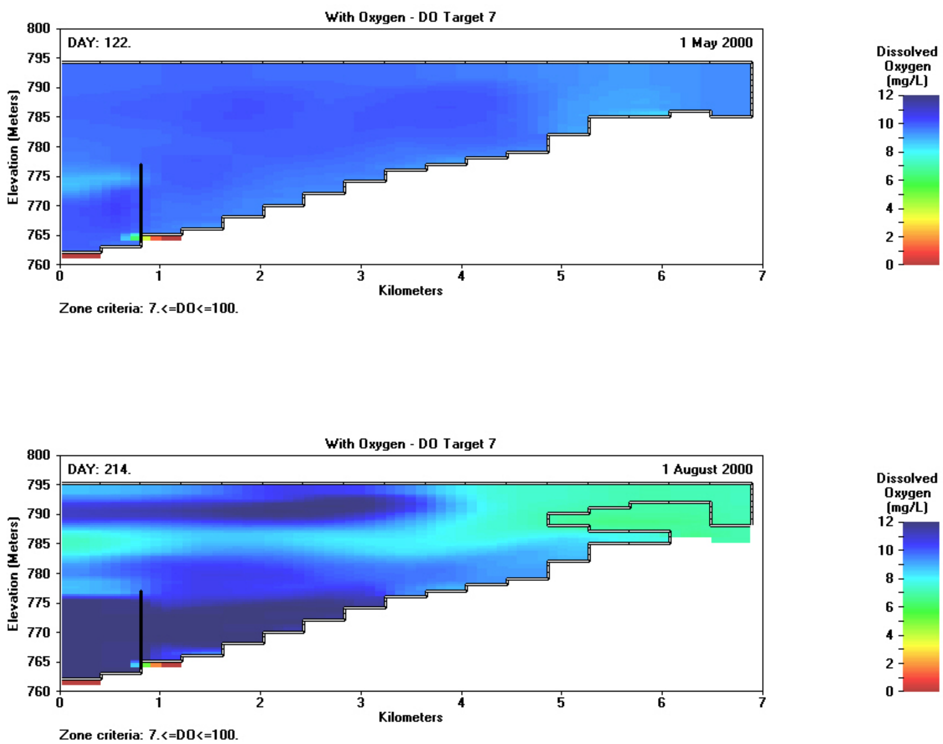

Figure 5: Copco Reservoir with Diffusers in Operation, Median Load, DO Target 7 mg/L

Copco	Reservoir Target	Oxygen Required	Diffuser 1	Diffuser 2	Diffuser 3	Diffuser 4	Diffuser 5
Median conditions	5 mg/L	20 tons/day	72 scfm	54 scfm	88 scfm	20 scfm	102 scfm
Median conditions	7 mg/L	25 tons/day	100 scfm	75 scfm	96 scfm	24 scfm	120 scfm
High organic peak	5 mg/L	48 tons/day	280 scfm	210 scfm	120 scfm	20 scfm	180 scfm
High organic peak	7 mg/L	63 tons/day	400 scfm	300 scfm	140 scfm	40 scfm	180 scfm

Table 1: Oxygen Inputs for Copco Model Simulations

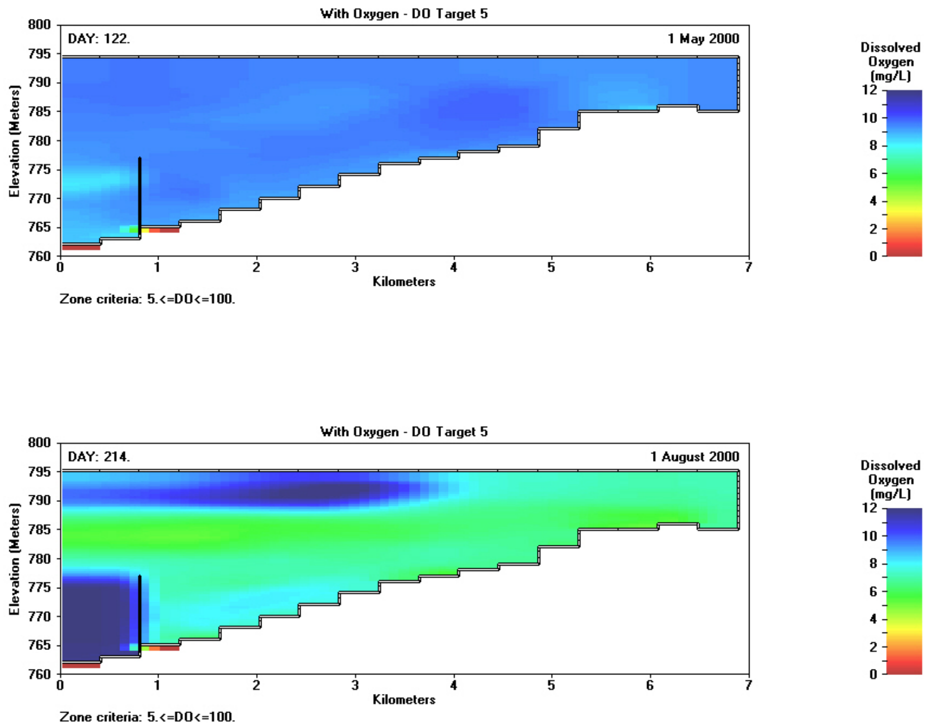

Figure 6: Copco Reservoir with Diffusers in Operation, Median Load, DO Target 5 mg/L

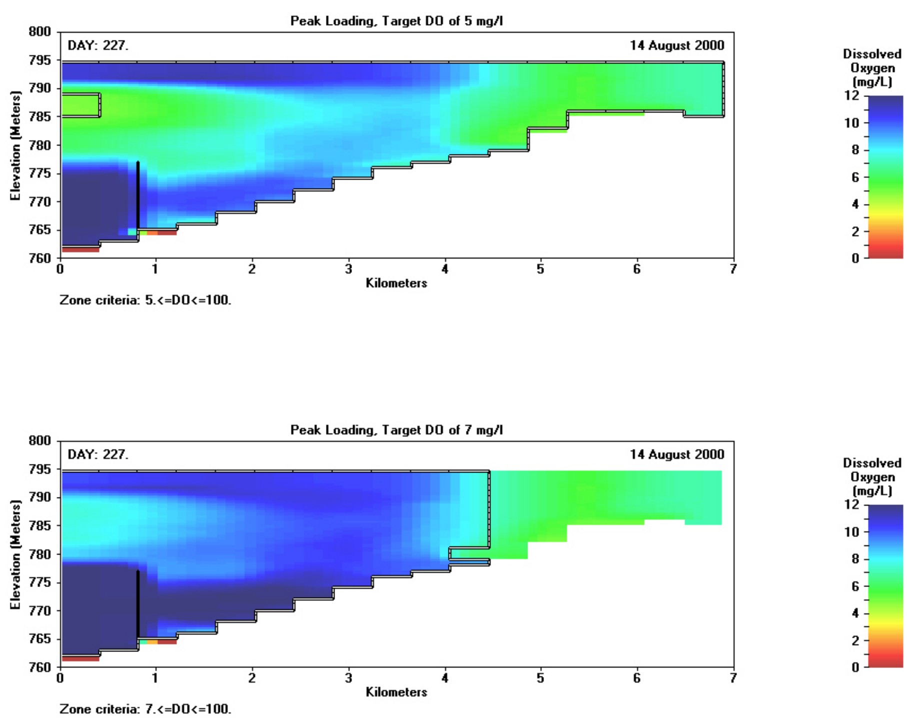

Figure 7: Copco Reservoir with Diffusers in Operation, Peak Load, DO Targets 5 and 7 mg/L

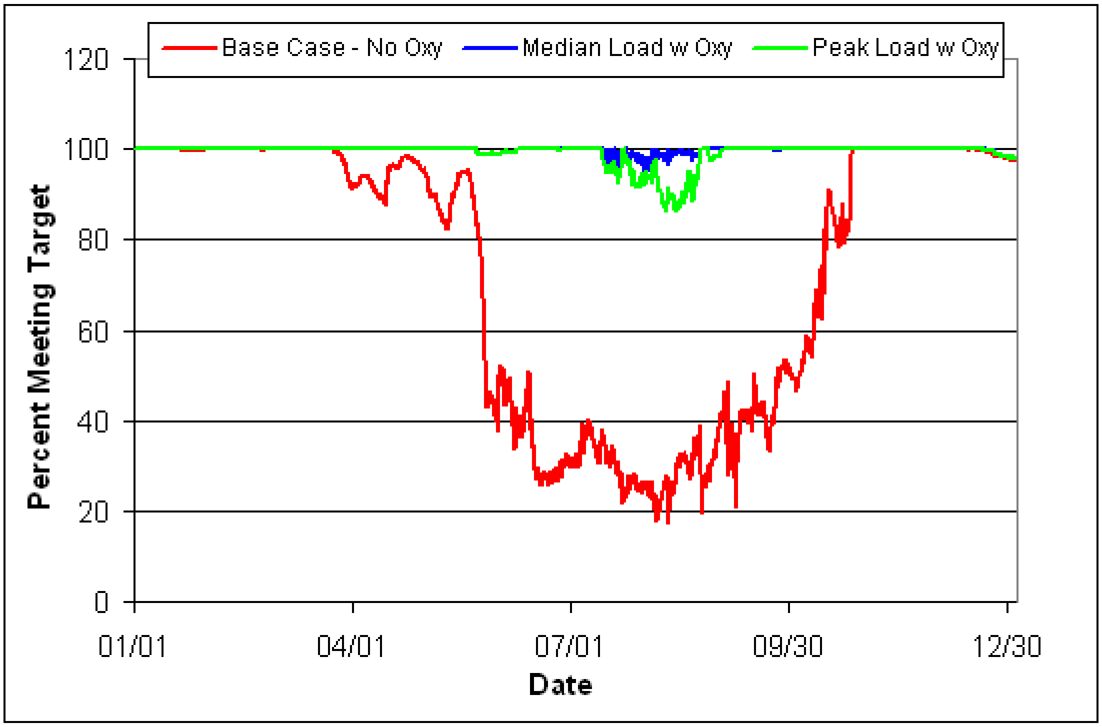

Figure 8: Copco Reservoir Dissolved Oxygen Improvement - Target 7 mg/L

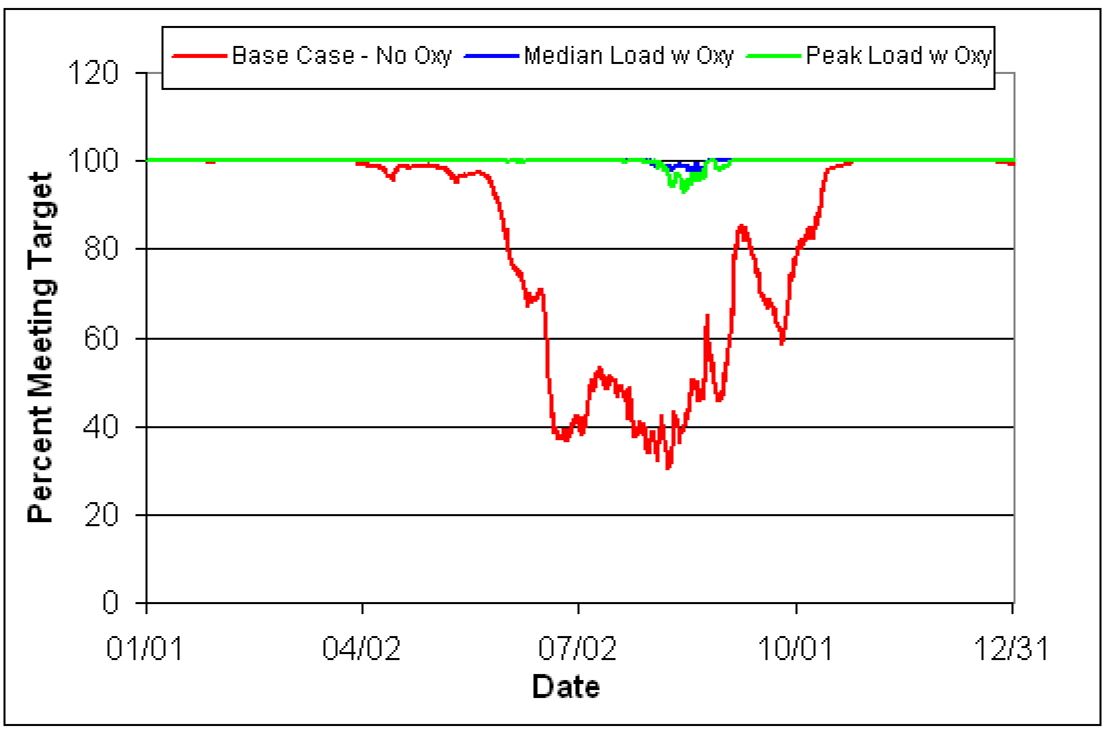

Figure 9: Copco Reservoir Dissolved Oxygen Improvement - Target 5 mg/L

Iron Gate Oxygenation Results

Diffuser systems were evaluated for Iron Gate Reservoir with three different cases; 1) median loading with a target of 7.0 mg/L; 2) peak loading with a target of 7.0 mg/L; and 3) time varying loading based on the Copco model outflow with diffusers operating in Copco Reservoir to achieve a target of 7.0 mg/L. The modeled diffuser operation for Iron Gate was slightly longer in duration than that for Copco beginning on 3/16/2001 and ending on 11/21/2001. For case 2, the peak loading period time period was longer than for the Copco model beginning on 7/14/2001 and ending on 10/12/2001. The extended operation was necessary given the longer residence time of Iron Gate. Case 3 was based on the Copco model outflows with median loadings to the Copco model and with the diffusers operating to achieve a target of 7.0 mg/L.

Figure 10 presents the DO concentrations for the median load case with a target of 7.0 mg/L for two days, May 1st and August 1st. The DO target is met throughout the reservoir with the exception of a small region at the entrance to the turbine withdrawal which occurs on August 1st. The total oxygen flow for each diffuser is detailed in **Table 2** which totaled 21 tons per day. Although most of the reservoir meets the target, there are large differences in the DO concentrations in different parts of the reservoir. These differences would be reduced with adjustment of the oxygen flow rates to match the time varying DO demands.

Figure 11 presents the DO concentrations for the peak load with diffuser operation to achieve a target of 7.0 mg/L on August 30. The target is achieved throughout the reservoir on this day. There is a stepwise change in DO that occurs at elevation 683. This is caused by the reservoir stratification which is clearly shown in the residence time contours, also shown on Figure 12.

Figure 12 presents the DO concentrations for the median load case with a target of 7.0 mg/L with the inflow concentrations from the Copco model outflow. This simulates how the Iron Gate oxygenation requirements would change if diffusers were operating in Copco to achieve a target of 7.0 mg/L. The total oxygen flow rate for this case was 19 tons/day and the distribution among the diffusers is presented in Table 2. This simulation shows that a small reduction in Iron Gate oxygen requirements would be achieved. For the August 1st date, the entrance region does not meet the target. However, no aeration was assumed from the Copco outflow to the Iron Gate inflow in this simulation.

A summary of the predicted performance of the oxygenation systems is shown in **Figure 13**. The base case conditions were obtained from the Iron Gate model as originally received with no modifications. Only the volume of the main branch of the reservoir is included in this summary.

Figure 13 shows that for the median and peak load case, a target of 7.0 mg/L is achieved throughout the reservoir for most of the year, except for a few points in time when approximately 90% of the reservoir volume meets the target. The volumes responsible for this deviation are the entrance region upstream of the diffusers and the volume directly in front of the turbine withdrawal zone.

