RECLAMATION
Managing Water in the West

Effects of Jet Grouting on Wetland Invertebrates at Mormon Island Auxiliary Dam, Folsom, California

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

December 2007

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Effects of Jet Grouting on Wetland Invertebrates at Mormon Island Auxiliary Dam, Folsom, California

Prepared by:

S. Mark Nelson
Research Aquatic Biologist

Gregory Reed
Natural Resources Specialist

Prepared for:

Central California Area Office
Folsom, California

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

December 2007

Contents

Tables

Figures

Executive Summary

A jet grouting test section was undertaken at the Mormon Island Auxiliary Dam (MIAD) during the spring and summer of 2007, and monitoring was undertaken at a nearby wetland complex. Results from pH measurements suggested there were no increases in pH coincident with jet grouting activities, and there were no detected impacts to aquatic invertebrates in wetlands adjacent to MIAD.

Introduction

Mormon Island Auxiliary Dam (MIAD) is a 110 ft/33m high earthfill dam that helps to impound the American River and form Folsom Lake near Sacramento, California. Because of the potential for seismic activity in the area, the dam foundation was modified in the 1990s to limit seismic deformations. Additional strengthening of the dam foundation is needed, and it has been suggested that jet grouting might achieve this purpose. This technique involves injecting cement grout into the soil (maximum depth to 70 ft/21 m) to form a series of grout columns which modify the physical properties of the existing soils. Injection of the material is under high pressures and uses large volumes of cement grout. While most of the excess material flows up to the surface where it is contained, it is possible that some of this alkaline cement compound might impact local geochemistry through the release of calcium hydroxide and cause increases in groundwater/surface water pH and allow for increased alkalinity. Alkalinity is a measure of the ability of water to buffer or resist acidity, while pH is a measurement of whether water is acidic or basic. Often these two measures are closely related. There is some evidence in the literature that placement of alkali materials in soils can alter water quality. Murarka et al. 2002 observed increases in surface water alkalinity in a case where coal ash was used to fill a mine pit in Indiana, and similar processes could occur with jet grouting. The purpose of the jet grouting test section was to investigate the viability of the procedure for producing adequate foundation improvement and to test for potential environmental impacts.

Extremely alkaline groundwater is rare in nature and is most often associated with human activities (Roadcap et al. 2005). Water altered in this manner may have profound effects on environments as observed in wetland complexes along Lake Michigan affected by high pH (Roadcap et al. 2005). Analyses of wetlands impacted by high pH limestone quarry water showed large differences in wetland plants between impacted and reference wetlands (Mayes et al. 2005). Laboratory studies of high pH water have demonstrated varying responses from macroinvertebrates; pH increased to $\geq$ 10 had no discernible impact to the midge, *Chironomus*, while the amphipod, *Hyalella azteca,* had survival decreased by ca. 50 percent after 4 days of exposure (Yee et al. 2000).

Extensive wetland areas exist immediately adjacent and downslope to the jet grouting operations at MIAD (ca. within 1,131 ft/345 m). Local resource agencies as well as Bureau of Reclamation (Reclamation) personnel have expressed concern that some harm to aquatic macroinvertebrate assemblages may occur from high pH water entering the wetlands during jet grouting. This paper reports on surface and groundwater monitoring for pH at sites associated with the wetland area and on aquatic invertebrate monitoring. Water chemistry monitoring was designed to determine if changes in pH at wetland sites occurred during jet grouting. Aquatic macroinvertebrates were sampled both before and during jet grouting to determine whether assemblages were altered in association with grouting activities. To avoid confounding jet grouting impacts with natural changes in macroinvertebrate assemblages over time, reference wetlands were also sampled to control for temporal variation. We assumed that impacts would be acute and observable in a short period of time.

