Figure IV-3: Chlorophyll a concentration as a function of time for the influent (Site A) and effluent (Site B) of the Grasslands Bypass Project between June 13th and October 4th, 2001.

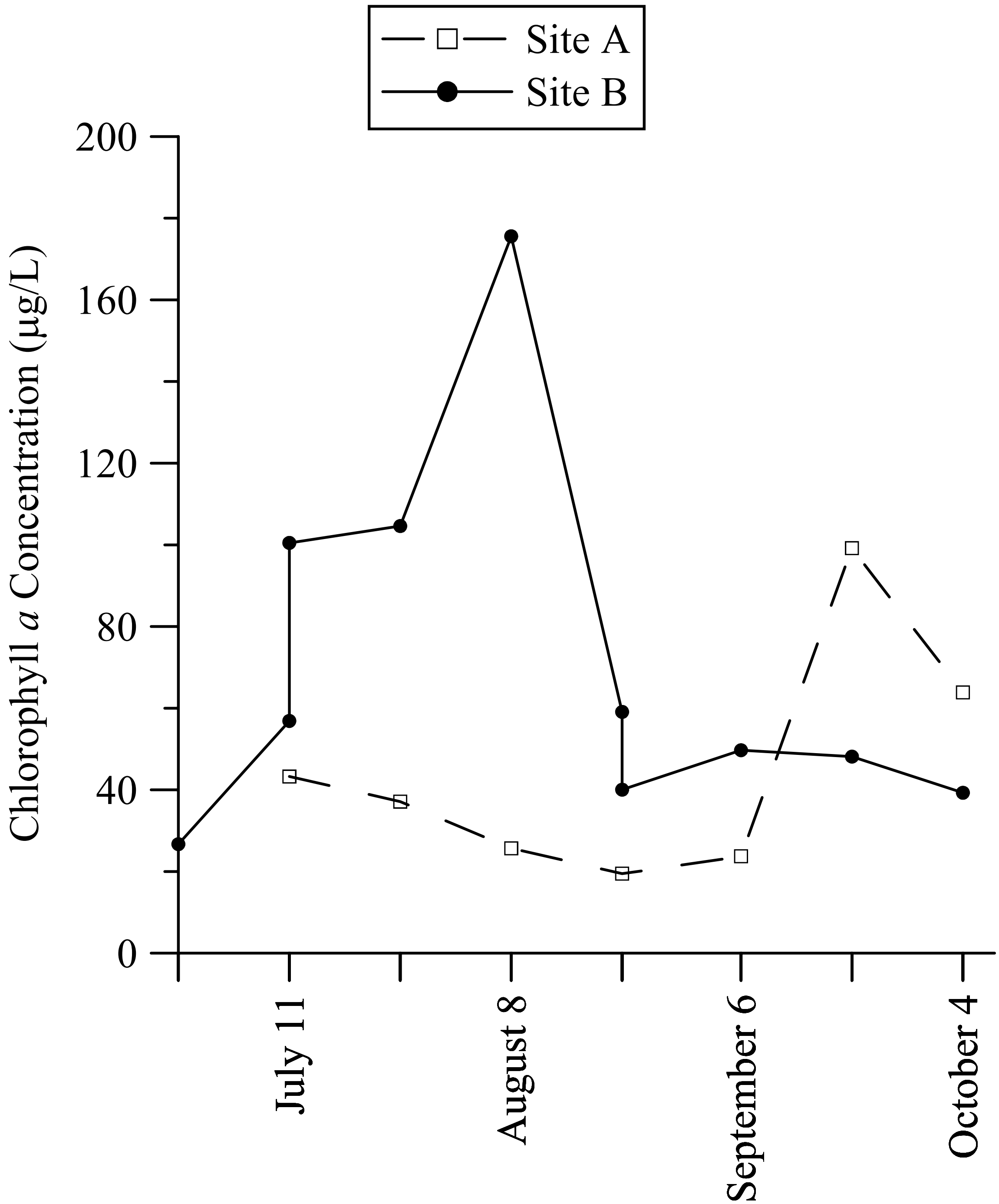


Figure IV-4: BOD_{10} concentration as a function of time for the influent (Site A) and effluent (Site B) of the Grasslands Bypass Project between June 13th and October 4th, 2001.