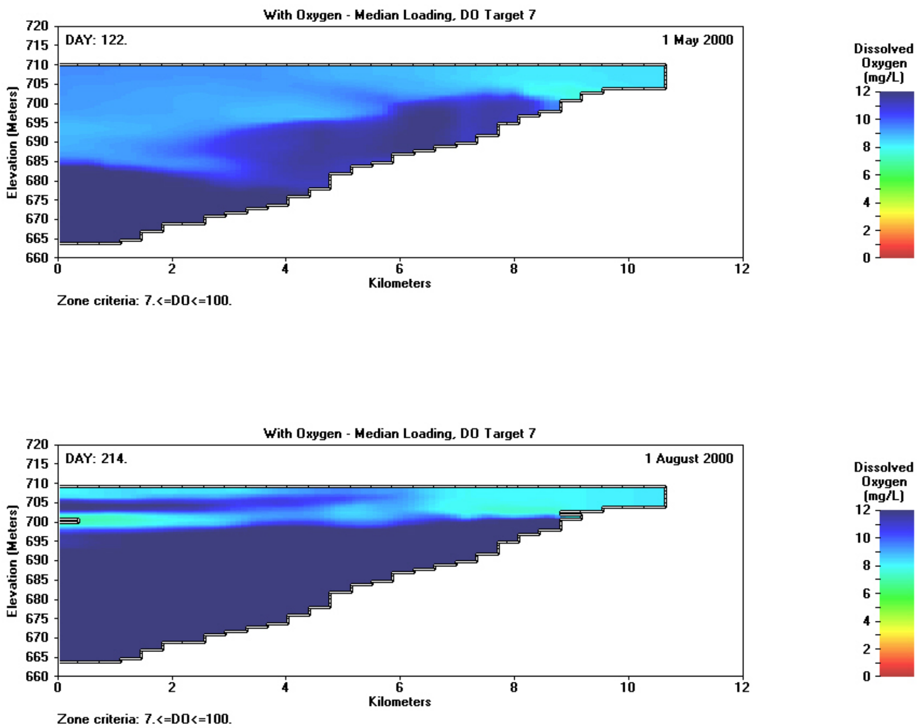

Figure 10: Iron Gate Reservoir with Diffusers in Operation, Median Load, DO Target 7 mg/L

Iron Gate	Copco Oxygenation	Reservoir Target	Oxygen Required	Diffuser 1	Diffuser 2	Diffuser 3
Median conditions	None	7 mg/L	21 tons/day	150 scfm	60 scfm	150 scfm
High organic peak	None	7 mg/L	45 tons/day	300 scfm	60 scfm	400 scfm
Median conditions	operational	7 mg/L	19 tons/day	125 scfm	45 scfm	150 scfm

Table 2: Oxygen Inputs for Iron Gate Model Simulations

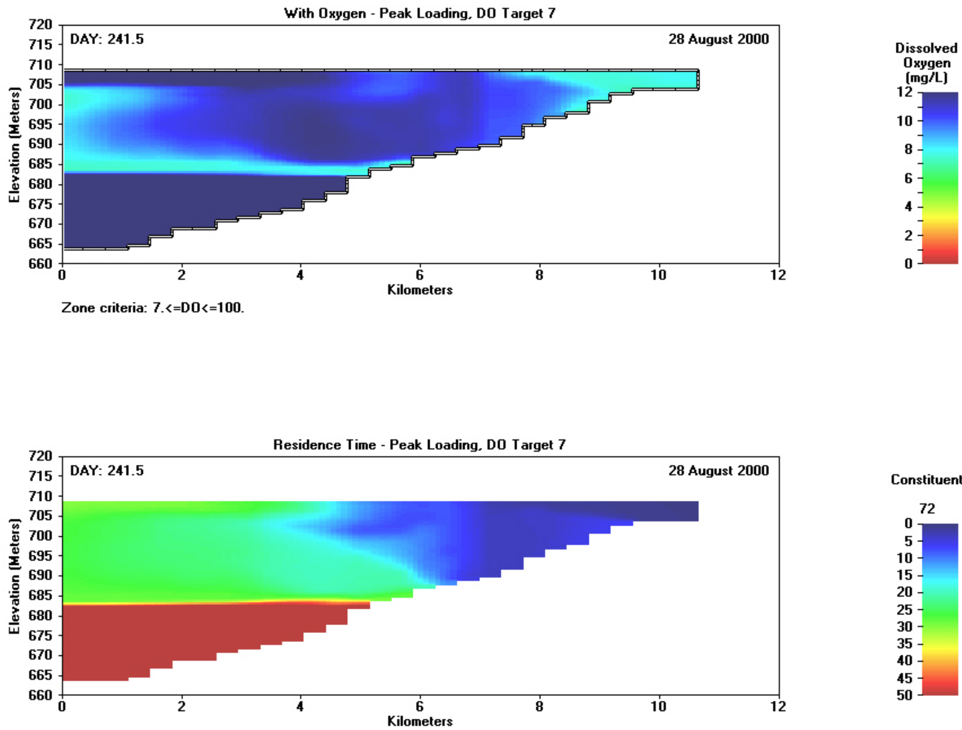

Figure 11: Iron Gate Reservoir with Diffusers in Operation, Peak Load, DO Target 7 mg/L

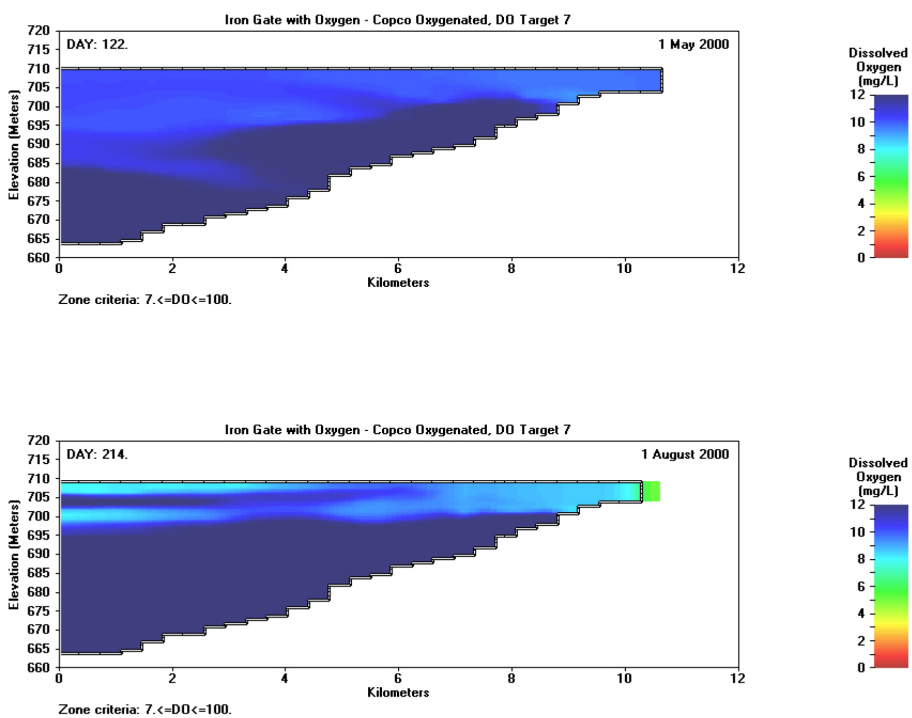

Figure 12: Iron Gate Reservoir with Diffusers in Operation with Copco Model Outflows and with Copco Oxygenation, DO Target 7 mg/L

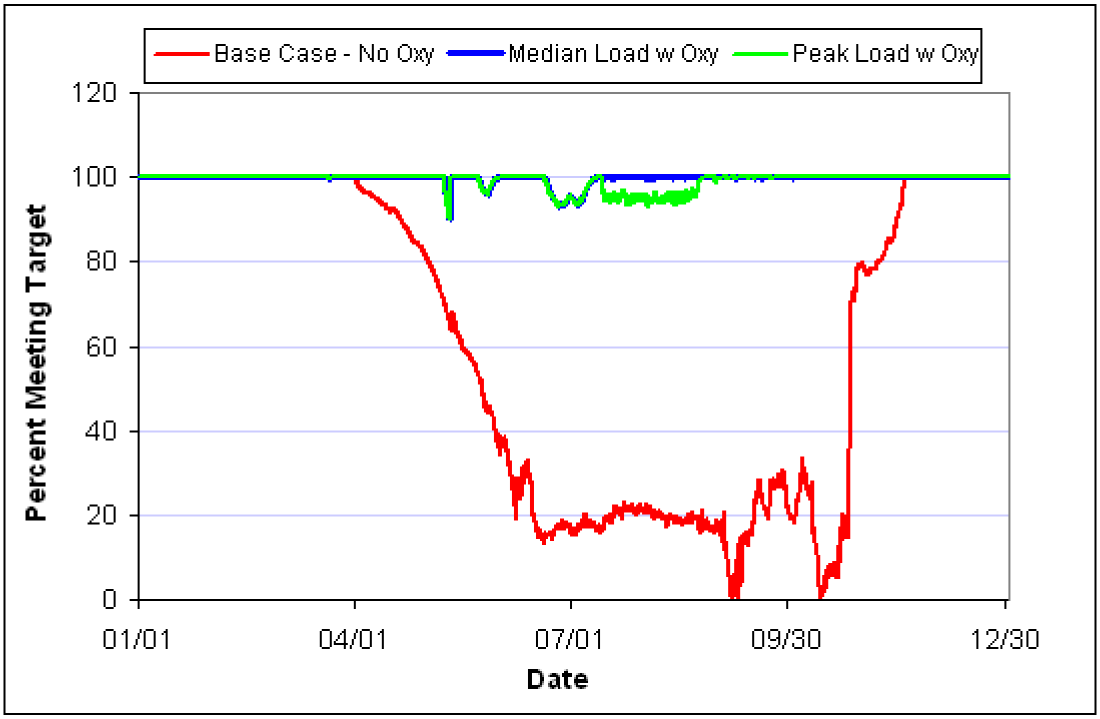

Figure 13: Iron Gate Reservoir Dissolved Oxygen Improvement - Target 7 mg/L

Discussion of Results

Diffuser systems operating in both Copco and Iron Gate Reservoirs were evaluated under several different scenarios. The oxygen requirements to meet the target most of the time are summarized above in Tables 1 and 2. The oxygen requirements in this table represent the maximum flow rates that would be required to meet the DO objectives throughout the majority of the reservoir. For Copco, the oxygen flow rates range from 20 tons/day to meet a target of 5 mg/L under a median load case to 63 tons/day to meet a target of 7.0 mg/L for a peak load condition. For Iron Gate the oxygen flow rates range from 19 tons/day to meet a target of 7.0 mg/L while diffusers are operating in Copco to 45 tons/day to meet a target of 7.0 mg/L under peak load conditions.

Although the desired targets can be largely obtained, there are specific areas in which it would be difficult to meet the target. When the inflowing water is below the target, the entrance to the reservoir will not meet the target. If oxygen diffusers are located in shallow water the oxygen transfer efficiency becomes very low because the oxygen exits through the water surface before being absorbed by the water. Because of this the diffusers would be located a few kilometers from the beginning of the reservoir. A second region in which the target will not be achieved is within a few meters of the reservoir bottom. The diffusers are not placed directly on the bottom to prevent sediment entrainment. Another point where the target may not be achieved at given time intervals is close to the dam in the turbine withdrawal zone. A portion of the diffusers are located in the primary flow stream through the reservoir which occurs in the mid layer of the reservoir. It is necessary to place these diffusers a few kilometers upstream from the face of the dam, in a shallower section of the reservoir to reduce the distance of the diffuser from the bottom. The shallower installation reduces installation and fabrication costs and enhances diffuser reliability. Larger oxygen flow rates are then required to increase the DO concentration to a sufficient level such that the target level will be maintained until the water exits the reservoir. It may not always be possible to achieve this given the transient flow events which may occur and any time lags that may occur in the diffuser operation.

The oxygen flow rates in this analysis are set to constant values or constant values with a single step change for this study. The oxygen flow rates represent a maximum daily flow rate that would be required during the entire oxygenation period. Significant reductions in annual oxygen use would be obtained by continually adjusting the oxygen flow rates to meet the current demands and DO deficit.

Reservoir Dissolved Oxygen Enhancement Method

Oxygen Diffuser System

The oxygenation technology evaluated in this report is a diffuser pipe system in the reservoir to place oxygen at the locations needed. Enhancement of reservoir DO levels can be obtained using diffusers in the reservoir that utilize the driving force of the deep water to achieve high gas transfer efficiencies. Diffusers can be designed to place oxygen at strategic locations in the reservoir to achieve specific design goals such as oxygenation of incoming organic loads or enhancement of hydropower releases as shown in **Figure 14**. The line diffuser system is the system most widely applied to hydropower applications although typically for enhancement of reservoir releases as compared to enhancement of the entire reservoir water volume. The line diffuser is of a simple and economical design and is installed and retrieved without divers. A reservoir diffuser system causes no adverse effects on hydro plant operation and can provide the additional benefit of increased release DO levels, improved fish habitat in the reservoir, and decreased anoxic products such as iron and sulfides in the releases.

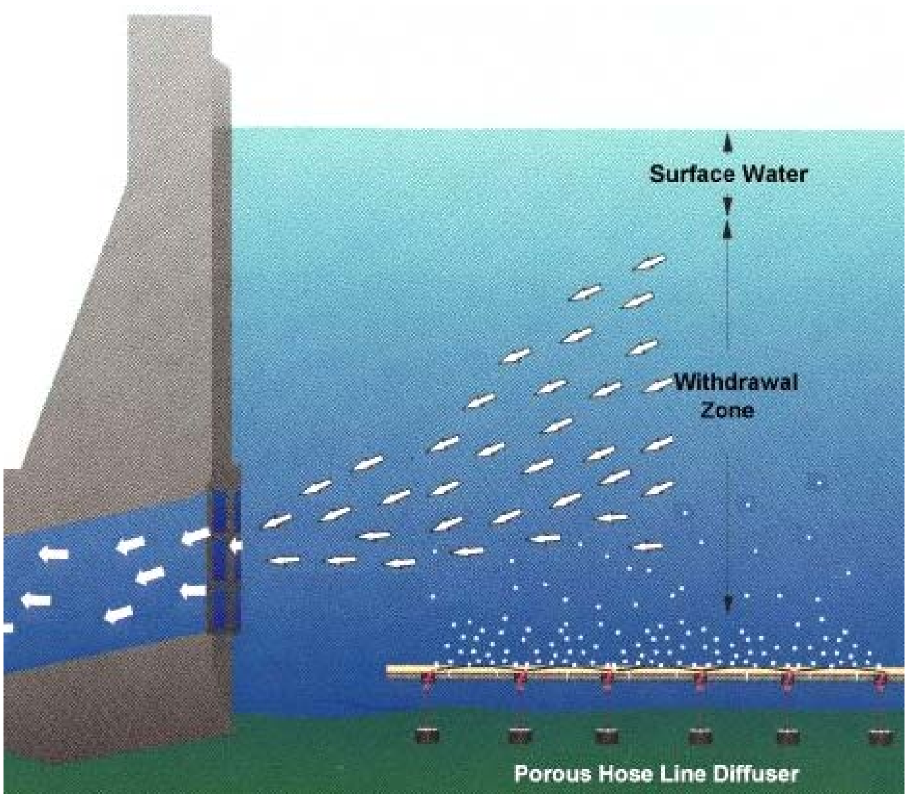

Figure 14: Reservoir Line Diffuser System

Oxygen Supply

The diffusers can be supplied with oxygen from a liquid oxygen storage facility, with trucked in oxygen or other gas supply system. A typical liquid oxygen supply facility is shown in **Figure 15**. A liquid oxygen facility would require truck access, concrete foundations, equipment pad, and unloading area. Liquid oxygen facilities require no electrical power except for lighting, instrumentation, and valve switching controllers (if so equipped). Liquid oxygen supply facilities can be installed in remote areas and require little maintenance other than monitoring of tank levels during operation. Another supply option is onsite oxygen generation with a pressure swing adsorption (PSA) oxygen supply that utilizes a molecular sieve to separate an oxygen stream from a compressed air supply. Small PSA systems (less than 3 tons of oxygen per day of capacity) are readily available as skid-mounted units. Larger units can be leased from gas supply companies. The PSA system would require electricity to power an air compressor capable of supplying 10 to 15 times the oxygen volume flow of compressed air. A picture of a PSA system with a 2,000 scfh oxygen delivery capacity is shown in **Figure 16**. PSA systems produce a low pressure (< 45 psi) oxygen gas stream and require an oxygen booster to provide the pressures necessary for a diffuser system in a deep reservoir. PSA systems require maintenance of rotating electrical equipment (electric motors and compressors), filters, and valve operators. Operating costs for PSA systems can be substantially less than liquid oxygen if wholesale electric power is available at the chosen site.

Figure 15: Typical Liquid Oxygen Storage and Supply Facility
(Los Vaqueros Reservoir, East Bay Municipal Utility District, Livermore, CA)

Figure 16: 2,000 scfh PSA System

Conceptual Reservoir Oxygenation System Design for Copco

A reservoir oxygen diffuser system for Copco would include long diffuser lines to place oxygen into the desired regions in the reservoir. An oxygen supply facility would supply oxygen at set flow rates to the diffusers. A facility utilizing a liquid oxygen storage tank, vaporizers, and trucked-in oxygen delivery would most likely be used at a location midway along the reservoir while a small onsite oxygen generator might be used to supply oxygen to the hypolimnion near the dam.

Reservoir Diffuser Layout

The diffusers in the reservoir would be located to place oxygen as required for their intended purpose. The recommended conceptual diffuser layout for Copco is presented in **Figure 17,** with design flow rates and lengths for each diffuser line presented in **Table 3**. The long run of Diffusers #1 and #2 are to place oxygen near the bottom of the reservoir at the upstream end of the reservoir to provide initial oxygenation of the incoming organic oxygen demands. These diffusers would be deployed close to the bottom in the deepest channel available at that location as shown with the bathymetry in Figure 17. Diffusers #3 and #4 are to place oxygen in the volumes of the hypolimnion upstream and downstream of the rock outcropping respectively and would also be deployed close to the reservoir bottom in the deepest areas available. Diffuser #5 is to place oxygen in the metalimnion and would be deployed along the side of the reservoir to obtain the 2545 foot elevation with minimum anchor cable lengths.

	Line 1	Line 2	Line 3	Line 4	Line 5	Total	
Oxygen flow per diffuser	100	75	90	24	120	409	scfm
	6,000	4,500	5,400	1,440	7,200	24,540	scfh
Diffuser Line Length (each)	4,600	3,280	3,600	2,700	4,260	18,440	feet
Diffuser Elevation	2,560	2,540	2,520	2,507	2,545		
Underwater Supply Line	700	625	1,500	600	1,400	4,825	feet
Underground Supply Line	600	600	600	600	600	3,000	feet

Table 3: Diffuser Line Details for Copco Reservoir Diffuser System

Oxygen Supply Facilities

The Mallard Point access area was chosen as the location for a liquid oxygen storage and supply facility for the Copco conceptual design. This location is owned by PacifiCorp, has room for truck access and is conveniently located to minimize underwater supply piping to the upstream diffusers. There are not a lot of options at Copco Reservoir for land owned by PacifiCorp, as shown on the property ownership map in **Figure 18**, but this location fits well in the conceptual design. A peak design capacity of 60 tons per day would be required for the liquid oxygen supply facility to meet the requirements of the peak organic loading case at Copco. This capacity would require two 15,000- to 20,000-gallon liquid oxygen storage tanks; 120,000 scfh of ambient air vaporizer capacity; and associated piping and controls. Sixty tons per day is a reasonable size. Hydropower reservoir oxygen diffuser systems currently in use range up to 200 tons per day of delivery capacity. However, liquid oxygen deliveries are not readily available in the remote area around Copco and may have to be trucked in from as far away as Vancouver, Washington or Sacramento, California. At the peak capacity of 60 tons per day, the facility would require two to three truck deliveries of liquid oxygen per day. Normal conditions would average closer to 24 tons and one truck delivery per day. Road conditions and bridge load ratings on the truck route from I-5 will need to be reviewed.