Methods

The basic study design goal was to estimate changes at the MIAD wetland site resulting from jet grouting operations. It should be noted that this jet grouting operation is not replicated and therefore all data for this study of jet grouting impacts are psuedo-replicated. The ability to detect differences caused by an impact at a site may be affected by temporal variation in communities and therefore reference sites were utilized to allow for some confidence in results. It was assumed that temporal variability would be similar between MIAD and reference sites, thus allowing for detection of changes at MIAD from jet grouting impacts. Long-term and frequent water monitoring for pH occurred only at the MIAD site and was used to regulate the grouting operation. The U.S. Environmental Protection Agency's current pH criterion for the protection of freshwater aquatic life (USEPA 1986, 2006) defines an acceptable ambient pH range (i.e., 6.5 to 9.0), and this range was used as a goal during monitoring activities. This criterion does not limit the magnitude of rapid change that organisms can be exposed to within this range, suggesting that the effects of rapid pH changes are insignificant when pH is maintained within the acceptable ambient range. These pH data are provided here as support for conclusions, but cannot be compared to reference sites for discrimination of temporal effects.

Site Locations

The spatial relationship between the three groups of sites [Mormon Island (MI), Maximus (MX), and Willow Creek (WC)] is presented in Figure 1. Sites at the MI complex are shown in Figure 2. MI-1 and MI-2 were closest, and MI-8, MI-9, and MI-10 furthest from the dam. MI-2 and MI-6 were in drainage ditch environments while MI-8, MI-9, and MI-10 appeared to be artificial pools created from historic dam building borrow pits (Sutter and Francisco 1998). Other MI sites were associated with swale areas (MI-1 and MI-7) or vernal pools (MI-3, MI-4, and MI-5). Sites that were given the MX code were found along Willow Creek and were largely located in the flood plain portion of the creek (Figure 3). There was direct interaction between the lotic creek environment and wetlands lateral to the creek. MX-4 differed somewhat from the other MX sites in that a drain from an industrial property entered the creek at that point, creating a slow moving slough type of environment. Willow Creek sites (Figure 4) were found at the Willow Creek State Recreational Area (Willow Creek SRA), and although they varied in surface area and depth, it appeared that all were relatively small artificial wetlands that may have been associated with historic mining/dredging activity.

Hydrology of the wetland areas likely differed, with flood plain wetlands at MX and swale type environments at MI probably containing water for a large part of the year.