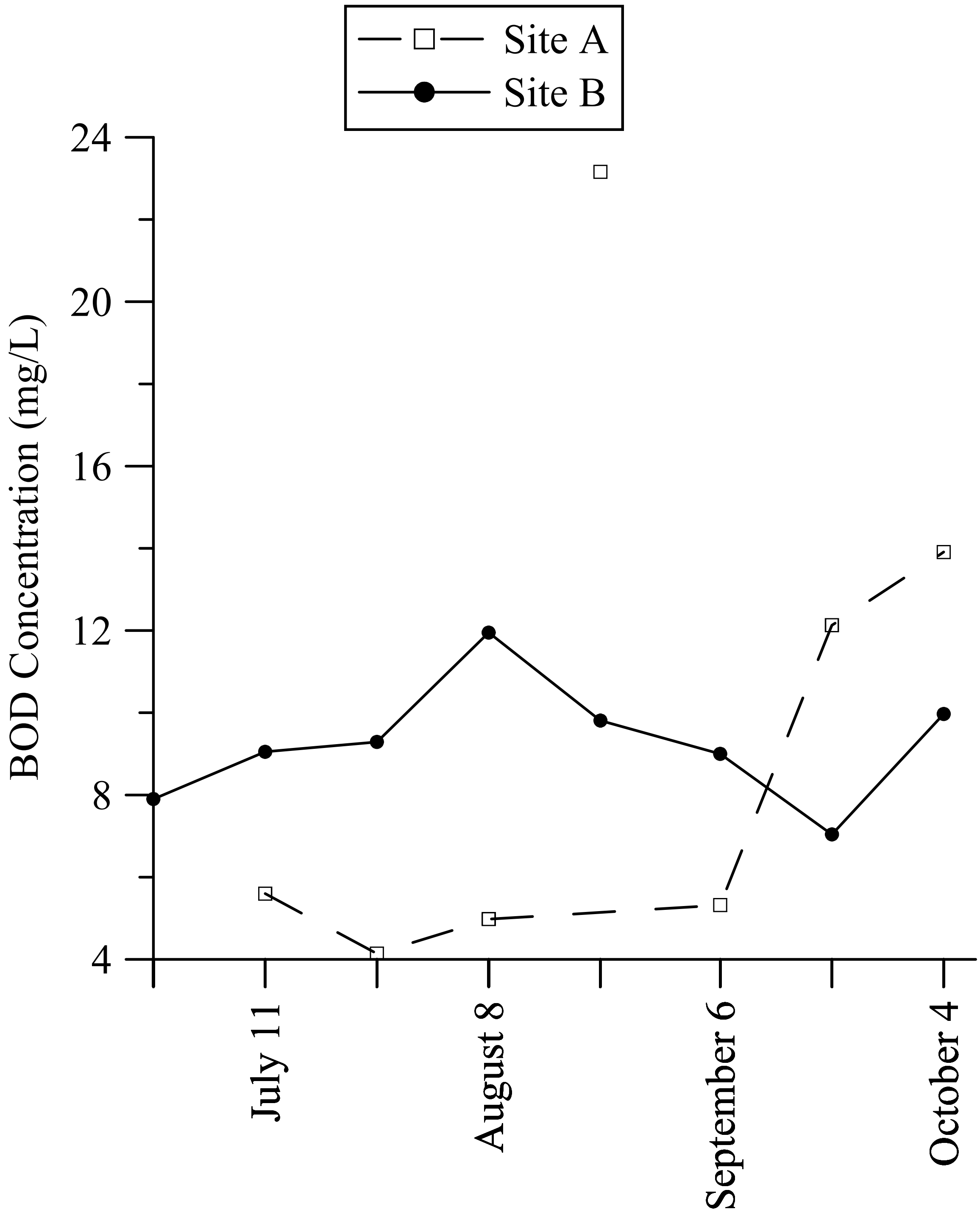


Figure IV-5: Ammonia-nitrogen concentration as a function of time for the influent (Site A) and effluent (Site B) of the Grasslands Bypass Project between June 13th and October 4th, 2001.