A second oxygen supply facility was placed at the Copco Dam in the conceptual design to supply Diffuser #4, the diffuser in the immediate forebay. This diffuser would be operated at low levels of oxygen supply and for probably the longest period of all the Copco diffusers to maintain DO levels in the hypolimnion. For this supply, a PSA system would be well suited to meet the oxygen capacity requirements of Diffuser #4 with two off-the-shelf 1400 scfh capacity units. Location at the dam would minimize the underwater supply piping required for Diffuser #4 and would have potential availability of electric power and convenient maintenance access. Supply piping to supply Diffuser #4 from the LOx facility at Mallard Point would cost approximately the same as the PSA system equipment. Operation of a PSA supply would reduce oxygen costs over that expected with all liquid oxygen.

Cost Estimate for Conceptual Design

Estimated costs for installation and operation of the conceptual oxygen diffuser system design for Copco Reservoir are presented in **Tables 4 through 6**. Installation cost estimates are presented in more detail in **Appendix B**. Installation cost estimates assume manual operation of the LOx facility oxygen flow rates. The estimates include purchase of all cryogenic equipment; though leasing the cryogenic equipment may be a desirable approach to be evaluated in the future. Operation costs include figures for maintaining the reservoir at 5 and 7 mg/L and oxygen costs that could range from $241 to $362 per ton of liquid oxygen delivered to the site. Liquid oxygen costs are based on budget prices provided by Linde Gases and Air Liquide.

Copco Reservoir
PacifiCorp
Reservoir Oxygenation System
Estimated Installation Costs

Installation Costs		**Labor**	**Material**	**Total**
Reservoir Diffuser System	18,440 feet of diffuser	$500,000	$690,000	$1,190,000
Liquid Oxygen Storage and Supply Facility	Two 20,000-gallon tanks	$480,000	$860,000	$1,340,000
Onsite Oxygen Generation Facility	Two 1,400 scfh PSA units	$170,000	$410,000	$580,000
Startup, Safety Training and O&M Manuals		$40,000	$10,000	$50,000
		$1,190,000	**$1,970,000**	**$3,160,000**

Table 4: Estimated Capital Costs for Copco Reservoir Oxygenation System Installation

Copco Reservoir
PacifiCorp
Reservoir Oxygenation System
Estimated Operating Costs to Maintain 5 mg/L

Operating Costs	**5 mg/L**	**Median**			**Low**	**High**
Annual LOx Usage	210	days (end March to Nov)				
	18.6	tons / day average				
	3,906	tons / year	$241	ton	$942,000	
			$362	ton		$1,414,000
LOx Facility Maintenance					$15,000	$15,000
Annual PSA Electric Usage	210	days (end March to Nov)				
	1.4	tons / day average				
	21	kW	$0.05	kWhr	$5,292	$5,292
PSA Facility Maintenance					$5,000	$5,000
Diffuser Maintenance					$19,000	$19,000
		Operating Costs Total:			**$986,292**	**$1,458,292**

Operating Costs	**5 mg/L**	**Peak**			**Low**	**High**
Annual LOx Usage Average Rate	143	days (end March to Nov)				
	18.6	tons / day average				
	2,660	tons / year	$241	ton	$642,000	
			$362	ton		$963,000
Annual LOx Usage Peak Rate	67	days (end March to Nov)				
	46.6	tons / day peak				
	3,122	tons / year	$241	ton	$753,000	
			$362	ton		$1,131,000
LOx Facility Maintenance					$15,000	$15,000
Annual PSA Electric Usage Average	143	days (end March to Nov)				
	1.4	tons / day average				
	21	kW	$0.05	kWhr	$3,604	$3,604
Annual PSA Electric Usage Peak	67	days (July to Sept)				
	1.4	tons / day peak				
	21	kW	$0.05	kWhr	$1,689	$1,689
PSA Facility Maintenance					$5,000	$5,000
Diffuser Maintenance					$19,000	$19,000
		Operating Costs Total:			**$1,439,293**	**$2,138,293**

Table 5: Estimated Costs for Operating Copco Oxygenation System to Maintain 5 mg/L in the Reservoir

Copco Reservoir
PacifiCorp
Reservoir Oxygenation System
Estimated Operating Costs to Maintain 7 mg/L

Operating Costs	**7 mg/L**	**Median**			**Low**	**High**
Annual LOx Usage	210	days (end March to Nov)				
	23.5	tons / day average				
	4,935	tons / year	$241	ton	$1,190,000	
			$362	ton		$1,787,000
LOx Facility Maintenance					$15,000	$15,000
Annual PSA Electric Usage	210	days (end March to Nov)				
	1.5	tons / day average				
	22.5	kW	$0.05	kWhr	$5,670	$5,670
PSA Facility Maintenance					$5,000	$5,000
Diffuser Maintenance					$0	$0
		Operating Costs Total:			**$1,215,670**	**$1,812,670**

Operating Costs	**7 mg/L**	**Peak**			**Low**	**High**
Annual LOx Usage Average Rate	143	days (end March to Nov)				
	23.6	tons / day average				
	3,375	tons / year	$241	ton	$814,000	
			$362	ton		$1,222,000
Annual LOx Usage Peak Rate	67	days (end March to Nov)				
	60.2	tons / day peak				
	4,033	tons / year	$241	ton	$973,000	
			$362	ton		$1,461,000
LOx Facility Maintenance					$15,000	$15,000
Annual PSA Electric Usage Average	143	days (end March to Nov)				
	1.4	tons / day average				
	21	kW	$0.05	kWhr	$3,604	$3,604
Annual PSA Electric Usage Peak	67	days (July to Sept)				
	2.8	tons / day peak				
	42	kW	$0.05	kWhr	$3,377	$3,377
PSA Facility Maintenance					$5,000	$5,000
Diffuser Maintenance					$0	$0
		Operating Costs Total:			**$1,813,981**	**$2,709,981**

Table 6: Estimated Costs for Operating Copco Oxygenation System to Maintain 7 mg/L in the Reservoir

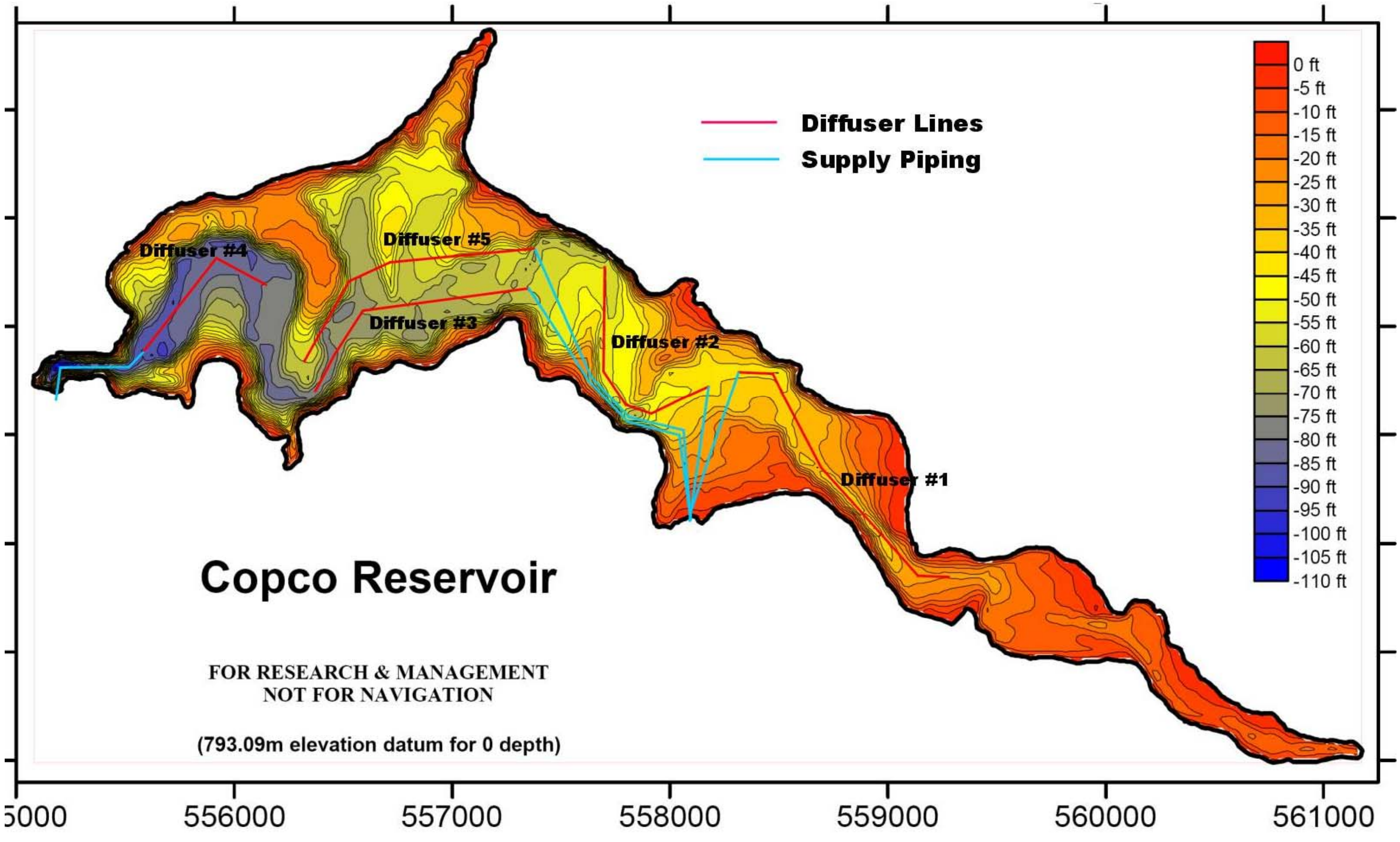

Figure 17: Conceptual Diffuser Layout at Copco Reservoir
(Bathymetry map from J.C. Headwaters, “Klamath Hydropower Impoundment Bathymetry,” 2003)

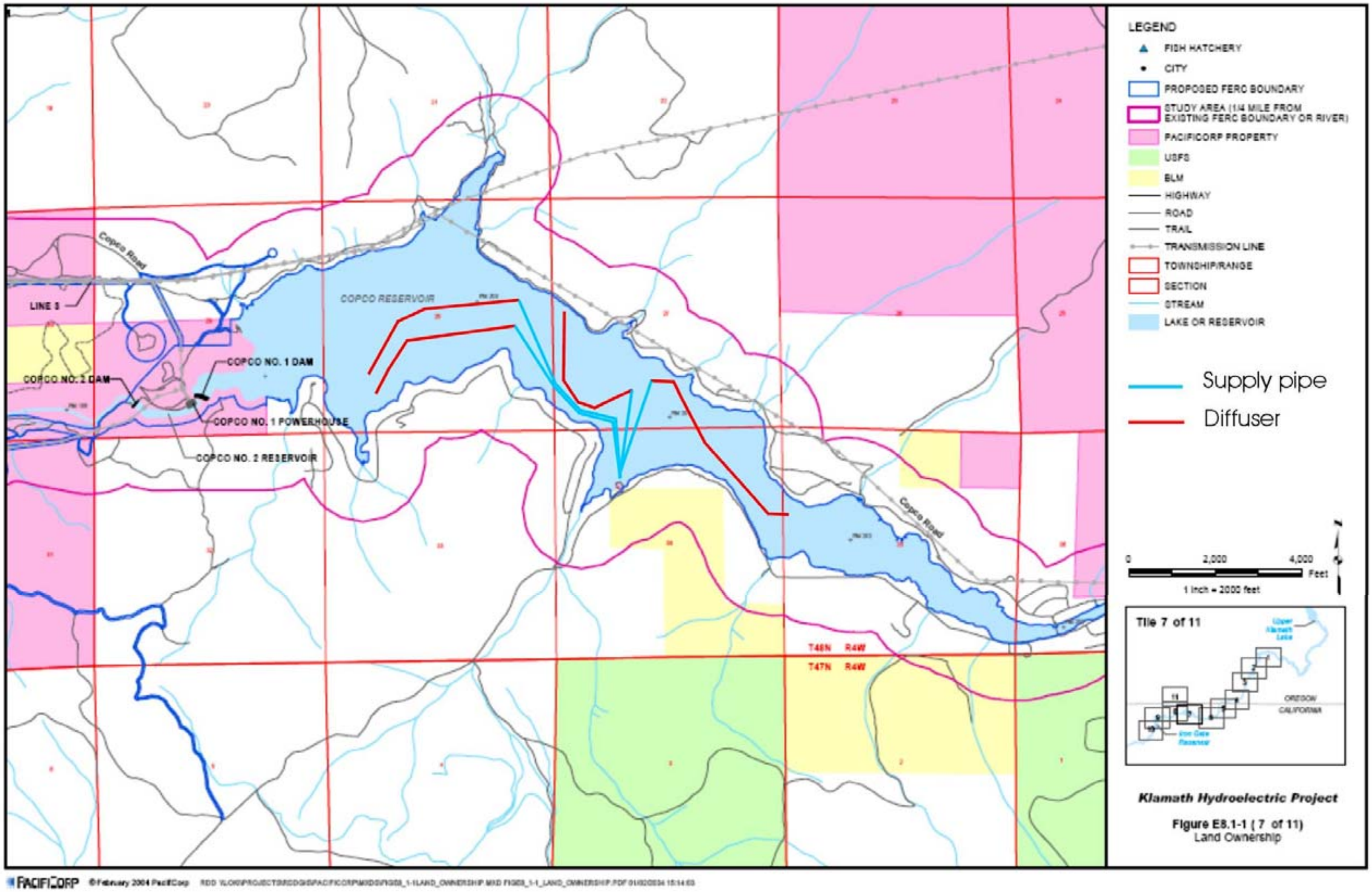

Figure 18: PacifiCorp Property Ownership Map and Conceptual Diffuser Layout for Copco Reservoir

Conceptual Reservoir Oxygenation System Design for Iron Gate

A reservoir oxygen diffuser system for Iron Gate would include long diffuser lines to place oxygen into the desired locations in the reservoir. An oxygen supply facility would supply oxygen at set flow rates to the diffusers. A facility utilizing a liquid oxygen storage tank, vaporizers, and trucked-in oxygen delivery would most likely be used at a location midway along the reservoir while a small onsite oxygen generator might be used to supply oxygen to the hypolimnion near the dam.

Reservoir Diffuser Layout

The diffusers in the reservoir would be located to place oxygen as required for their intended region in the reservoir. The recommended conceptual diffuser layout for Iron Gate is presented in **Figure 19,** with design flow rates and lengths for each diffuser line presented in **Table 7**. Diffuser #1 would place oxygen near the bottom of the reservoir at the upstream end of the reservoir to provide initial oxygenation of the incoming organic oxygen demands. This diffuser would be deployed close to the bottom in the deepest channel available at that location as shown with the bathymetry in Figure 19. Diffusers #2 would place oxygen in the hypolimnion just upstream of the dam and would also be deployed close to the reservoir bottom in the deepest areas available. Diffuser #3 is to place oxygen in the metalimnion and would be deployed along the side of the reservoir to obtain the 2,244-foot elevation with minimum anchor cable lengths.

	Line 1	Line 2	Line 3	Total	
Oxygen flow per diffuser	150	60	180	390	scfm
	9,000	3,600	10,800	23,400	scfh
Diffuser Line Length (each)	5,400	3,000	7,200	15,600	feet
Diffuser Elevation	2,260	2,178	2,244		
Underwater Supply Line	2,400	600	300	3,300	feet
Underground Supply Line	600	1,000	600	2,200	feet

Table 7: **Diffuser Line Details for Iron Gate Reservoir Diffuser System**

Oxygen Supply Facilities

An area along Copco Road on the shoreline of Iron Gate Reservoir was chosen as the location for a liquid oxygen storage and supply facility for conceptual design. This location is owned by PacifiCorp, has room for truck access, and is conveniently located to minimize underwater supply piping to the upstream diffusers as shown on the property ownership map in **Figure 20**. A truck access road, turnaround, and spill pad would have to be constructed alongside Copco Road. A tank configuration with retaining walls and oxygen fill piping routed up near the road similar to that shown in **Figure 21** may be required. A peak design capacity of approximately 40 tons per day would be required for the liquid oxygen supply facility to meet the requirements of the peak organic loading case at Iron Gate with Copco oxygenated or 45 tons per day if it is not. A 40-ton per day capacity would require a 20,000-gallon liquid oxygen storage tank, 80,000 scfh of ambient air vaporizer capacity, and associated piping and controls. The 20 to 45 tons per day range is a reasonable size. Hydropower reservoir oxygen diffuser systems currently in use range up to 200 tons per day of delivery capacity. However, liquid oxygen deliveries are not readily available in the remote area around Iron Gate and may have to be trucked in from as far away as Vancouver, Washington or Sacramento, California. At the peak capacity of 45 tons per day, the facility would require two truck deliveries of liquid oxygen per day. Normal conditions would average closer to 20 tons and one truck delivery per day. Road conditions and bridge load ratings on the truck route from I-5 will need to be reviewed.