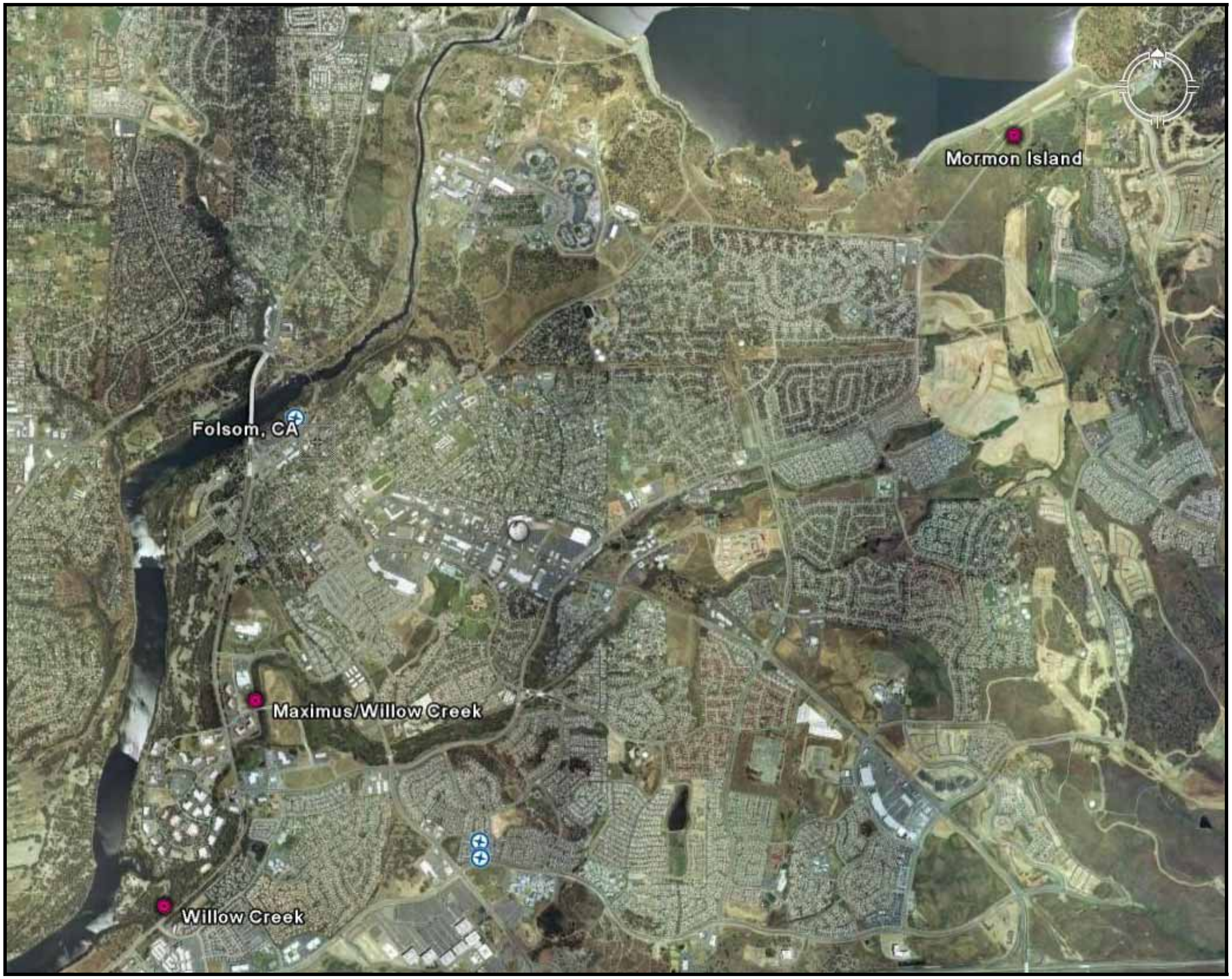

Figure 1. Relative positions of the three groups of sites. MI sites were potentially exposed to jet grouting impacts, while other sites (MX and WC) were considered to be reference wetlands.

Figure 2. MI sites.

Figure 3. MX sites.

Figure 4. WC sites.

Many of the wetlands at MI and WC may have been vernal, filling with water during the winter rains and drying out during the early summer.

Long-term Monitoring for pH

Monitoring of pH took place at MI-3 and MI-7 surface water locations and at two wells that were upslope of the wetlands just below MIAD. Sampling took place on a near daily basis starting on May 23, 2007, during jet grouting operations and ended on August 8 for surface water samples (sites were dry at this time) and September 7 for groundwater wells. The pH in groundwater wells was measured at 30 ft/9 m depth. Meters were calibrated on a weekly basis using the appropriate standards.

Macroinvertebrate Monitoring

Samples were collected before (February 2007) and about 1 month after initiation of jet grouting (June 2007). Samples were collected at 10 sites associated with MIAD that had the potential to be affected by jet grouting and 10 reference sites. Reference sites were palustrine emergent wetlands selected because of gross similarities in vegetation, structure, and flow to MIAD sites, however none of the sites would be considered pristine. Sampling took place at the same 20 sites on each occasion (drought conditions impacted June sampling and resulted in a decreased number of sites) so that they were linked through time. Locations are presented in Figures 1 to 4 with the codes MI referring to MIAD associated wetlands and MX and WC referring to reference wetlands near the Maximus building and the Willow Creek SRA.

Aquatic invertebrates were collected with a D-frame net over a 1-minute period. Biotic samples were preserved in alcohol and shipped back to the Technical Service Center laboratory for processing. Other collected variables included dissolved oxygen, conductivity, pH, and temperature as measured with a portable meter. Water samples for alkalinity and hardness were analyzed using titration methods. Estimates of detritus, percent plant cover, sampling depth, vegetation height, and vegetation type were also obtained at each site.