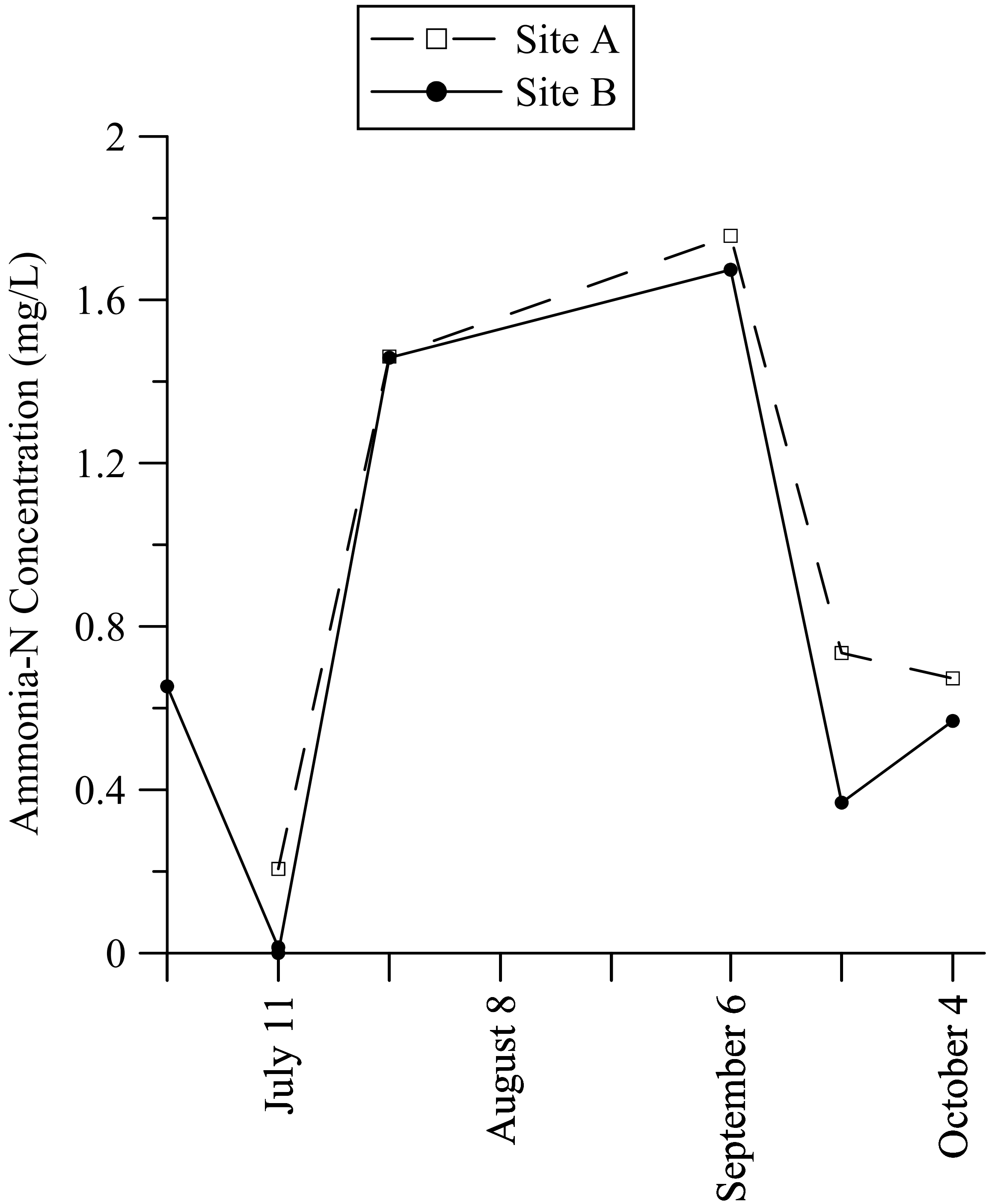


Figure IV-6: Dissolved organic carbon (DOC) concentration as a function of time for the influent (Site A) and effluent (Site B) of the Grasslands Bypass Project between June 13th and October 4th, 2001.