A second oxygen supply facility was placed at the Iron Gate Dam in the conceptual design to supply Diffuser #2, the diffuser in the immediate forebay. This diffuser would be operated at low levels of oxygen supply and would probably be operated for the longest period of all the Iron Gate diffusers to maintain DO levels in the hypolimnion. For this supply, a PSA system would be well suited to meet the oxygen capacity requirements of Diffuser #2 with two off-the-shelf 1800 scfh capacity units. Location at the dam would minimize the underwater supply piping required for Diffuser #2 and would likely have easy access to electric power and convenient maintenance access. Supply piping to supply Diffuser #2 from the LOx facility at Mallard Point would cost approximately the same as the PSA system equipment. Operation of a PSA supply would reduce oxygen costs over that expected with all liquid oxygen.

Estimated Costs

Estimated costs for installation and operation of the conceptual oxygen diffuser system design for Iron Gate are presented in **Tables 8 through 10**. Installation cost estimates are presented in more detail in **Appendix C**. Installation cost estimates assume manual operation of the LOx facility oxygen flow rates. The estimates include purchase of all cryogenic equipment; though leasing the cryogenic equipment may be a desirable approach to be evaluated in the future. Operation costs include figures for maintaining the reservoir at 7 mg/L with and without an oxygenation system in operation at Copco. Estimated oxygen costs could range from $241 to $362 per ton of liquid oxygen delivered to the site, based on budget prices provided by Linde Gases and Air Liquide (included in **Appendix D and E**).

Iron Gate Reservoir
PacifiCorp
Reservoir Oxygenation System
Estimated Installation Costs

Installation Costs		Labor	Material	Total
Reservoir Diffuser System	15,600 feet of diffuser	$450,000	$610,000	$1,060,000
Liquid Oxygen Storage and Supply Facility	One 20,000-gallon tank	$440,000	$570,000	$1,010,000
Onsite Oxygen Generation Facility	Two 1,800 scfh PSA units	$190,000	$490,000	$680,000
Startup, Safety Training and O&M Manuals		$40,000	$10,000	$50,000
		$1,120,000	**$1,680,000**	**$2,800,000**

Table 8: Estimated Capital Costs for Iron Gate Reservoir Oxygenation System Installation

Iron Gate Reservoir
PacifiCorp
Reservoir Oxygenation System
Estimated Operating Costs to Maintain 7 mg/L Without Oxygenation at Copco

Operating Costs	**7 mg/L**	**Median**			**Low**	**High**
Annual LOx Usage	240	days (mid-March to late Nov)				
	17.4	tons / day average				
	4,176	tons / year	$241	ton	$1,007,000	
			$362	ton		$1,512,000
LOx Facility Maintenance					$15,000	$15,000
Annual PSA Electric Usage	240	days (mid-March to late Nov)				
	3.6	tons / day average				
	54	kW	$0.05	kWhr	$15,552	$15,552
PSA Facility Maintenance					$5,000	$5,000
Diffuser Maintenance					$16,000	$16,000
		Operating Costs Total:			**$1,058,552**	**$1,563,552**

Operating Costs	**7 mg/L**	**Peak**			**Low**	**High**
Annual LOx Usage Average Rate	150	days (mid-March to late Nov)				
	17.4	tons / day average				
	2,610	tons / year	$241	ton	$630,000	
			$362	ton		$945,000
Annual LOx Usage Peak Rate	90	days (mid-July to mid-Oct)				
	43.6	tons / day peak				
	3,924	tons / year	$241	ton	$946,000	
			$362	ton		$1,421,000
LOx Facility Maintenance					$15,000	$15,000
Annual PSA Electric Usage Average	143	days (end March to Nov)				
	3.6	tons / day average				
	54	kW	$0.05	kWhr	$9,267	$9,267
Annual PSA Electric Usage Peak	67	days (July to Sept)				
	1.4	tons / day peak				
	21	kW	$0.05	kWhr	$1,689	$1,689
PSA Facility Maintenance					$5,000	$5,000
Diffuser Maintenance					$16,000	$16,000
		Operating Costs Total:			**$1,622,956**	**$2,412,956**

Table 9: Estimated Costs for Operating Iron Gate Oxygenation System to Maintain 7 mg/L in the Reservoir without Oxygenation at Copco

Iron Gate Reservoir
PacifiCorp
Reservoir Oxygenation System
Estimated Operating Costs to Maintain 7 mg/L with Oxygenation at Copco

Operating Costs	**7 mg/L**	**Median**			**Low**	**High**
Annual LOx Usage	240	days (mid-March to late Nov)				
	16.3	tons / day average				
	3,912	tons / year	$241	ton	$943,000	
			$362	ton		$1,417,000
LOx Facility Maintenance					$15,000	$15,000
Annual PSA Electric Usage	240	days (end March to Nov)				
	2.7	tons / day average				
	40.5	kW	$0.05	kWhr	$11,664	$11,664
PSA Facility Maintenance					$5,000	$5,000
Diffuser Maintenance					$0	$0
		Operating Costs Total:			**$974,664**	**$1,448,664**

Table 10: Estimated Costs for Operating Iron Gate Oxygenation System to Maintain 7 mg/L in the Reservoir with Oxygenation at Copco

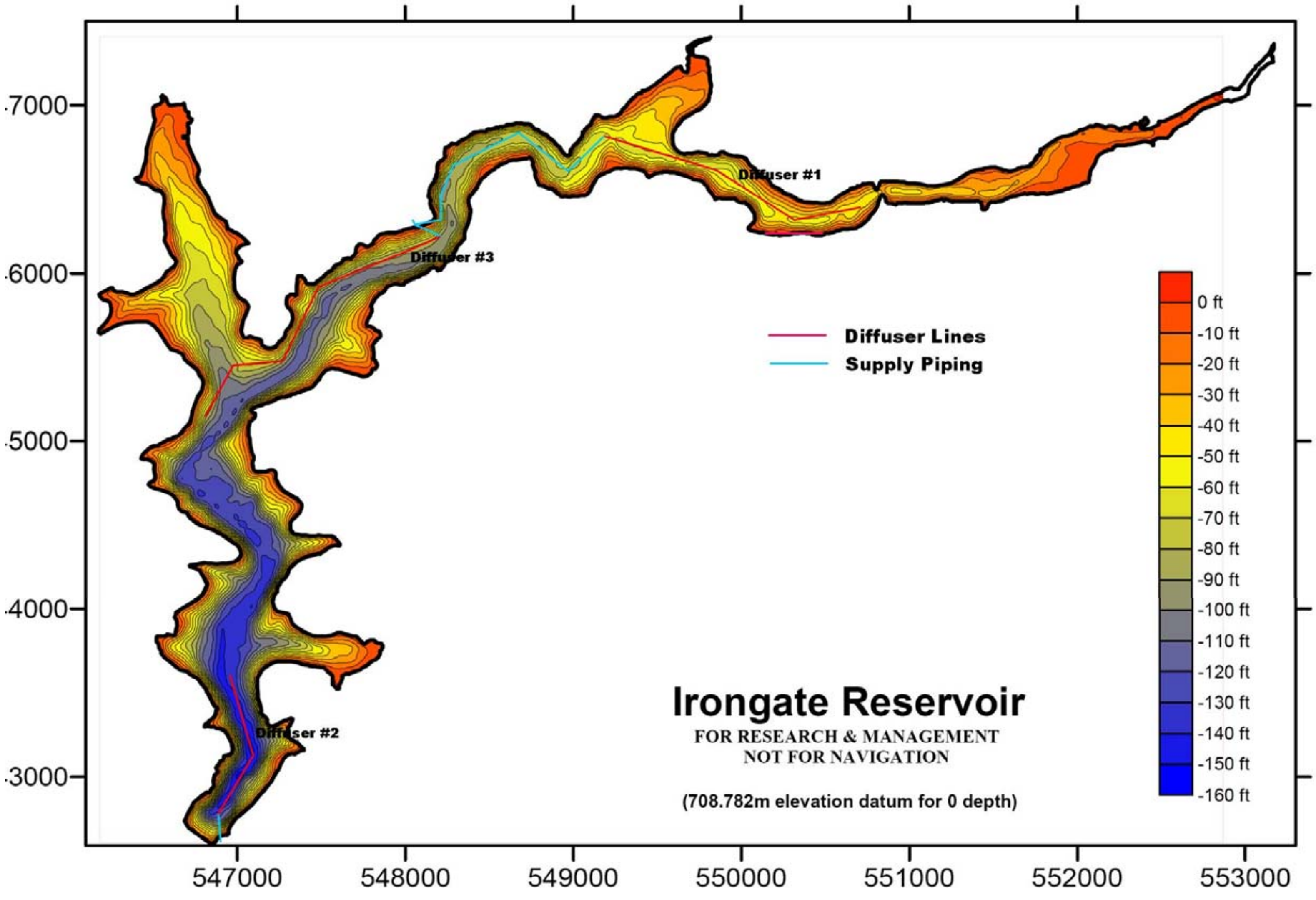

Figure 19: Conceptual Diffuser Layout at Iron Gate Reservoir

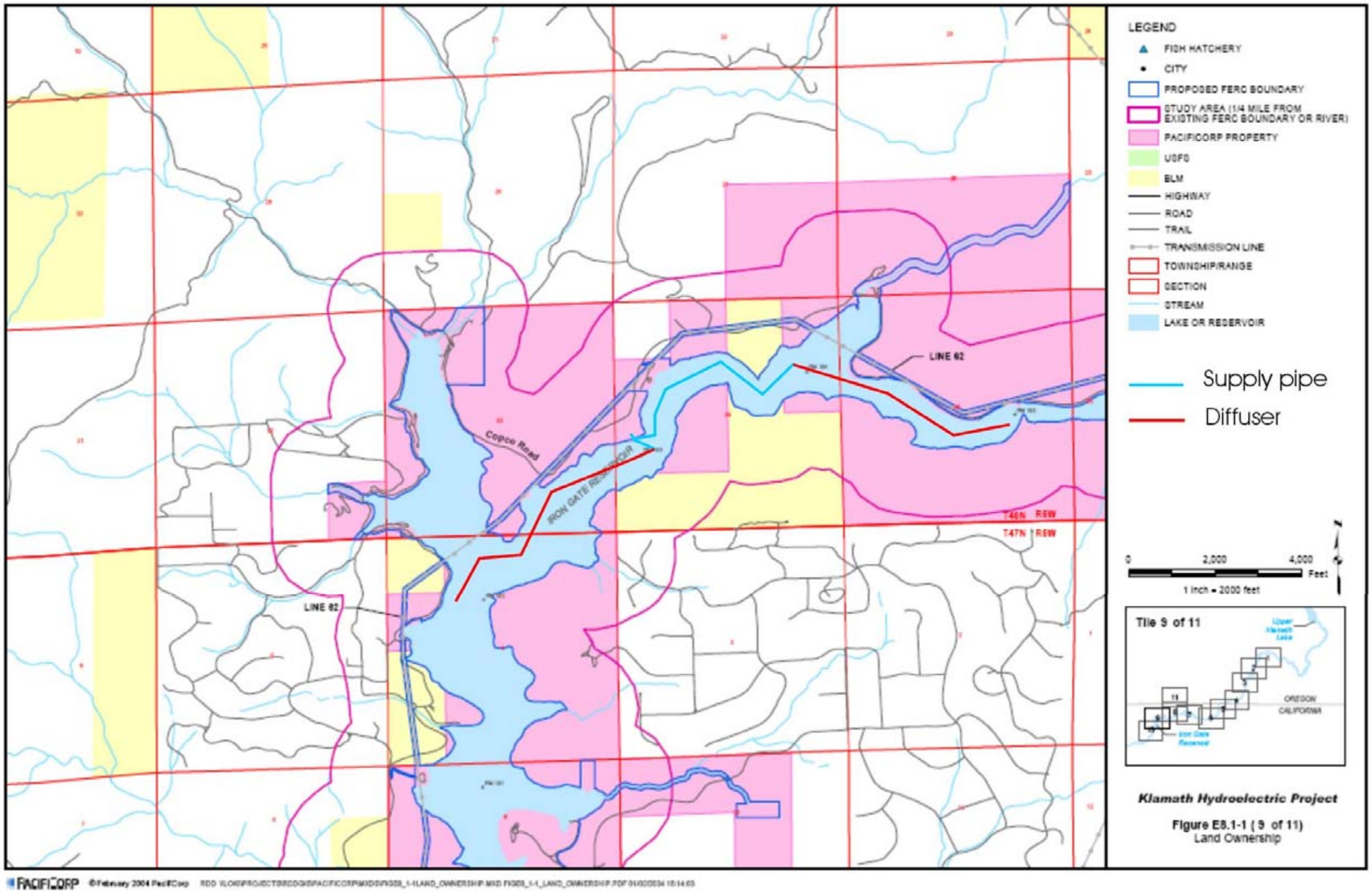

Figure 20: PacifiCorp Property Ownership Map and Conceptual Diffuser Layout for Iron Gate Reservoir

Figure 21: Photograph of a Liquid Oxygen Facility Configured for a Hillside (TVA Tims Ford Dam, 1995)

Discussion of Feasibility Study Results

Oxygen supply for these facilities will be a potential issue that will affect the feasibility and economics of the solution. Long distances are required to deliver liquid oxygen product from the nearest generation facilities to Iron Gate and Copco. Transportation, fuel, and logistics would be expensive.

- Linde
  - Limited LOx capacity available in Northern CA (27 tons per day)
  - Response from Linde representative included in Appendix D
- Air Liquide
  - LOx capacity available
  - VPSA system near Eureka with supplemental LOx delivery from Pittsburg, CA
  - Response from Air Liquide representative included in Appendix D

Both suppliers lease onsite oxygen generation systems and recommend evaluation of those systems to handle base loads at both sites with LOx supplemental system to handle peak loads.

The majority of costs estimated in this study are for oxygen delivery to the sites. Closer analysis of the operational oxygen requirements could result in significant cost savings. Oxygen demands in the W2 model calibration used for this study are intentionally higher than those used in previous calibrations to account for the potential increase in demand due to enhanced DO demands being created by a diffuser and to provide a conservative safety factor in the results which is appropriate for a feasibility study, based on a single model year. Further evaluation of more field data and additional model years may allow some reduction in the oxygen demands modeled and thus the predicted operational costs. For the feasibility model median case runs, the oxygen input to the reservoir was held constant 24 hours a day from the day the reservoir oxygen levels fell below desired limits to reservoir turnover in the fall. Optimization of the oxygen input on a time-varying basis could hold reservoir levels closer to the desired limits and significantly reduce predicted oxygen use.

Liquid oxygen facilities can handle a wide operation range with only a small change in installation costs and can economically be built oversize to provide extra capacity for worst case conditions. Capacity reductions for the oxygen facilities would result in limited cost savings. Contact specifications and detailed design requirements may significantly change these estimates.

Conclusions

Based on the results of this study it is feasible to maintain desired oxygen levels in both reservoirs even with extreme incoming loading conditions. Model results show clear and dramatic improvements in reservoir DO levels with the conceptual oxygen diffuser systems in operation. Very few areas of the reservoir did not meet the desired DO levels nearly 100% of the time.

Model results indicated that oxygenation in Copco resulted in only a relatively small savings in oxygenation requirements at Iron Gate. These savings could possibly be increased with continual adjustment of the oxygen flow rates in Iron Gate to meet the time-varying DO demands. Reducing the target level from 7 to 5 mg/L reduced the oxygen requirements for Copco Reservoir from 25 to 20 tons per day for the median load case and from 63 to 48 tons per day for the peak load case.

The installation and operation of systems to maintain the desired DO levels would be costly. The diffusers and oxygen supply facilities that would be required are readily available. Oxygen supply can be provided by at least one gas company though delivery and transportation logistics may be problematic. Liquid oxygen supply costs dominate system economics. Oxygen delivery costs to these sites is costly but could be reduced with investment in onsite generation. Liquid oxygen storage and supply facility costs will not decrease dramatically with reduced size, but operating costs could be significantly reduced with optimization of oxygen input.

Recommendations

Should PacifiCorp decide to pursue maintenance of reservoir DO levels at Copco and Iron Gate, several areas of additional study are recommended:

- Optimization of oxygen use
- Investigation of PSA versus LOx systems
- Purchase versus leased equipment evaluation

Appendix A:

Description of Modifications for the Copco and Iron Gate CE-QUAL-W2 Models

Introduction

The CE-QUAL-W2 model calibrations were modified for this feasibility study. Past experience with dissolved oxygen (DO) systems has shown that they typically increase a reservoir's oxygen demand. It was therefore important to ensure that the model settings created a DO demand which was conservatively high.

The significant model changes included modifying the inflow concentrations (organic loading and nutrients) and modifying some of the CE-QUAL-W2 control file settings. The inflow concentrations were set to median values for two reasons. Median values are well suited for modeling inflows based on data with infrequent sampling. This prevents a single event from biasing the inflows to be too high if average values were used. In addition, median values are well suited for feasibility studies, because they can be easily changed to modify peak loading events and clearer cause and effect relationships can be observed with the model.

Plots and descriptive text of the significant changes in the Copco and Iron Gate W2 models are presented below.

Copco Reservoir

Figures A1-A4 present the inflow data and model settings for Copco. The data were obtained from the web site http://www.pacificorp.com/Article/Article579.html from the download links labeled Klamath Water Quality Data 2000-2003 and Klamath Water Quality Data 2004. Copco inflow data were obtained from the site ID KR20642 - KLAMATH RIVER U/S SHOVEL CREEK while the Copco Reservoir data were acquired from the site KR19874 - COPCO LAKE NR COPCO.

In general, model inflow concentrations were based on the median data values which were then adjusted for model calibration. The labile organic matter concentrations were based on both the total organic carbon data and the volatile suspended solids data. Data from 2003 and 2004 were used for the total organic carbon and volatile suspended solids because these data did not exist for the 2000 data set.