Data Analysis for pH Monitoring

Data were presented as means and ranges. There was no long-term pH data collected before the jet grouting activity was initiated. The main goal from these data was to ensure that pH values did not increase to the point where wetland biota were impacted (pH > 9.0).

Data Analysis for Macroinvertebrate Monitoring

Paired *t*-tests were used to determine whether significant differences in taxa richness occurred from before to during jet grouting activities. Sites at Mormon Island (MI-1 to MI-10) were randomly paired with other reference sites in the Folsom area (MX and WC sites) and number of taxa subtracted from the number of taxa at the reference sites. It was assumed that impacted MI sites would have reduced taxa richness after initiation of jet grout treatment and that this treatment would not impact reference sites that were spatially unassociated with jet grouting. A paired *t*-test was then used to compare data before and during jet grouting. The alternative hypothesis was that differences in site pairs would be higher in February than in June, therefore leading to a value different than zero and suggesting occurrence of a negative impact between the two periods. In some cases richness measures may be ineffective in detecting impacts because of replacement of sensitive species by tolerant species. We therefore also used ordination to determine whether there were changes in macroinvertebrate assemblages that might potentially be associated with grouting impacts. Paired *t*-tests were also used to compare differences in water quality data between months. In these cases individual sites from the two different months were paired.

Ordination techniques were used to examine patterns in the macroinvertebrate data, and to identify physical and chemical variables that were most closely associated with invertebrate distributions. Initial analysis of the macroinvertebrate data set used detrended correspondence analysis, and revealed that the data set had a gradient length > 3, suggesting that unimodal models were appropriate for analysis. Therefore, canonical correspondence analysis (CCA) was used for direct gradient analysis. Faunal data were transformed (square root transformation) before analysis. Forward selection of environmental variables and Monte Carlo permutations were used to determine whether variables exerted a significant effect on invertebrate distributions. If environmental variables were strongly correlated (Pearson correlation, $r \geq |0.6|$), only a single variable was selected for use in CCA to avoid problems with multicollinearity. Environmental variables were normalized [(ln(X+1)) or arcsin squareroot transformation for percentage data] if the Shapiro-Wilk Test indicated the necessity for this transformation. In the ordination diagram, taxa and sites are represented by geometric points and the environmental variables by arrows. The arrows roughly orient in the direction of maximum variation of the given variable, and the length of the arrow indicates how much influence a given environmental variable has on macroinvertebrate data. Perpendicular lines drawn from an arrow to macroinvertebrate taxon points determine the relative position of that taxon along the environmental axis.

Results

Jet grouting along the downstream toe of MIAD started on May 17, 2007. This initial activity ended on May 28 but was resumed from June 11 to 15 and June 18 to 20. Aquatic macroinvertebrates were collected on February 6 and 7 and then again on June 12 and 13. Sampling of macroinvertebrates in June was a compromise between allowing enough time for potentially impacted water to reach the wetlands and sampling before rapidly drying pools were lost for the season. Final sampling occurred several weeks after jet grouting initiation and during a period while it was still ongoing.

Long-term monitoring of pH suggested that there were no large deleterious increases in pH that occurred while jet grouting. Values for pH at MI-3 averaged 6.86 and ranged from 6.26 to 7.71 (n=90) while those at MI-7 averaged 7.06 and ranged from 6.63 to 7.65 (n=77). Overall, pH in groundwater wells ranged from 5.80 to 7.43. Averages for pH at the two wells were 6.98 (n=113) and 6.69 (n=114), respectively. Figure 5 shows pH data for the sampling period and suggests that values did not even reach a pH of 8 in either surface water (MI-3 and MI-7) or groundwater (GRND-1 and GRND-2) at any time during or following the jet grouting process.