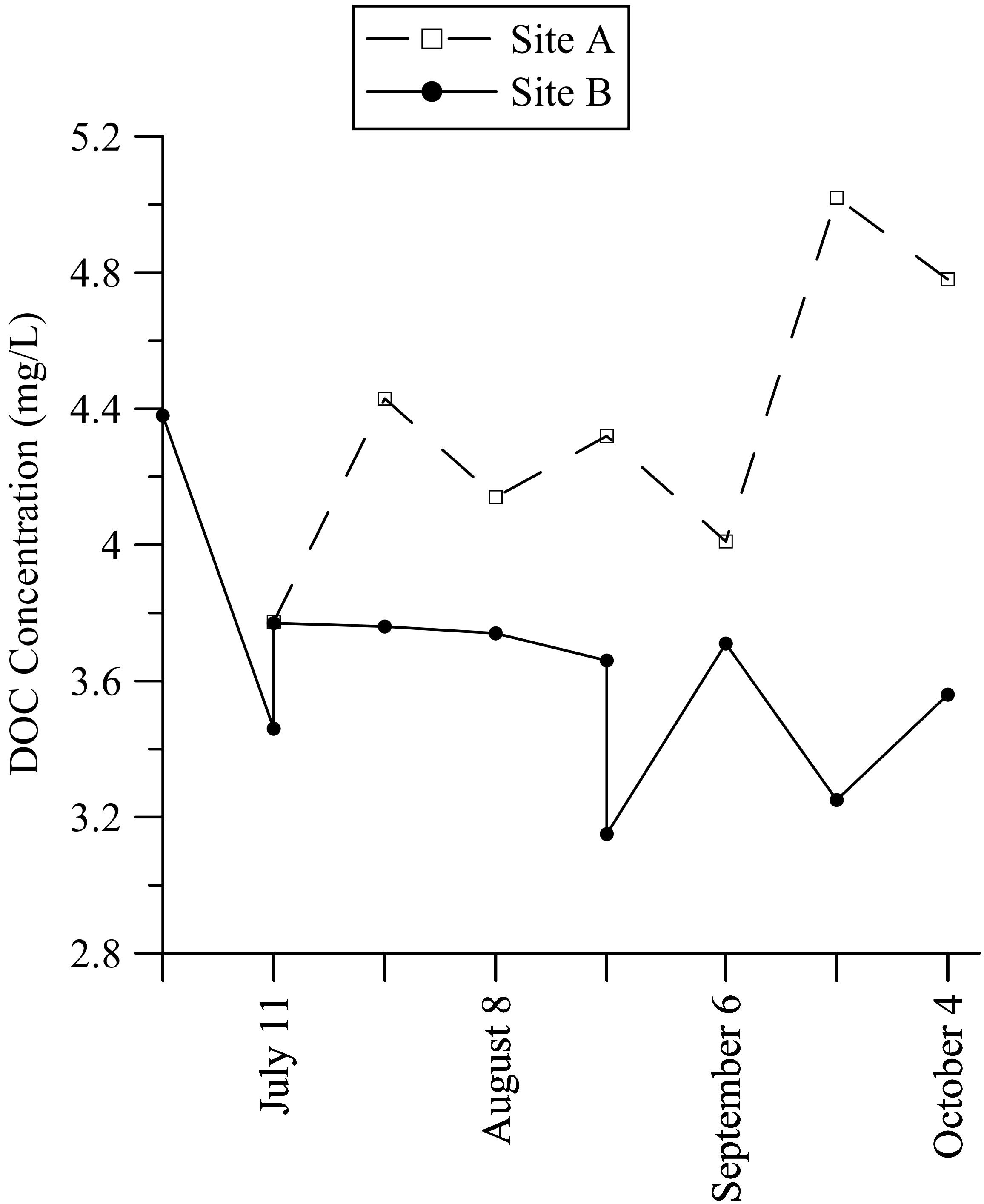


Figure IV-7: Relationship of TOC and BOD_{10} for all data collected between June 13th and October 4th, 2001.