Tables A1-A4 present the control file changes that were made. In general, the model settings were modified to increase the DO demand to ensure that it was conservatively high. An additional algal group was added to provide more flexibility in controlling the model algal dynamics. The peak load time frame was determined based on conversations with Mike Deas of Watercourse Engineering. The peak load begins on 7/13/2000 and ends on 8/22/2000, for a duration of 40 days.

Figures A5-A9 compare the model results to field data acquired from site KR19874. In general, the model DO is slightly lower than the field DO data, indicating that the model DO demand is higher than actual. The results shown in Figures A5-A9 are based on a zero order sediment oxygen demand of 1.05. This was subsequently raised in the runs which included oxygen diffusers to 2.25 to simulate a diffuser induced sediment oxygen demand. Figures A10 and A11 compare the field data to the model dam release data for DO and temperature. The field dam release data were obtained from site KR19645 - COPCO 2 DAM OUTFLOW.

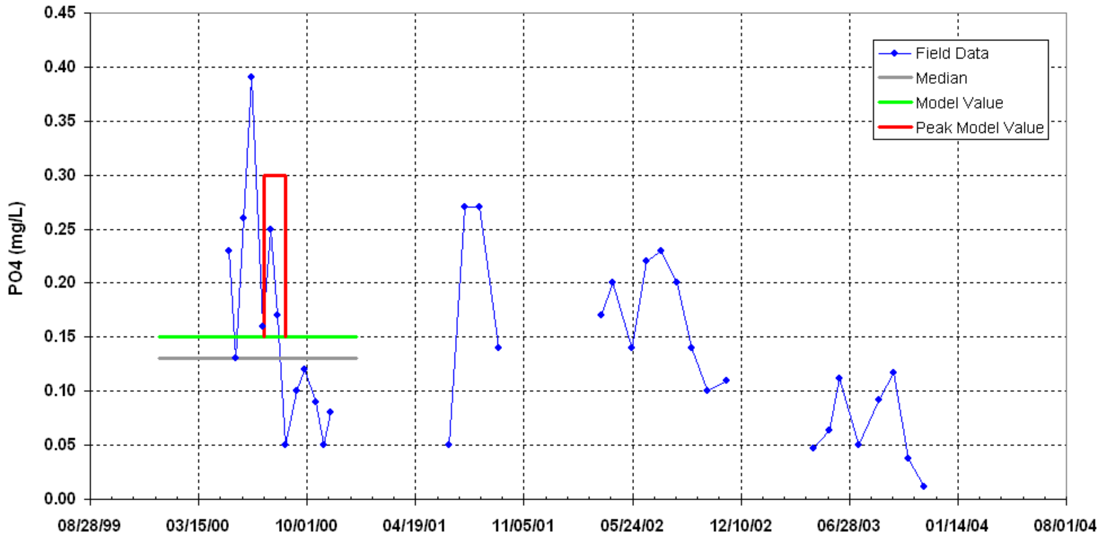

Figure A1. Copco Orthophosphate Inflow Data and Model Settings

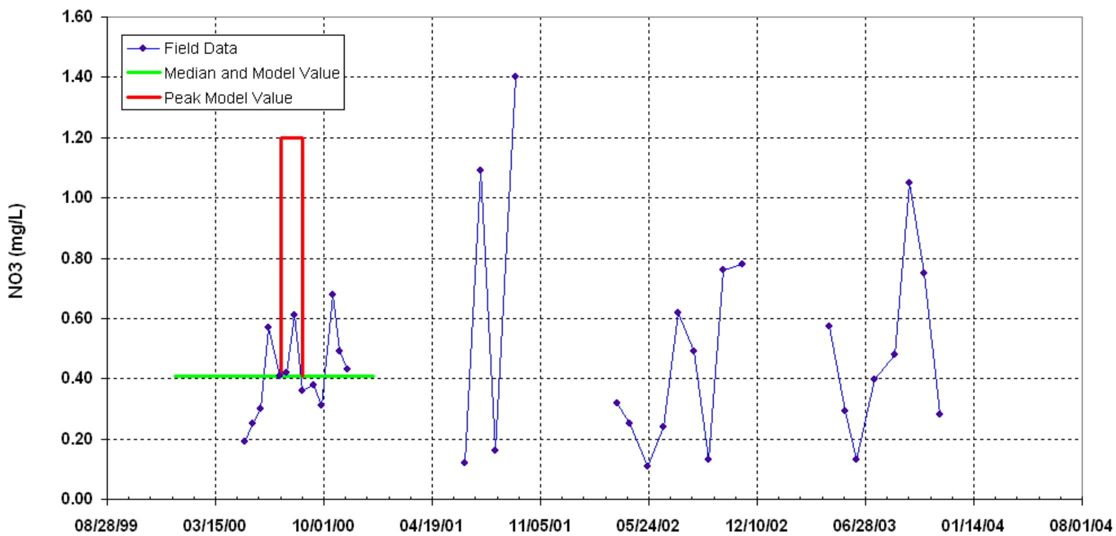

Figure A2. Copco Nitrate Inflow Data and Model Settings

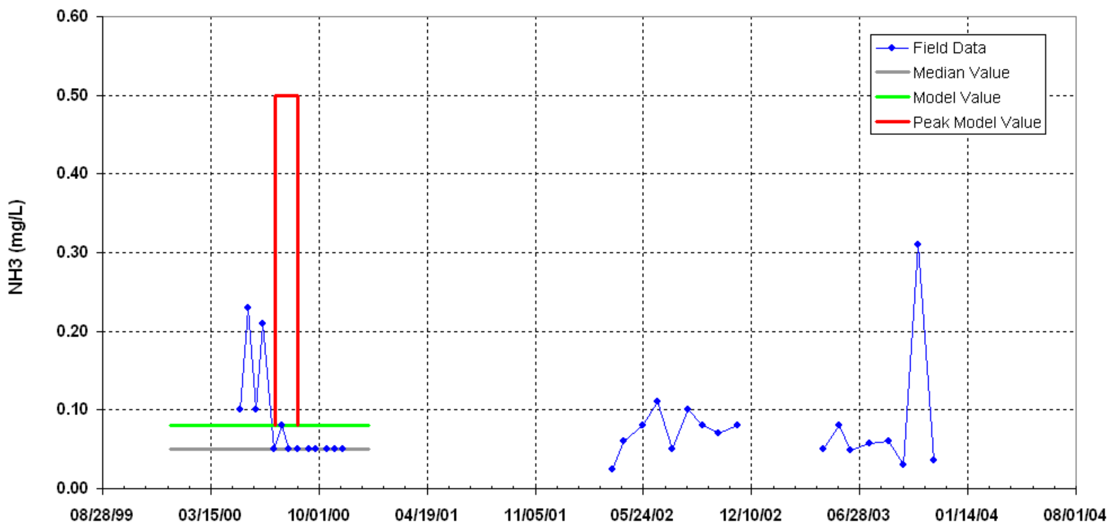

Figure A3. Copco Ammonium Inflow Data and Model Settings

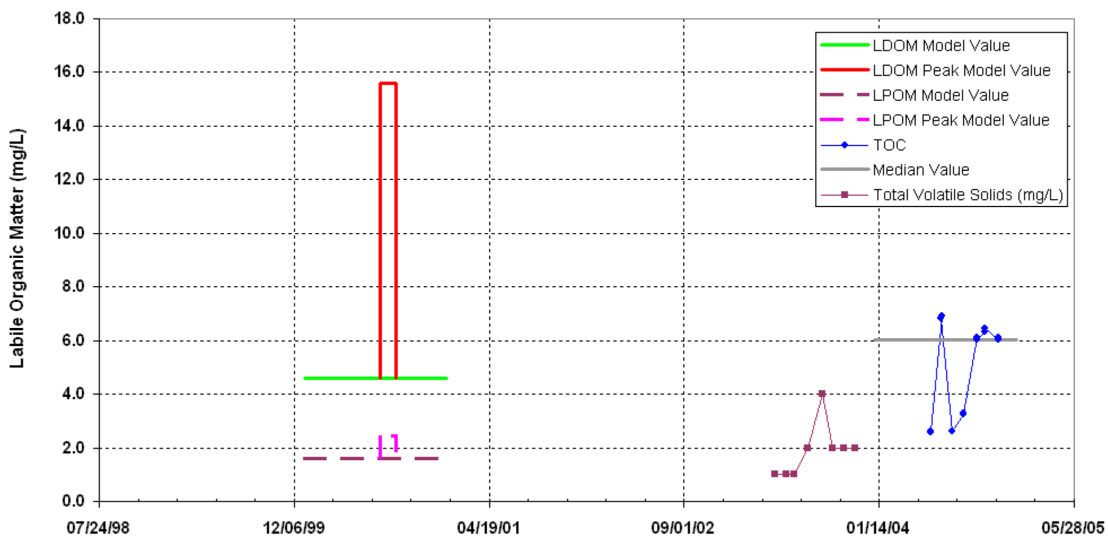

Figure A4. Copco Inflow Data and Model Settings for Labile Organic Matter

Input Group	Variable	Initial W2 Control File	Modified W2 Control File	Difference	Description
DOM	LDOMDK	0.050	0.080	0.030	Labile dissolved organic matter decay rate
POM	POMS	0.800	0.300	-0.500	Particulate organic matter settling rate
OM STOICH	ORGP	0.006	0.008	0.002	Mass fraction of phosphorus in organic matter
OM STOICH	ORGN	0.070	0.065	-0.005	Mass fraction of nitrogen in organic matter
OM RATE	OMK1	0.010	0.100	0.090	Decay rate at initial temp for organic matter
PHOSPHOR	PO4R	0.010	0.005	-0.005	Phosphorus release rate from sediment
AMMONIUM	NH4R	0.040	0.060	0.020	Ammonium release rate from sediment
AMMONIUM	NH4DK	0.100	0.150	0.050	Ammonium decay rate
NH4 RATE	NH4T2	20.000	25.000	5.000	Higher limit temp for ammonium decay rate
SOD RATE	SODK1	0.500	0.100	-0.400	Decay rate of SOD at lower temp

Table A1. Changes in Copco Model Settings

	ALG1-Initial	ALG1-Modified W2	ALG2-Modified W2
AG	1.2	1	1
AR	0.1	0.04	0.04
AE	0.02	0.02	0.02
AM	0.06	0.08	0.08
AS	0.3	0.3	0.3
AHSP	0.003	0.003	0.003
AHSN	0.021	0.01	0.002
AHSSI	0	0	0
ASAT	75	75	100

Table A2. Copco Algal Rate Model Settings

	ALG1-Initial	ALG1-Modified W2	ALG2-Modified W2
AT1	5	5	5
AT2	17	15	20
AT3	35	22	35
AT4	45	45	45
AK1	0.1	0.1	0.1
AK2	0.99	0.99	0.99
AK3	0.99	0.99	0.99
AK4	0.1	0.1	0.1

Table A3. Copco Algal Temperature Model Settings

	ALG1-Initial	ALG1-Modified W2	ALG2-Modified W2
ALGP	0.006	0.0075	0.0075
ALGN	0.07	0.065	0.065
ALGC	0.45	0.45	0.45
ALGSI	0.18	0.18	0.18
ACHLA	67	150	125
ALPOM	0.8	0.8	0.8
ANEQN	2	2	2
ANPR	0.001	0.001	0.001

Table A4. Copco Algal Stoichiometry Model Settings

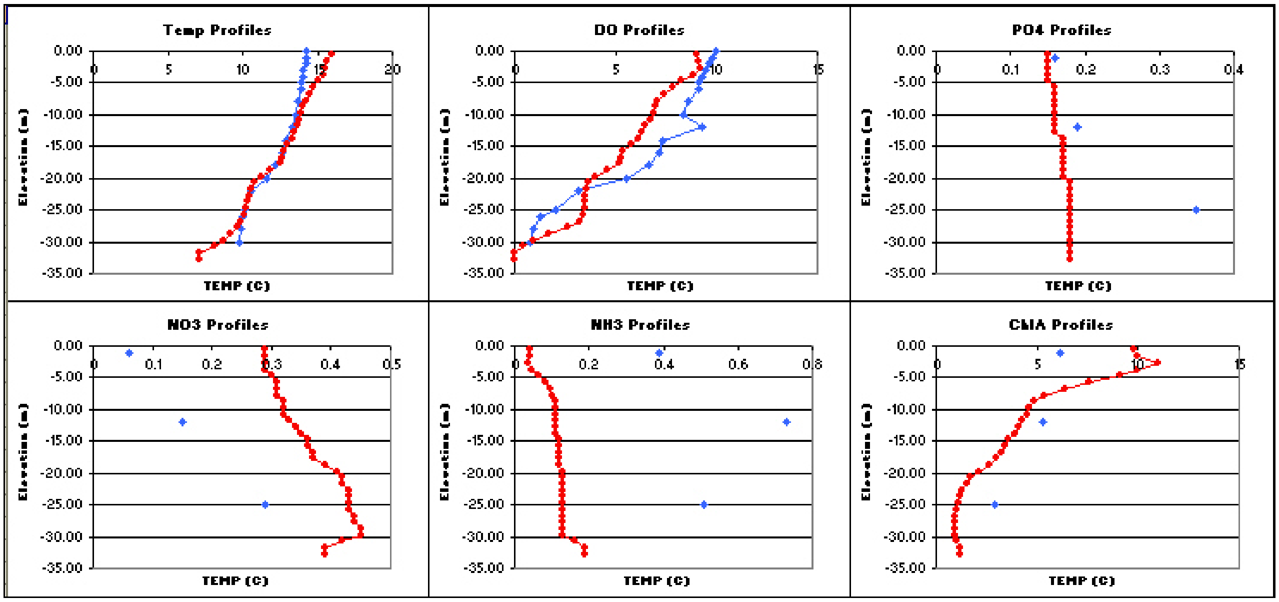

Figure A5. 5-9-2000 Copco Temperature, DO, PO_4, NO3, NH3, and Chlorophyll A Profiles: Model versus Field Data (Field Data is Blue, Model is Red)

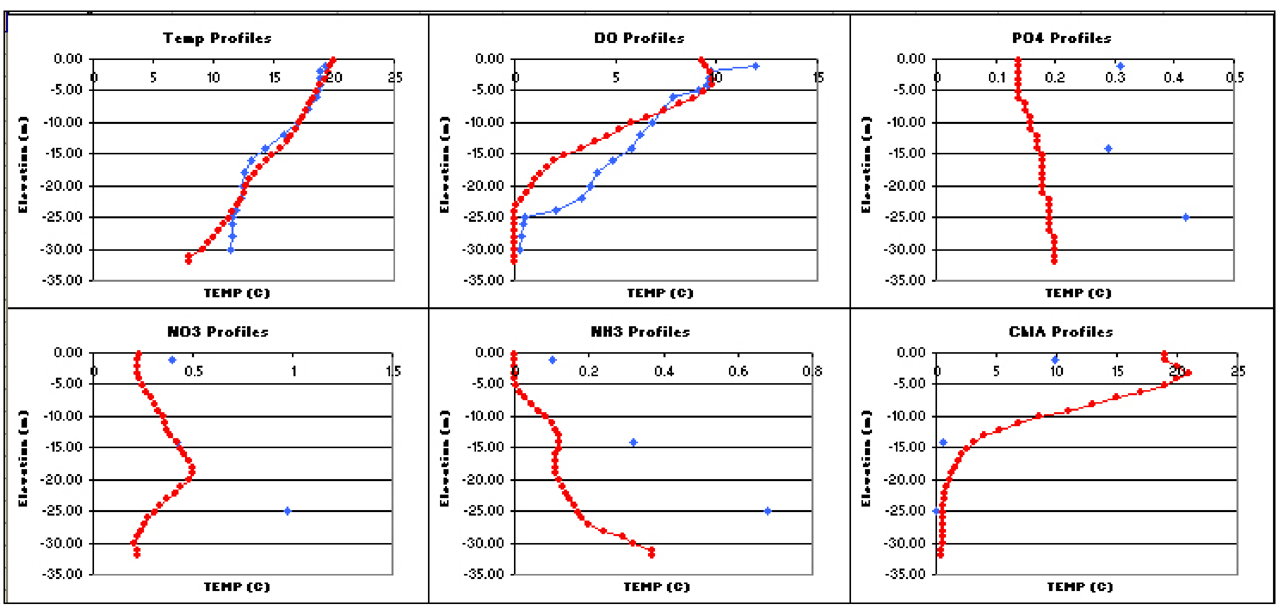

Figure A6. 6-6-2000 Copco Temperature, DO, PO_4, NO3, NH3, and Chlorophyll A Profiles: Model versus Field Data (Field Data is Blue, Model is Red)