Environmental variables from the various wetland sites are presented in Table 1. There were differences in hardness between groups of sites, with alkalinity and hardness generally lower at MX compared to WC sites (Table 1). Water quality values ranged widely at the MI complex (Table 1). In general, conditions at MX appeared to be more stable than at other sites with, for example, maximum ranges in conductivity at given MI and WC sites of around 100 µS/cm, while the maximum range at MX sites was 30 µS/cm. This also, by and large, appeared to be the case for alkalinity and hardness measurements. Others have noted that concentrations of dissolved substances vary more widely in temporary waters than in most permanent waters (Williams 2005) such as the perennial flood plain sites at MX. With the exception of MX sites, all sites decreased in wetted area (pers. obs.) between February and June. Three sites were totally without

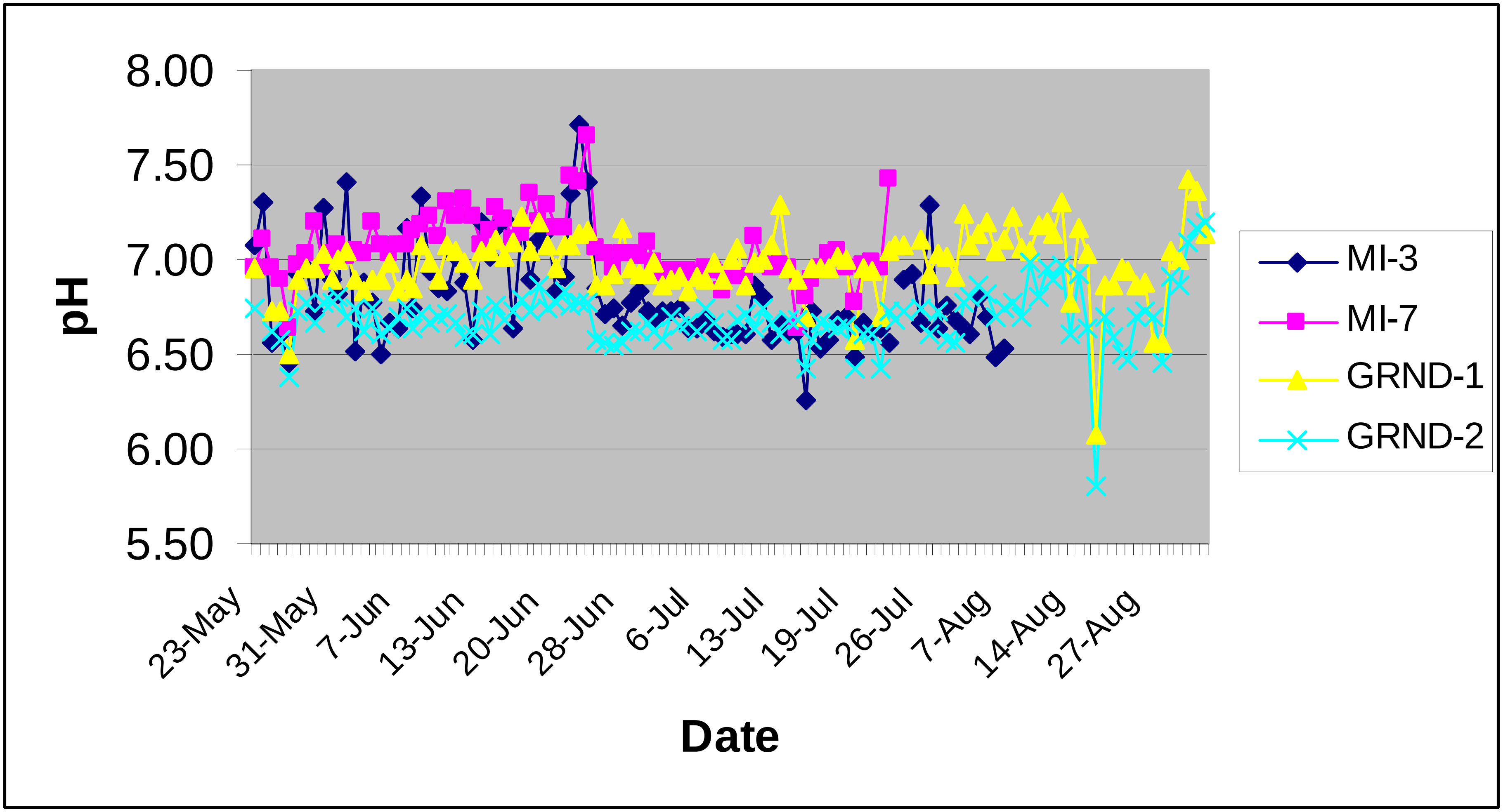

Figure 5. Patterns in pH at surface water (MI-3 and MI-7)) and groundwater (GRND-1 and GRDN-2) MIAD sites.