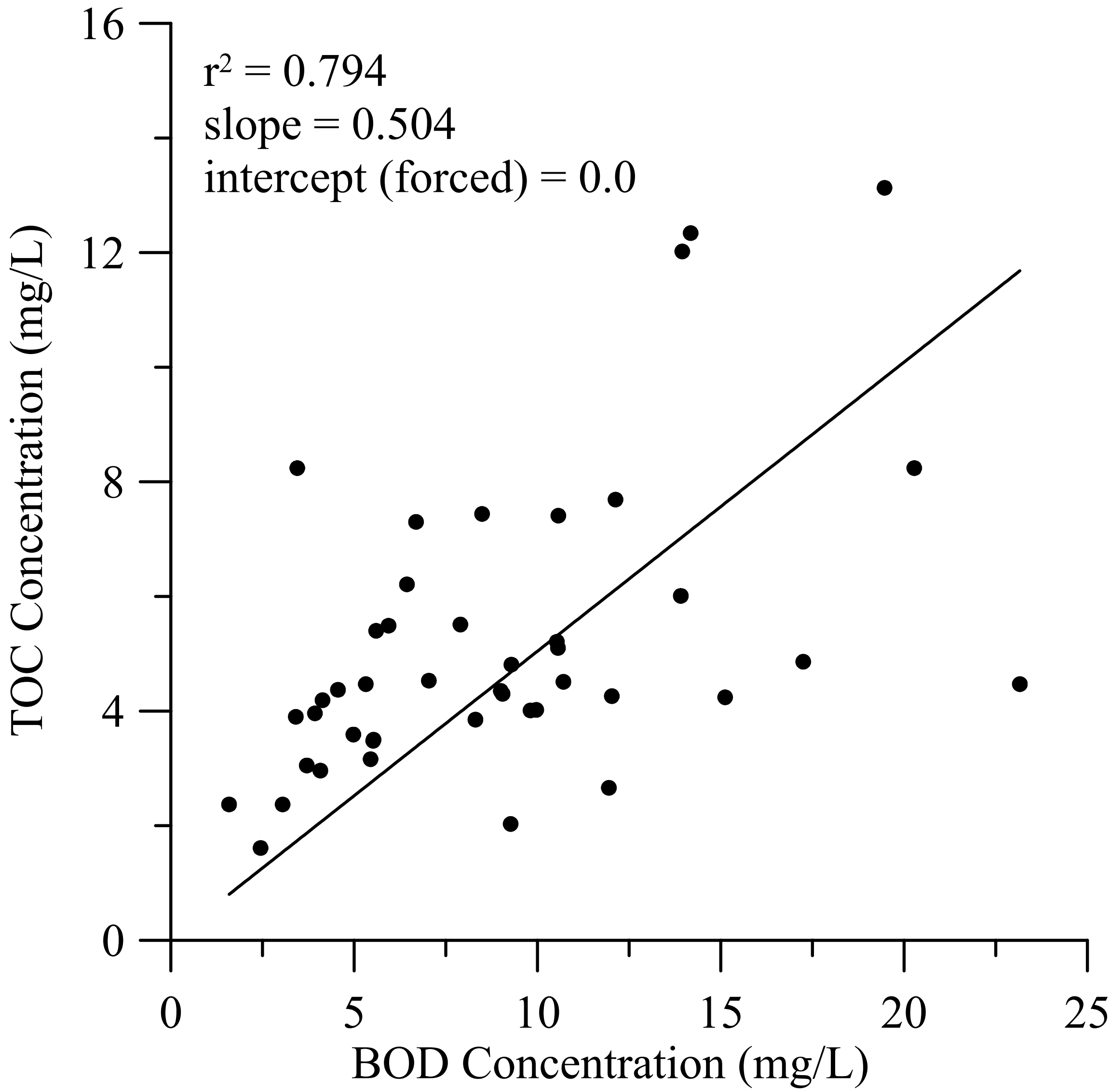
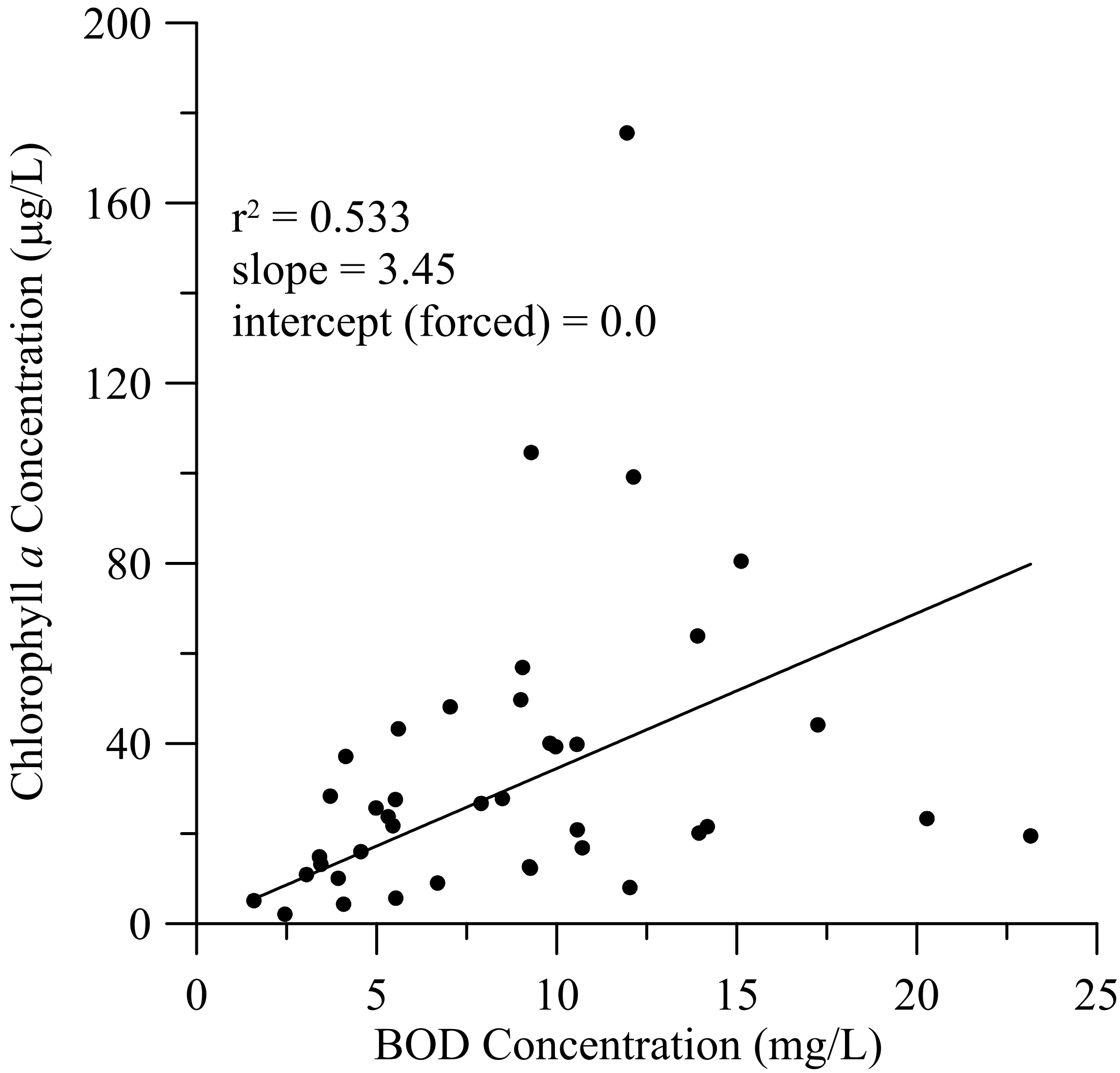