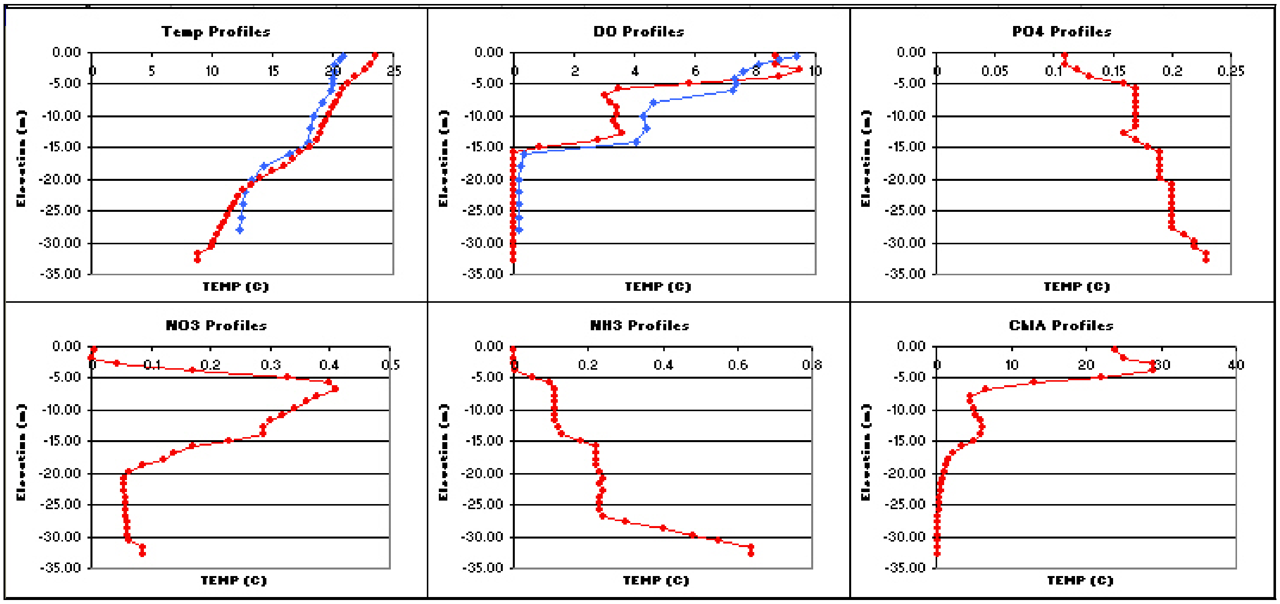

Figure A7. 7-11-2000 Copco Temperature, DO, PO_4, NO3, NH3, and Chlorophyll A Profiles: Model versus Field Data (Field Data is Blue, Model is Red)

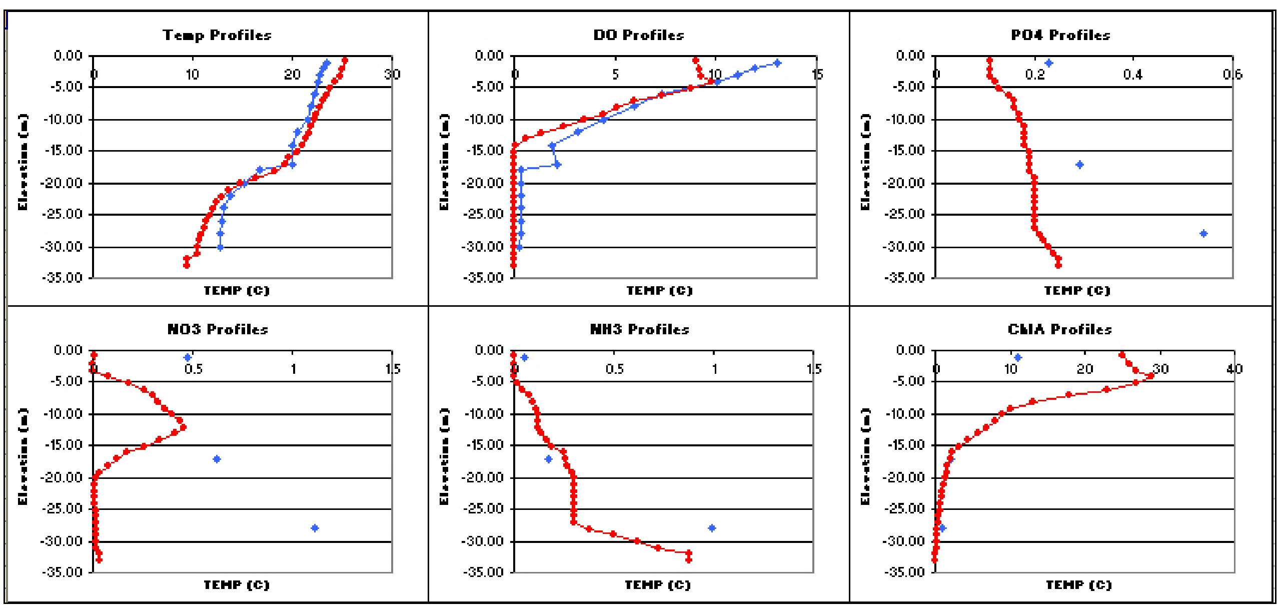

Figure A8. 8-8-2000 Copco Temperature, DO, PO_4, NO3, NH3, and Chlorophyll A Profiles: Model versus Field Data (Field Data is Blue, Model is Red)

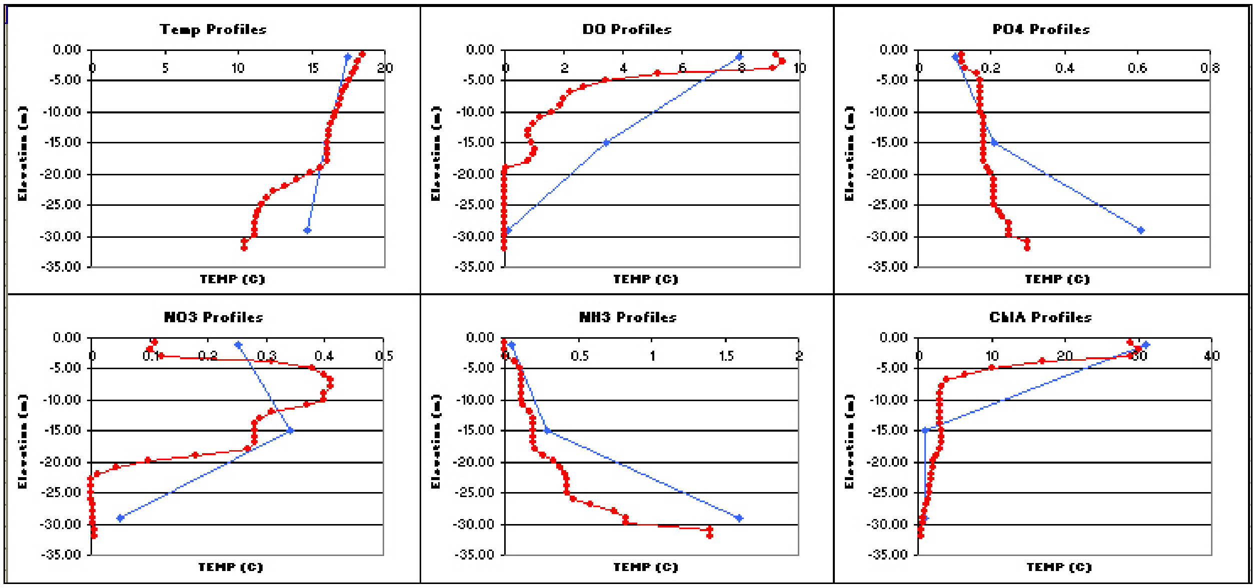

Figure A9. 9-27-2000 Copco Temperature, DO, PO_4, NO3, NH3, and Chlorophyll A Profiles: Model versus Field Data (Field Data is Blue, Model is Red)

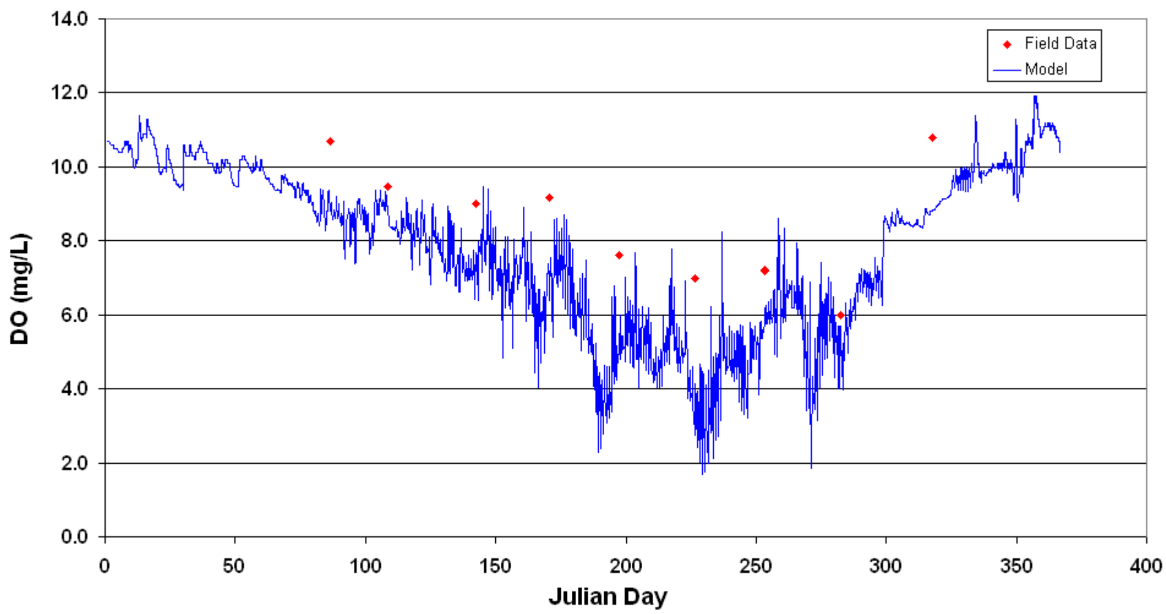

Figure A10. Copco Tailrace DO, Model versus Field Data

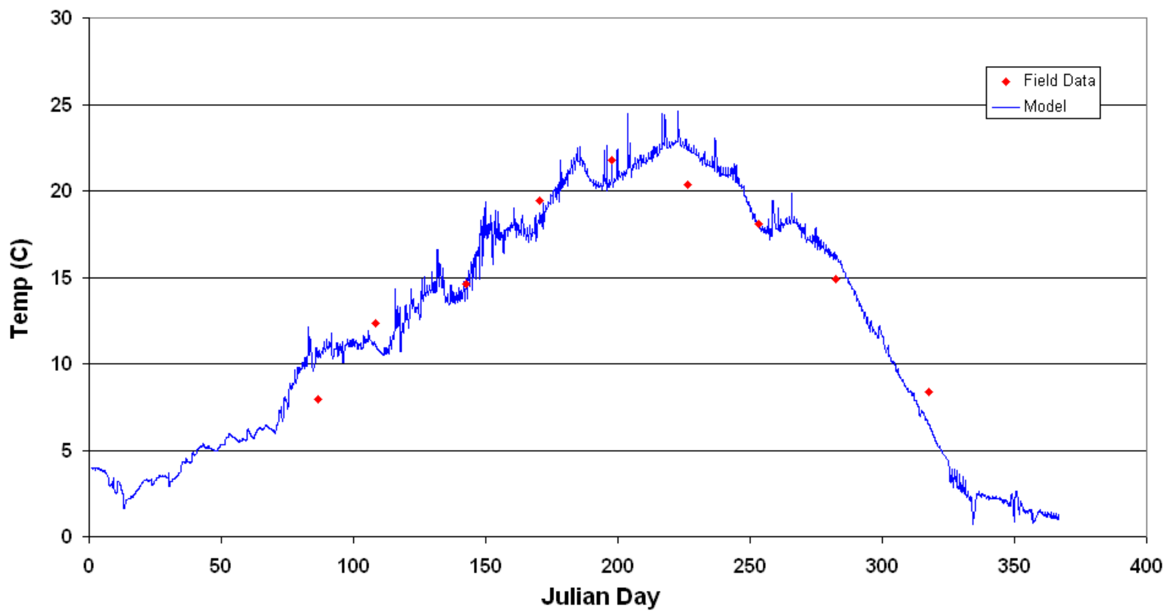

Figure A11. Copco Tailrace Temperature, Model versus Field Data

Iron Gate

Figures A12-A15 present the inflow data and model settings for Iron Gate. The data were obtained from the web site http://www.pacificorp.com/Article/Article579.html from the download links labeled Klamath Water Quality Data 2000-2003 and Klamath Water Quality Data 2004. Iron Gate inflow data were obtained from the site ID KR19645 – COPCO 2 DAM OUTFLOW, while the Iron Gate Reservoir data were acquired from the site KR19019 - IRONGATE RES NR HORNBROOK.

In general, model inflow concentrations were based on the median data values which were then adjusted for model calibration. The orthophosphate, nitrate, and ammonium data were based on 2002 values because those data were not available for 2000. The labile organic matter concentrations were based on both the total organic carbon data and the volatile suspended solids data. Data from 2003 and 2004 were used for the total organic carbon and volatile suspended solids because these data did not exist for the 2000 data set.

Table A5 presents the control file changes that were made. In general, the model settings were modified to increase the DO demand to ensure that it was conservatively high. An additional algal group was added to provide more flexibility in controlling the model algal dynamics. These model settings were identical to the Copco algal settings, with the exception of the ASAT value for algal group 1 which was changed from 75 to 100 during the calibration process. The peak load time frame is identical to that used for the Copco model runs.

Figures A16-A22 compare the model results to field data acquired from site KR19019. The tailrace data are from site KR18973 - IRON GATE DAM OUTFLOW. In general, the model DO is slightly lower than the field DO data, indicating that the model DO demand is higher than actual. The results shown in Figures A16-A22 are based on a zero order sediment oxygen demand of 0.5. This was subsequently raised in the runs which included oxygen diffusers to 2.25 to simulate a diffuser induced sediment oxygen demand.