Table 1. Environmental variables measured at wetland sites near Folsom, California

Site	DO (mg/L)-surface	DO (mg/L)-bottom	Cond. (uS/cm)	Temp (oC)	pH	Veg height (m)	Cover (%)	Detritus volume (ml)	Depth (m)	Alkalinity (mg/L)	Hardness (mg/L)
MI-1	3.54-4.99	3.54-4.99	172-175	14.24-16.7	7.02-7.4	1.3-2.0	90	50-400	0.1	62-67	23-24
MI-2	3.85-6.61	3.85-6.61	150-186	8.54-21.01	6.57-7.05	1.5-1.6	100	20-500	0.05	56-70	49-62
MI-3	2.14-5.9	1.22-1.76	169-173	8.9-19.45	6.51-6.74	0.2-0.9	70-100	300-1200	0.5-0.6	63-85	25-28
MI-4[a]	9.4	7.47	216	11	6.9	0.2	50	800	0.2	53	50
MI-5[a]	7.7	7.7	216	12.4	6.92	0.7	60	250	0.1	49	50
MI-6	2.91-5.7	2.91-5.6	174-183	7.6-20.26	6.5-6.98	1.5-2.0	40-75	60-900	0.2-0.3	68-74	28-31
MI-7	1.53-9.14	1.53-9.14	318-360	9.91-24.5	6.6-6.81	3-4	50	125-500	0.05-0.1	89-95	30-52
MI-8	9.47-14.4	7.5-10.2	464-564	9.4-27.7	6.8-7.3	0	0-100	0-900	0.30-0.35	123-142	138-148
MI-9	5.3-12.4	2.36-8.5	389-447	9.8-22.3	6.45-6.6	0	0-50	200-1000	0.35-0.45	126-137	105-137
MI-10	3.4-4.05	3.81-4.15	483-505	9-20.07	6.5-6.6	0-0.1	0-50	500-700	0.3-0.6	147-162	156-183
MX-1	2.3-6.1	2.3-6.1	239-269	10.9-19.6	6.95-7.12	0.8-1.0	80-100	20-125	0.05	87-89	97-143
MX-2	4.41-6.3	4.40-6.3	235-263	10.22-19.88	7.07-7.34	1.5-1.9	85-100	50-250	0.05	85-90	94-101
MX-3	5.15-8.13	5.15-8.13	235-262	11.51-19.75	7.12-7.38	1.7-2.0	95-100	125-500	0.05-0.4	87-93	98-99
MX-4	4.06-7.83	5.06-6.23	217-236	12.14-19-32	6.94-7.17	1.4-2.2	90-100	375-750	0.3	72-77	79-81
WC-1	1.64-3.8	1.64-5.3	286-377	9.1-20.04	6.52-6.81	0.0-0.3	30-40	1200-2000	0.2-0.3	107-117	115-117
WC-2	0.28-5.03	0.28-5.03	274-331	12.86-21.47	6.60-6.63	0.0-0.5	70-100	125-1500	0.05-0.2	116-131	119-133
WC-3	0.54-3.51	0.54-2.01	433-531	10.57-20.18	6.61-6.97	0.0-0.6	20-50	200-1000	0.20-0.25	177-206	164-200
WC-4	1.1-1.97	1.1-2.14	436-487	7.62-18.54	6.7-7.06	0.7-2.0	50-75	250-750	0.20.4	188-205	175-210
WC-5	2.8-7.3	2.16-7.3	359-405	11.37-21.3	6.67-7.65	0.2-0.6	30-35	10-1000	0.02-0.25	148-178	146-178
WC-6[a]	3.72	3.46	423	9.23	7.09	0	10	1000	0.3	175	177

water, MI-4, MI-5, and WC-6. Paired *t*-tests with pH data from February and June at MI sites indicated that there were significant differences in pH between the two dates (T=-2.89, p=0.0233). However, this was also the case with reference sites (T=-3.52, p=0.0078). It appeared that pH increased at all sites in June when compared to February (Figure 6).