Figure IV-8: Relationship of Chlorophyll *a* and BOD_{10} for all data collected between June 13th and October 4th, 2001.



Section V – Implementation of Results

The SJR DO TAC has determined that in order to resolve the SJR DWSC low-DO problem, better information is needed concerning the sources and types of oxygen demanding material entering the SJR. This study was design to address one of the data gaps identified by the TAC. This study has demonstrated that Salt and Mud Sloughs do contribute significant amounts of BOD to the SJR. We have gathered preliminary information concerning the sources of BOD in the Grassland watershed and have determined that agricultural discharges are an important source of BOD in the region and that wetland drainage has it greatest significance in September and later.

Our analysis of the SLD has suggested a possible approach for controlling BOD production in the region (phosphate precipitation in the SLD). Results of this study suggest that algal growth in the SLD could be phosphate limited. A more complete study is needed to determine if the nutrient limited hypothesis is true. If algal growth is limited by phosphate, then phosphate removal could be used to limit algal production in the drain. Studies should be conducted to determine if coagulants or other methods of phosphate sequestration would be effective and economic at limiting algal production in the drain and thereby limit BOD loading from the watershed.

Section VI – Additional Studies Needed

Algal growth in agricultural drainage is an important source of BOD in the SJR Watershed. Studies are needed to develop a better understanding of algal growth patterns in agricultural drains. The hydraulic configuration of the SLD provides a unique opportunity for conducting well-controlled field experiments examining algal growth in agricultural drainage. Studies should be conducted in the SLD to investigate growth patterns of algae in the drain, determine what conditions limit growth, and to develop rapid methods to survey algal biomass and growth patterns in agricultural drains. Rapid methods (using such approaches as fluorescent measurement) could then be utilized through the SJR watershed to characterize algal production in agricultural drains and to prioritize drains for remedial action.

A better understanding of the relationship between Chlorophyll *a* measurements, algal biomass concentration, and the production of oxygen demanding materials by algae would be valuable for the development of more complete model of oxygen demand in the SJR and the DWSC. Chlorophyll *a* measurements are typically converted to algal biomass using conversion factors that are averages for diverse species under widely varying environmental conditions (Bowie et al. 1985, Vymazal 1995). A more focused study of the types and conditions of algae in agricultural drains, tributaries, and the river would lead to better conversion factors more specific to this region. A better understanding of the specifics of algal BOD production would remove some uncertainty from the TMDL load allocation model.

Sources of drainage in the Salt Slough watershed are not well documented. This watershed drains lands that include wildlife habitat, dairies, fruit crops, vegetable crops, and homes. The importance of this tributary to water quality in the SJR is apparent from this study and other studies (Dubrovsky et al. 1998, Domagalski et al. 2001, Dahlgren 2001, Kratzer and Dileanis 2001). Information available from public sources needs to be compiled and integrated and a BOD sampling plan for the watershed developed.

Changes in water quality that occur in wetlands are usually investigated in the context of using wetlands to treat polluted water. We are not aware of studies investigating changes in water quality that occur when wetlands are supplied with fresh water. The influence of regional wildlife refuges and wetlands to surface and groundwater quality is unknown and deserves further investigation.