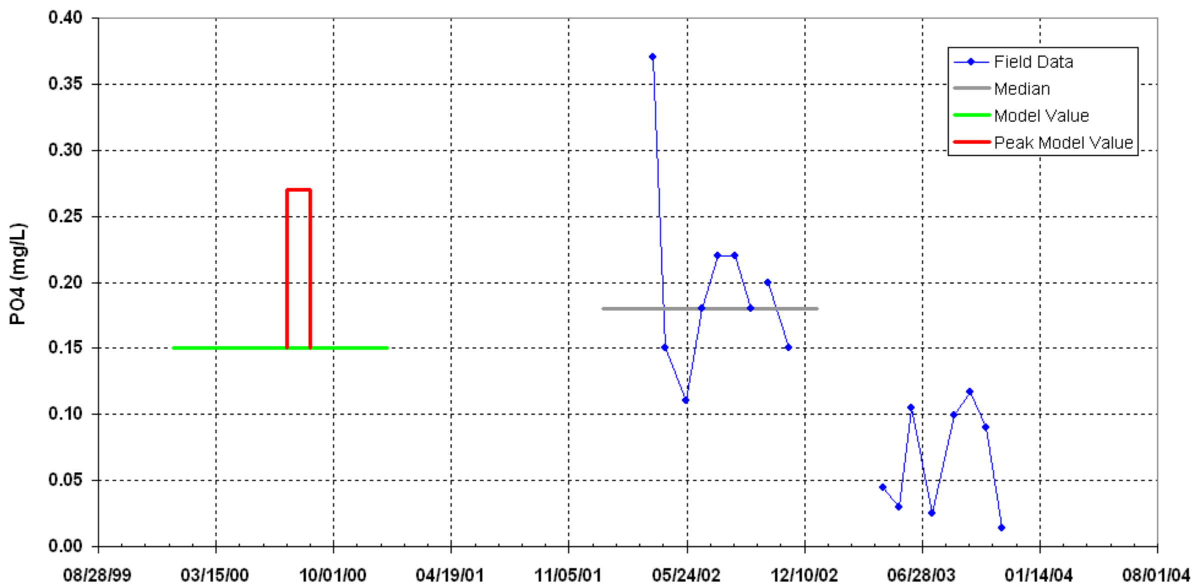

Figure A12. Iron Gate Orthophosphate Inflow Data and Model Settings

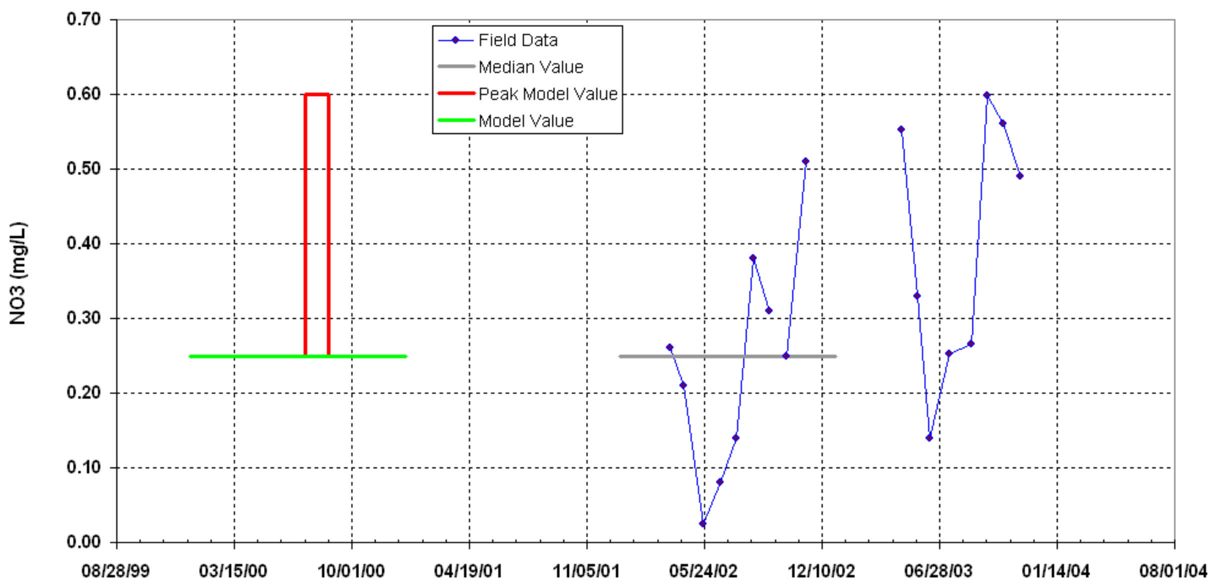

Figure A13. Iron Gate Nitrate Inflow Data and Model Settings

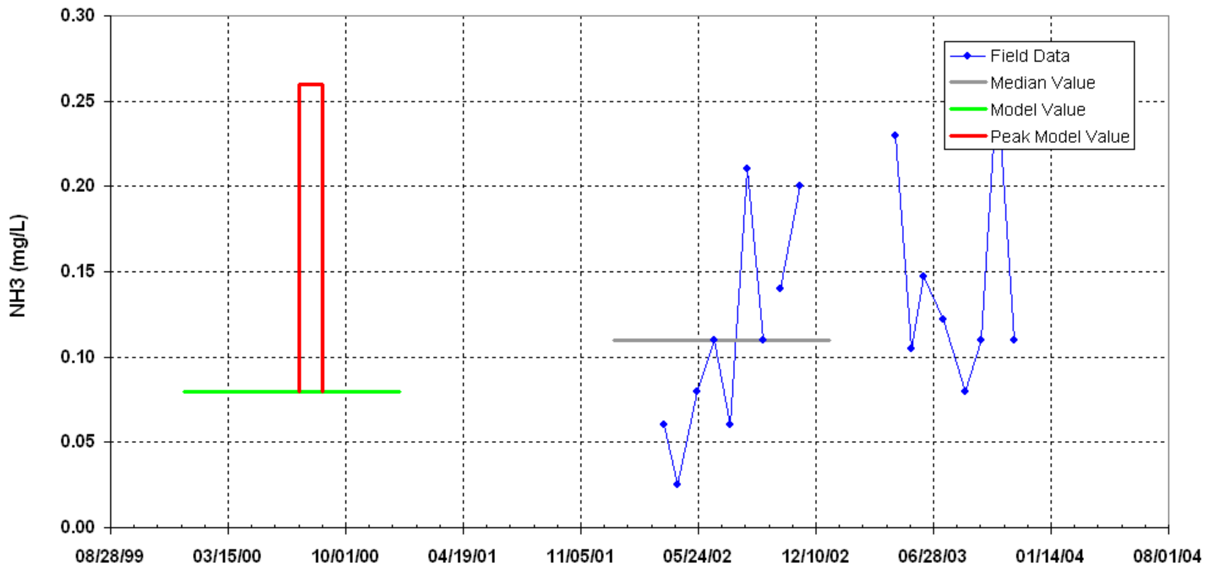

Figure A14. Iron Gate Ammonium Inflow Data and Model Settings

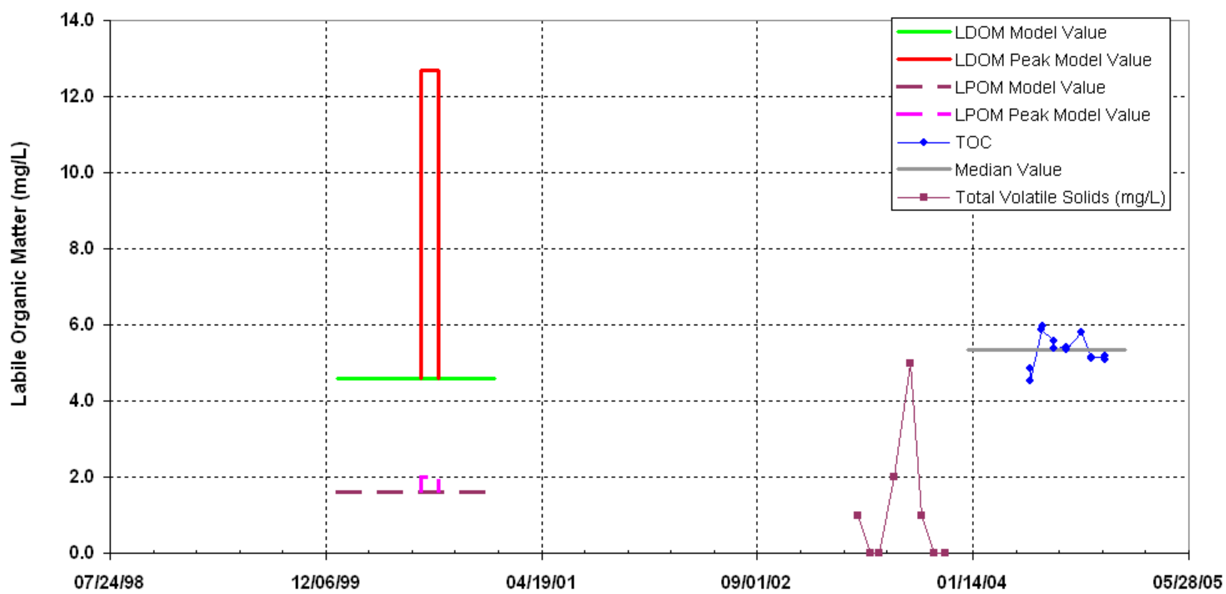

Figure A15. Iron Gate Inflow Data and Model Settings for Labile Organic Matter

Input Group	Variable	Initial W2 Control File	Modified W2 Control File	Difference	Description
DOM	LDOMDK	0.050	0.080	0.030	Labile dissolved organic matter decay rate
POM	POMS	0.800	0.300	-0.500	Particulate organic matter settling rate
OM STOICH	ORGP	0.006	0.008	0.002	Mass fraction of phosphorus in organic matter
OM STOICH	ORGN	0.070	0.065	-0.005	Mass fraction of nitrogen in organic matter
PHOSPHOR	PO4R	0.010	0.005	-0.005	Phosphorus release rate from sediment
AMMONIUM	NH4DK	0.100	0.150	0.050	Ammonium decay rate
NH4 RATE	NH4T2	20.000	25.000	5.000	Ammonia decay rate at higher temp
SOD RATE	SODK1	0.500	0.100	-0.400	Decay rate of SOD at lower temp

Table A5. Changes in Iron Gate Model Settings

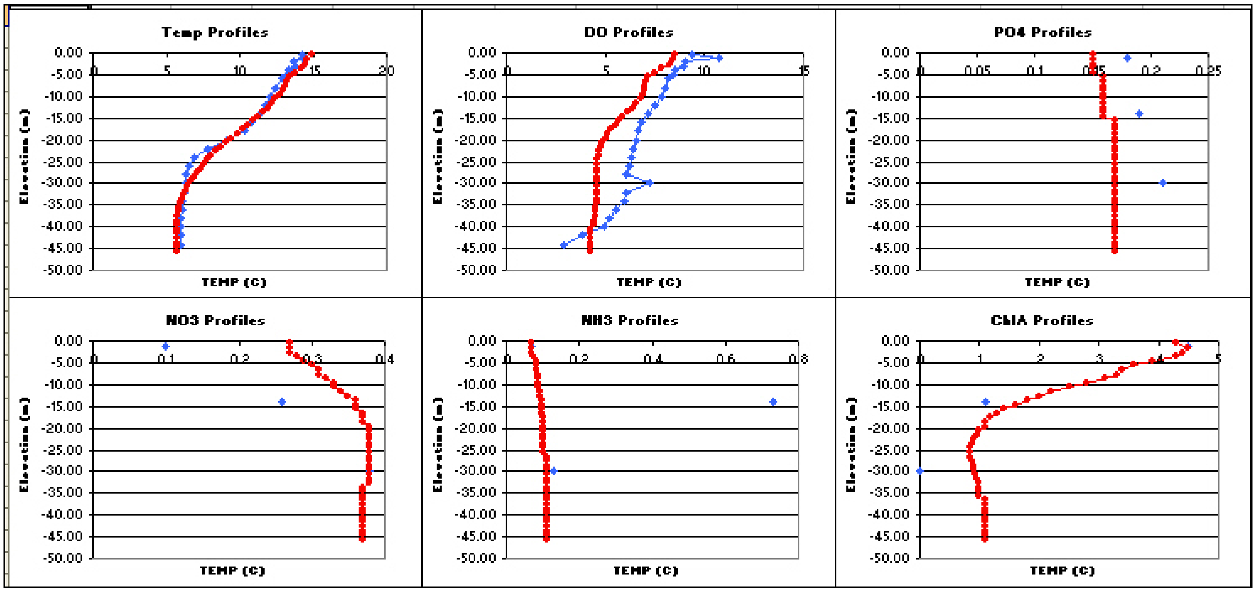

Figure A16. 5-9-2000 Iron Gate Temperature, DO, PO_4, NO3, NH3, and Chlorophyll A Profiles: Model versus Field Data (Field Data is Blue, Model is Red)

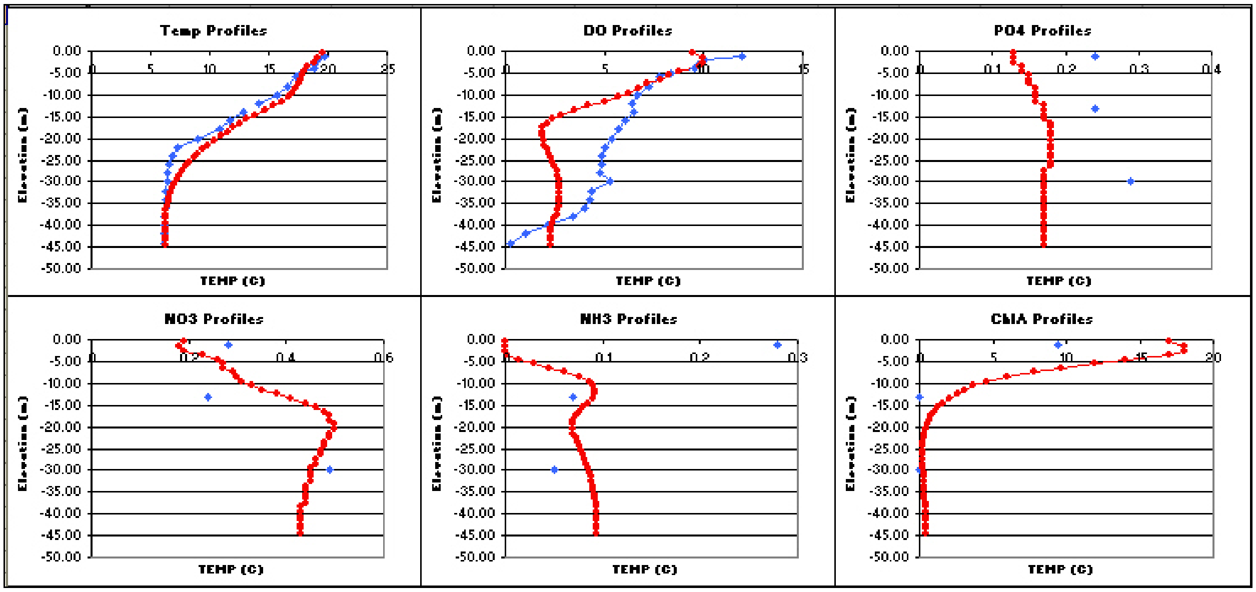

Figure A17. 6-6-2000 Iron Gate Temperature, DO, PO_4, NO3, NH3, and Chlorophyll A Profiles: Model versus Field Data (Field Data is Blue, Model is Red)

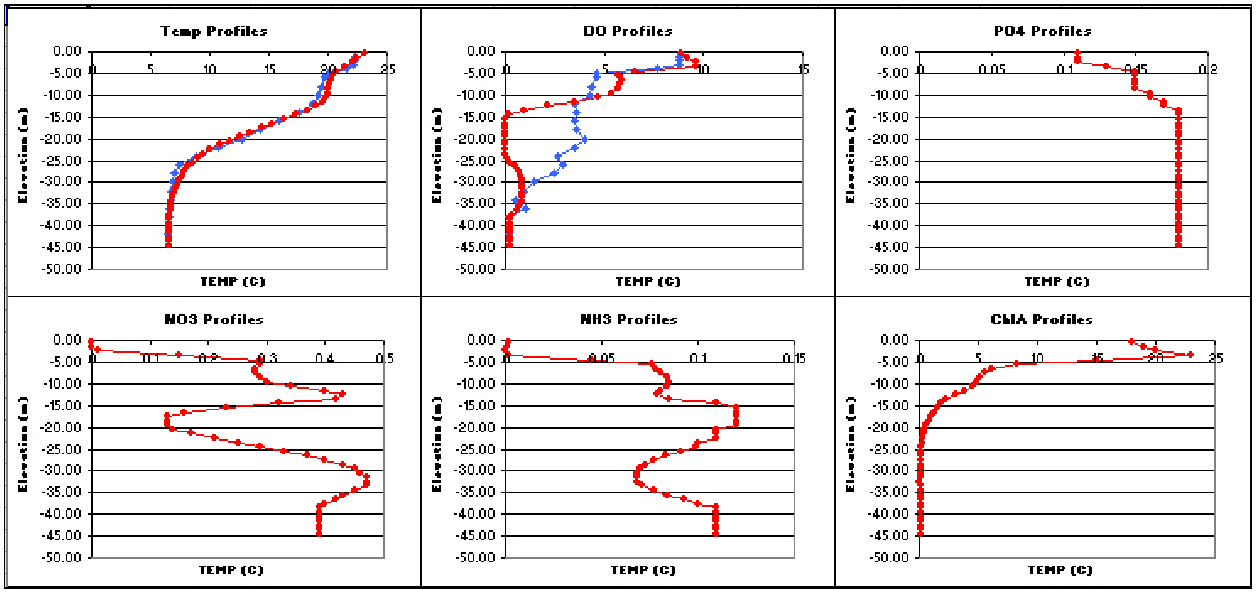

Figure A18. 7-11-2000 Iron Gate Temperature, DO, PO_4, NO3, NH3, and Chlorophyll A Profiles: Model versus Field Data (Field Data is Blue, Model is Red)

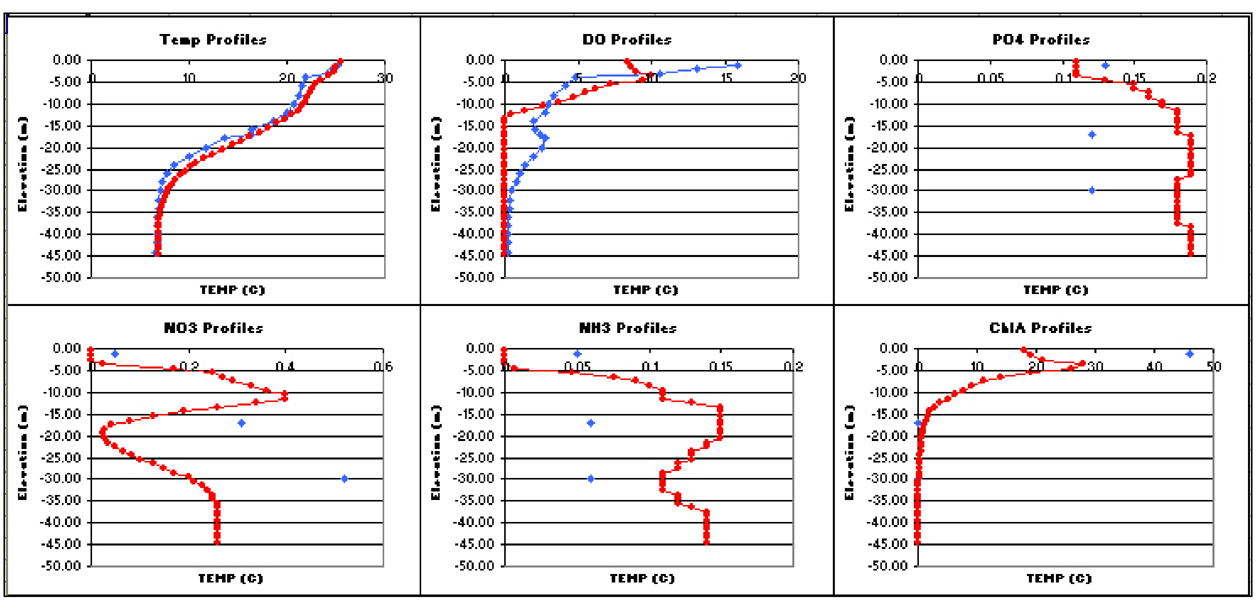

Figure A19. 8-8-2000 Iron Gate Temperature, DO, PO_4, NO3, NH3, and Chlorophyll A Profiles: Model versus Field Data (Field Data is Blue, Model is Red)

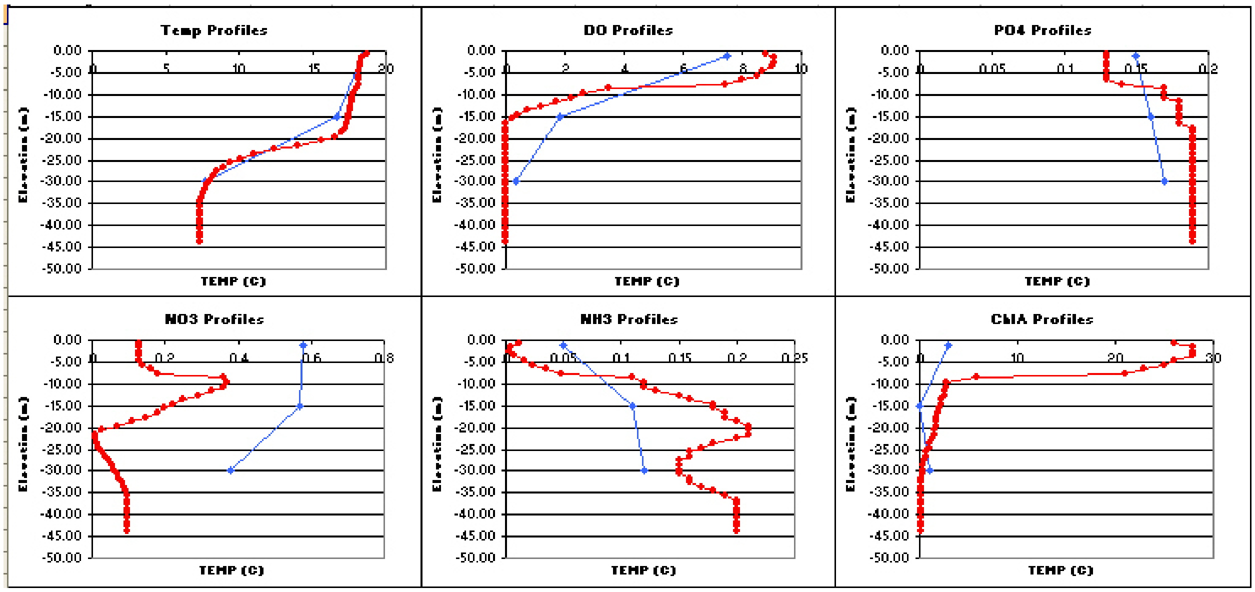

Figure A20. 9-27-2000 Iron Gate Temperature, DO, PO_4, NO3, NH3, and Chlorophyll A Profiles: Model versus Field Data (Field Data is Blue, Model is Red)