Vegetation such as cattails (*Typha* sp.) were found at a most of the sites. Other emergent plants such as bulrush (*Schoenoplectus* sp.), sedges (*Cyperus* sp.), and spikerush (*Eleocharis* sp.) were more commonly observed at MX and WC locations than they were at MI sites.

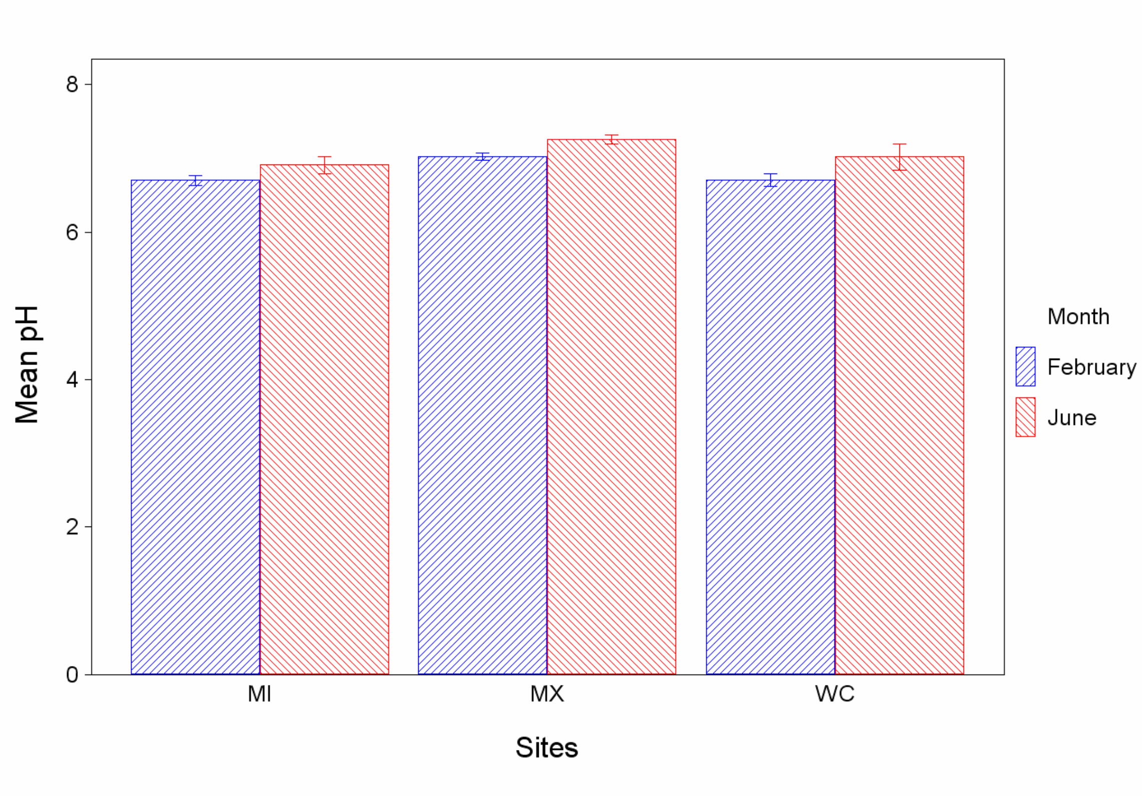

Figure 6. Mean pH values from wetland sampling in February and March. Variance is represented as standard error.