A study relating agricultural practices to changes in water quality would be useful to the development of watershed remediation plan. Some concentrated slugs of BOD originate upstream of the SLD (Figure IV-4). The source and composition the BOD releases remains unknown. There is a need for a through study of how different crops and farming practices influence water quality.

Results of this research suggest that modifications of our current TOC analysis would improve the correlation of the TOC and BOD analysis. There is a need to support development of an improved protocol for automated analysis of particulate carbon by the Combustion Method (American Public Health Association 1995). A rapid method for monitoring oxygen demanding materials would allow increased sampling at reduced costs, leading to an improved time resolved analysis of BOD sources in the region.

Improved rapid methods for organic carbon measurement could be combined with analysis of ammonia to give a mechanistic model for calculation of BOD.

Production of an integrated report on the Grasslands Watershed studies would be useful to the development of the TMDL allocation. Data collected by the USGS, UC Davis, and the CVRWQCB should be compiled with the data in this study and reanalyzed to improve our mass balance characterization of the region. This report could be a joint project between LBNL and UC Davis.

Section VII – Conclusions and Recommendations

In this report we have described the results of our investigation of the Salt Slough and Mud Slough drainages of the Grasslands Watershed. This report includes data collected in the watershed between July 11th and October 4th, 2001. The objectives of our research were to identify sources of BOD in the watershed, measure the importance of each source to the total mass of oxygen demanding materials originating in the watershed, and to relate our findings to the water quality conditions observed in the SJR. Additionally, we compared the water quality changes associated with two major water uses in the region: irrigation of agricultural lands and maintenance of managed wetlands for recreational duck hunting.

The Salt Slough Drainage was shown to be an important source of BOD to the SJR. Concentrations of BOD were moderate in Salt Slough compared to other sources in the watershed, but flows were higher, and it is estimated that Salt Slough contributes approximately 20% of the BOD loading observed at Crows Landing on the SJR. The temporal pattern of BOD loading observed in Salt Slough indicates that BOD loading is higher in July than August and September. The cause of this trend is not clear and requires further investigation.

Salt Slough is an important tributary and it recommended that the investigation of Salt Slough be continued and expanded. The influence of the San Luis National Wildlife Refuge on water quality in Salt Slough could not be resolved this year without the flow data from the proposed Wolfsen Road monitoring station. Funding is now available for the installation of this station and station will be available for research next summer. It is important to determine if the seasonal change in BOD concentration and loading observed this year in Salt Slough is typical or unusual. An investigation of land use and drainage sources on Salt Slough up-stream of Wolfsen Road would be the first step in developing a sampling plan for the upper Salt Slough watershed. An expanded water quality survey of the region is needed to differentiate the influence of the wildlife refuge, dairies, and farms in the region on water quality. An expanded survey would provide a foundation for the development of a remediation plan for the area.

Mud Slough was estimated to produce about 16% of the BOD loading observed at Crows Landing on the SJR. In the Mud Slough Watershed, we were able to differentiate drainage coming from two significant land uses in the Grassland Watershed: managed wetlands and agricultural. Wetland drainage had a higher BOD concentration than agricultural drainage, but because the wetland flows were lower, agricultural drainage was a more important source of BOD loading to Mud Slough and the SJR. It is recommended that changes in water quality that occur in wetlands be further investigated. Spring and fall releases of wetland drainage are poorly characterized despite their apparent importance to algal blooms observed in the SJR.

The only important source of agricultural drainage in Mud Slough was the SLD, which conveys drainage as part of the Grasslands Bypass project. An investigation of the SLD revealed that there was prolific seasonal algal growth in the SLD. Corresponding to an increase in algal biomass in the drain was an almost complete disappearance of *ortho*-phosphate. These results lead us to propose the hypothesis that algal growth in the SLD is limited by available phosphate. We recommend that this hypothesis be tested, because if it is true, then we should be able to limit algal growth in the drain by removing or binding available phosphate at the head of the drain.

Finally, it is recommended that the development of a rapid method to supplement or replace BOD analysis be developed and implemented. A rapid analytical technique, based on a chemical rather than biochemical method, is needed to increase the time resolution of oxygen demand measurements for the Grasslands Watershed. A rapid method, applicable to acid or base preserved samples, would allow the use of bottle samplers to collect daily measurements in the region, an improvement over the biweekly sample period now implemented. Increased sample frequency would help resolve trends and identify BOD releases that are less than two weeks in duration.

Section VIII – Acknowledgements

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Section IX – Literature Cited

American Public Health Association. 1995. Standard Methods of the Examination of Water and Wastewater, 19th Edition. American Public Health Association, Washington, DC.