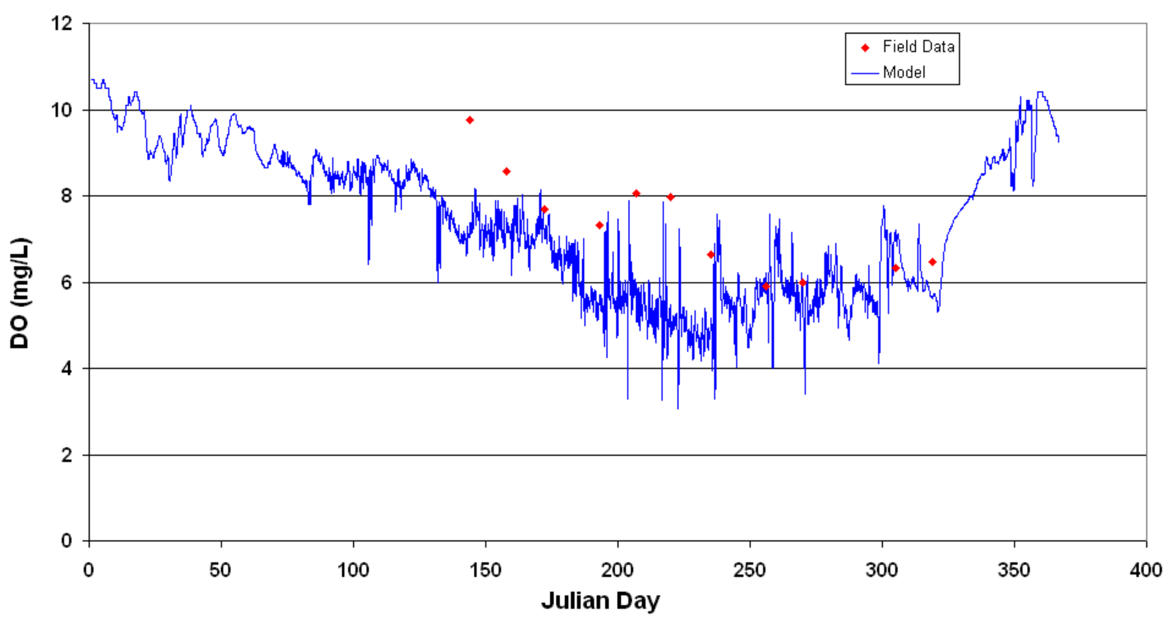

Figure A21. Iron Gate Tailrace DO, Model versus Field Data

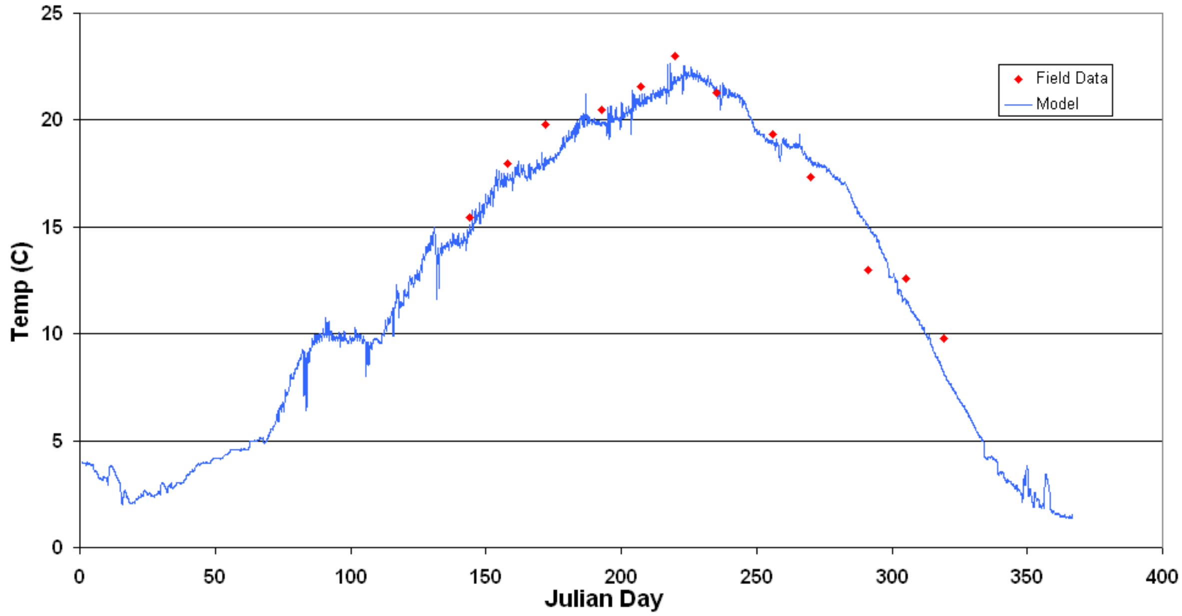

Figure A22. Iron Gate Tailrace DO, Model versus Field Data

Appendix B:

Detailed Cost Estimate for Conceptual Design of Copco Reservoir Oxygenation System

Copco Reservoir
PacifiCorp
Reservoir Oxygenation System
Estimated Costs

			Labor	Material	Total
System Design:					
Site-specific design development			$11,248	$9,735	$20,983
Detailed design and drawing submittals			$13,300	$750	$14,050
		System design total:	$24,500	$10,500	$35,000
Diffuser Installation:					
Shop assembly			$46,333	$88,718	$135,051
Diffuser lines and supply lines	23,265	feet total	$397,811	$248,848	$646,659
Sleeve pipe and trench	600	feet total	$9,865	$25,229	$35,094
Travel expenses and shipping			$21,181	$115,890	$137,071
Equipment rental			$0	$17,826	$17,826
Installation tools			$0	$44,916	$44,916
Bonding, Warranty, Special Insurance, CA Licenses				$129,562	$129,562
		Diffuser installation total:	$475,190	$670,988	$1,146,178
	Diffuser Total:		**$499,690**	**$681,488**	**$1,181,178**

BULK LOx STORAGE FACILITY:

		Labor	Material	Total
Design:				
Oxygen distribution header design		$10,000	$200	$10,200
Facility design		$45,000	$5,000	$50,000
Design drawings		$20,000	$800	$20,800
	Facility design total:	$75,000	$6,000	$81,000
Installation:				
Grade and drainage		$18,750	$6,250	$25,000
Access road and truck turnaround area		$15,000	$5,000	$20,000
Concrete pad for tank and vaporizers		$120,000	$40,000	$160,000
Pipe trench and sleeve pipe to water		$18,750	$6,250	$25,000
Final landscape		$3,000	$1,000	$4,000
Fence and gate		$6,000	$6,000	$12,000
Supply manifold, piping, control valves, pipe supports		$35,000	$35,000	$70,000
Oxygen flowmeter and controls		$25,000	$25,000	$50,000
Electrical power supply		$13,500	$4,500	$18,000
Monitoring and control system		$0	$0	$0
Lighting		$7,500	$2,500	$10,000
Installation of phone line, instrument cable		$5,250	$1,750	$7,000
Electrical wiring on pad		$11,250	$3,750	$15,000
	Facility installation total:	$279,000	$137,000	$416,000

Copco Reservoir
PacifiCorp
Reservoir Oxygenation System
Estimated Costs (Continued)

		Labor	Material	Total
Cryogenic Equipment:				
20,000-gallon tank	2	$120,000	$368,000	$488,000
Ice racks and vaporizers	20		$300,000	$300,000
Controls			$40,000	$40,000
Cryogenic equipment total:		$120,000	$708,000	$828,000
Liquid Oxygen Facility Total:		**$474,000**	**$851,000**	**$1,325,000**
PSA OXYGEN SUPPLY FACILITY:		**Labor**	**Material**	**Total**
Facility design drawings		$50,000	$5,000	$55,000
Grade and drainage		$7,500	$2,500	$10,000
Access road and truck turnaround area		$7,500	$2,500	$10,000
Concrete equipment pad		$15,000	$15,000	$30,000
PSA equipment building		$24,000	$36,000	$60,000
Electrical power supply		$12,500	$12,500	$25,000
Electrical wiring in building		$4,000	$4,000	$8,000
Lighting		$3,750	$1,250	$5,000
Installation of phone line, instrument cable		$750	$250	$1,000
PSA system: Two OG1200 with Atlas Copco rotary screw air compressor		$24,000	$280,000	$304,000
Oxygen compressor Riggs		$6,000	$25,000	$31,000
PSA controls and telecommunication package		$1,000	$6,000	$7,000
Supply manifold, piping, control valves, pipe supports		$7,500	$7,500	$15,000
Oxygen flowmeter and controls		$1,000	$3,000	$4,000
Pipe trench to water		$1,500	$200	$1,700
Final landscape		$1,500	$500	$2,000
PSA Oxygen Facility Total:		**$167,500**	**$401,200**	**$568,700**
START-UP AND INITIAL OPERATION TECHNICAL ASSISTANCE:				
Operation manuals and operator training		$20,000	$5,000	$25,000
Performance verification and technical assistance		$15,000	$5,000	$20,000
Start-up total:		$35,000	$10,000	$45,000
GRAND TOTAL:		**$1,176,190**	**$1,943,688**	**$3,119,878**

Appendix C:

Detailed Cost Estimate for Conceptual Design of Iron Gate Reservoir Oxygenation System

Iron Gate Reservoir
PacifiCorp
Reservoir Oxygenation System
Estimated Costs

RESERVOIR DIFFUSER SYSTEM:

			Labor	Material	Total
Diffuser Design:					
Site-specific design development			$11,248	$9,735	$20,983
Detailed design and drawing submittals			$13,300	$750	$14,050
		System design total:	$24,500	$10,500	$35,000
Diffuser Installation:					
Shop assembly			$40,959	$74,827	$115,786
Diffuser lines and supply lines	18,900	feet total	$352,636	$204,794	$557,430
Sleeve pipe and trench	600	feet total	$9,865	$25,229	$35,094
Travel expenses and shipping			$21,181	$106,440	$127,621
Equipment rental			$0	$17,826	$17,826
Installation tools			$0	$44,916	$44,916
Bonding, Warranty, Special Insurance, CA Licenses				$120,527	$120,527
		Diffuser installation total:	$424,641	$594,558	$1,019,200
	Diffuser Total:		**$449,141**	**$605,058**	**$1,054,200**

BULK LOx STORAGE FACILITY:

		Labor	Material	Total
LOx Facility Design:				
Oxygen distribution header design		$10,000	$200	$10,200
Facility design		$55,000	$5,000	$60,000
Design drawings		$20,000	$800	$20,800
	Facility design total:	$85,000	$6,000	$91,000
LOx Facility Installation:				
Grade and drainage		$26,250	$8,750	$35,000
Access road and truck turnaround area		$30,000	$10,000	$40,000
Concrete pad for tank and vaporizers		$120,000	$40,000	$160,000
Pipe trench and sleeve pipe to water		$18,750	$6,250	$25,000
Final landscape		$3,000	$1,000	$4,000
Fence and gate		$6,000	$6,000	$12,000
Supply manifold, piping, control valves, pipe supports		$35,000	$35,000	$70,000
Oxygen flowmeter and controls		$15,000	$15,000	$30,000
Electrical power supply		$13,500	$4,500	$18,000
Monitoring and control system		$0	$0	$0
Lighting		$7,500	$2,500	$10,000
Installation of phone line, instrument cable		$5,250	$1,750	$7,000
Electrical wiring on pad		$11,250	$3,750	$15,000
	Facility installation total:	$291,500	$134,500	$426,000

Iron Gate Reservoir
PacifiCorp
Reservoir Oxygenation System
Estimated Costs (Continued)

		Labor	Material	Total
Cryogenic Equipment:				
20,000-gallon tank	1	$60,000	$184,000	$244,000
Ice racks and vaporizers	14		$210,000	$210,000
Controls			$30,000	$30,000
Cryogenic equipment total		$60,000	$424,000	$484,000
Liquid Oxygen Facility Total:		**$436,500**	**$564,500**	**$1,001,000**

PSA OXYGEN SUPPLY FACILITY:	**Labor**	**Material**	**Total**
Facility design drawings	$50,000	$5,000	$55,000
Grade and drainage	$7,500	$2,500	$10,000
Access road and truck turnaround area	$7,500	$2,500	$10,000
Concrete equipment pad	$15,000	$15,000	$30,000
PSA Equipment Building	$24,000	$36,000	$60,000
Electrical power supply	$12,500	$12,500	$25,000
Electrical wiring in building	$4,000	$4,000	$8,000
Lighting	$3,750	$1,250	$5,000
Installation of phone line, instrument cable,	$750	$250	$1,000
PSA system: Two OG1800 with Atlas Copco rotary screw air compressoı	$44,000	$360,000	$404,000
Oxygen compressor Riggs	$6,000	$30,000	$36,000
PSA controls and telecommunication package	$1,000	$6,000	$7,000
Supply manifold, piping, control valves, pipe supports	$7,500	$7,500	$15,000
Oxygen flowmeter and controls	$1,000	$3,000	$4,000
Pipe trench to water	$1,500	$200	$1,700
Final landscape	$1,500	$500	$2,000
PSA Oxygen Facility Total:	**$187,500**	**$486,200**	**$673,700**

START-UP AND INITIAL OPERATION TECHNICAL ASSISTANCE:			
Operation manuals and operator training	$20,000	$5,000	$25,000
Performance verification and technical assistance	$15,000	$5,000	$20,000
Start-up total:	$35,000	$10,000	$45,000

GRAND TOTAL:	**$1,108,141**	**$1,665,758**	**$2,773,900**

Appendix D:

Responses from Potential Oxygen Suppliers

From: Vreeburg,Gregory [mailto:Gregory.Vreeburg@boc.com]
Sent: Thursday, November 01, 2007 7:46 PM
To: Mark H Mobley
Cc: Vreeburg,Gregory; Iannelli, Mike; Lawson, Jeff
Subject: RE: Questions and Location for O2 Supply

Hello Mark,
Thank you for your request for Supply of Oxygen to the COPCO and IRON GATE locations in Northern California. I wanted to get back to you with an answer to your very significant Oxygen demand.

Following are numbers that I calculate based on your estimated demand
COPCO 138 days at 20,000 scfh 66,240,000 scf
45 days at 60,000 scfh 64,800,000 scf
COPCO Total 6 month demand 113,040,000 scf
21,840,000 scf per month 189,748 gallons per mo or 48 trailers per mo

IRON GATE 138 days at 15,000 scfh 49,680,000 scf
45 days at 30,000 scfh 32,400,000 scf
COPCO Total 6 month demand 82,080,000 scf
13,346,000 scf per month 115,960 gallons per mo or 30 trailers per mo

TOTAL DEMAND 35,185,000 scfm 306,000 gallon mo or approx 80 deliveries per month.

Oxygen product in No California is limited. To address this need, LINDE would be able to supply 20,000,000 scfm from Vancouver WA 340 miles north. Product price from this location and this dedication would cost from $1.20 to $1.50 per 100 scf. Total monthly cost for product only at $1.20 per 100 scf would be $240,000.00 per month or $1,440,000.00 per 6 months. Compare this to an estimated cost for 2 ONSITE O2 Generation units for less than $1,000,000 per year in operating costs that would be sized to meet your entire O2 needs. With the Demand that you have stated, it would be more economical to install an ECOVAR O2 onsite plant.

Please call me with your thoughts on this.

Regards

Gregory Vreeburg
Account Manager
LINDE
510-258-8183

From: Cheng, David [mailto:David.Cheng@Airliquide.com]
Sent: Tuesday, November 06, 2007 12:24 AM
To: Mark H Mobley
Subject: RE: Oxygen Supply for Hydro Reservoirs in Northernmost CA.

Hi Mark,

As we discussed over the phone, a seasonal volume such as this is hard to do since we would need drivers and trailers brought in to accommodate the added work. But with proper notice, that could be done. We do have the oxygen capacity out of our plant in Pittsburg, CA.

I was under the impression that this was close to Eureka, CA. However, the location of the reservoirs is closer to Redding. Highway 5 does not suffer the same passage restrictions. It is a little farther, but still very doable. I would stick with a rough guess of $ 1.00 / ccf on liquid oxygen, pending a discussion with our Product Management on the seasonal factors. What does concern me is that the reservoirs are set back from the freeway and our trailers don't make tight turns and have trouble on smaller roads.

Being so far from any source of oxygen, I would recommend that you oversize the LOX storage facilities.

Look forward to hearing more about the project.

David Cheng
Account Manager
Air Liquide Industrial U.S. LP.
510-851-0488