Bowie, G. L., W. B. Mills, D. B. Porcella, *et al.* 1985 (June). Rates, Constants, and Kinetics Formulations in Surface Water Quality Modeling (Second Edition). Office of Research and Development, U. S. Environmental Protection Agency, Athens Georgia. EPA/600/3-85/040.

Brown, R. 2001. Data Summary Report for San Joaquin River Dissolved Oxygen TMDL City of Stockton Year 2000 Field Sampling Program. Jones & Stokes, Sacramento, CA.

Chen, C. W. and W. Tsai. 2001 (June). Improvements and Calibrations of Lower San Joaquin River DO Model. Technical report to the San Joaquin River Dissolved Oxygen Total Maximum Daily Load Technical Advisory Committee.

Chilcott, J., *et al.* 2000. Agricultural drainage contribution to Water Quality in the Grasslands Watershed of Western Merced County, California: October 1997 – September 1998. Regional Water Quality Control Board, Central Valley Region.

Dahlgren, R. 2001. Presentation to the San Joaquin River Dissolved Oxygen Total Maximum Daily Load Technical Advisory Committee, December 18, 2001.

Dileanis, P. 2001. Personal communication concerning results from sampling in the upper San Joaquin River during Summer 2000.

Domagalski, J., Z. Xinquan, L. Chao, *et al.* 2001. Comparative Water-Quality Assessment of the Hai He River Basin in the People's Republic of China and Three Similar Basins in the United States. U. S. Geological Survey Professional Paper 1647, National Water Quality Assessment Program, U. S. Geological Survey, Information Services, Denver, CO.

Dubrovsky, N. M., C. R. Kratzer, L. R. Brown, J. M. Gronberg, and K. R. Burow. 1998. Water Quality in the San Joaquin-Tulare Basins, California, 1992 – 1995. U. S. Geological Survey Circular 1159, National Water Quality Assessment Program, U. S. Geological Survey, Information Services, Denver, CO.

Foe, C. 2001. Presentation to the San Joaquin River Dissolved Oxygen Total Maximum Daily Load Technical Advisory Committee.

Kratzer, C. and P. Dileanis. 2001. Presentation to the San Joaquin River Dissolved Oxygen Total Maximum Daily Load Technical Advisory Committee, December 18, 2001.

Kratzer, C. R., and J. L. Shelton. 1998. Water Quality Assessment of the San Joaquin-Tulare Basins, California: Analysis of Available Data on Nutrients and Suspended Sediments in Surface Water, 1972-1990. U. S. Geological Survey, Sacramento, CA.

Lee, G. F. 2001(July 29). Summary of current knowledge on the SJR DWSC low DO problem. Technical report to the San Joaquin River Dissolved Oxygen Total Maximum Daily Load Steering Committee.

Lehman, P. 2001 (June). The Contribution of Algal Biomass to Oxygen Demand in the San Joaquin River Deep Water Channel. Technical report to the San Joaquin River Dissolved Oxygen Total Maximum Daily Load Technical Advisory Committee.

Lehman, P. and C. Ralston. 2000 (June). The Contribution of Algal Biomass to Oxygen Depletion in the San Joaquin River, 1999. Technical report to the San Joaquin River Dissolved Oxygen Total Maximum Daily Load Technical Advisory Committee.

Quinn, N. W. T. 2001. Real-time water quality management in the San Joaquin River, California. Presented at the ASCE/USCID Joint Meeting, San Luis Obispo, CA July 10 – 13.

Steppan, D., D. J. Werner and R. P. Yeater. 1998. Essential Regression 2. 218. *http://www.geocities.com/SiliconVally/Network/1900/ERPref.html/*.

Stringfellow, W. T. and N. W. T. Quinn. 2001. Presentation to the San Joaquin River Dissolved Oxygen Total Maximum Daily Load Technical Advisory Committee, December 18, 2001.

Tochobanoglous, G., and F. L. Burton. 1991. *Wastewater Engineering: Treatment, Disposal, and Reuse*. 3rd ed. Metcalf & Eddy Inc. New York: McGraw-Hill Publishing Co.

U. S. Bureau of Reclamation. 1991. San Luis Drainage Program Central Valley Project, California, Draft Environmental Impact Statement. U. S. Department of the Interior, Bureau of Reclamation, Sacramento, CA.

Vymazal, J. 1995. Algae and Elemental Cycling in Wetlands. Lewis Publishers, Boca Raton, FL.

Young, B., *et al.* 1999. Grassland Bypass Project Annual Report 1998-1999. U. S. Bureau of Reclamation, Sacramento, CA.