Folsom wetland sites contained 105 different macroinvertebrate taxa during the two sampling periods (Appendix A). Only sites that contained water in June were used in the taxa richness analysis, resulting in a decrease to eight pairs of sites used in the analysis. Sites from reference and MI locations were randomly paired together and differences in taxa richness between the pairs calculated for February and June. The 1-tailed test resulted in a P value of 0.5592 (T= -0.15) suggesting that there were no pairwise differences between divergences in taxa richness values before and during grouting at the MI sites. A simple graph comparing mean values at each group of sites supports the paired *t*-test results (Figure 7). We also present a graph of abundance which suggests similar abundance at MI sites between the two periods (Figure 8).

Results of CCA analysis had eigenvalues of 0.436 and 0.367 for the first two axes and explained 13.7 percent of the species data variation and 47.6 percent of the species-environment relation. Initial environmental variables used in the model included percent cover, conductivity, depth, dissolved oxygen at the surface, detritus, pH, temperature, and vegetation height. Other variables were not used because of high (r>0.6, p<0.05) significant correlations with other model variables. Variables found to be significant in the model were dissolved oxygen, percent cover, conductivity, depth, vegetation height, and temperature. The weighted correlation matrix showing the relationship between species axes and significant environmental variables is presented in Table 2. The water quality indicator of concern in this study, pH, was not a significant variable (p=0.1738) in this model. Water temperature and depth were largely associated with the positive portion

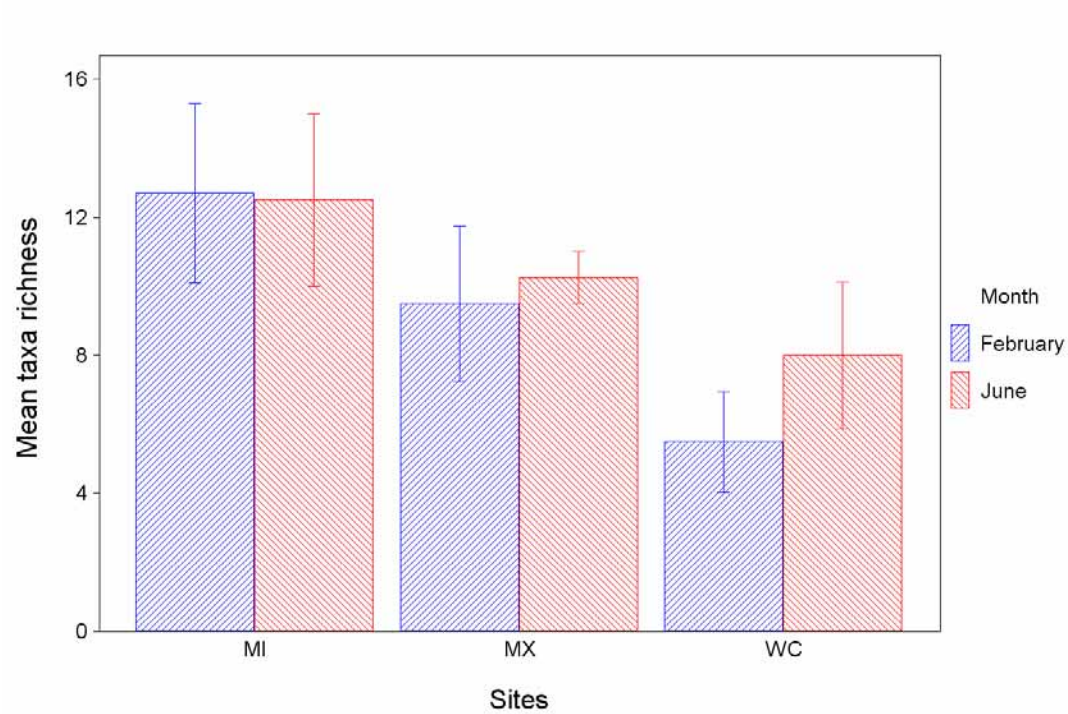

Figure 7. Mean taxa richness at groups of sites in February and June. Variance is represented as standard error.

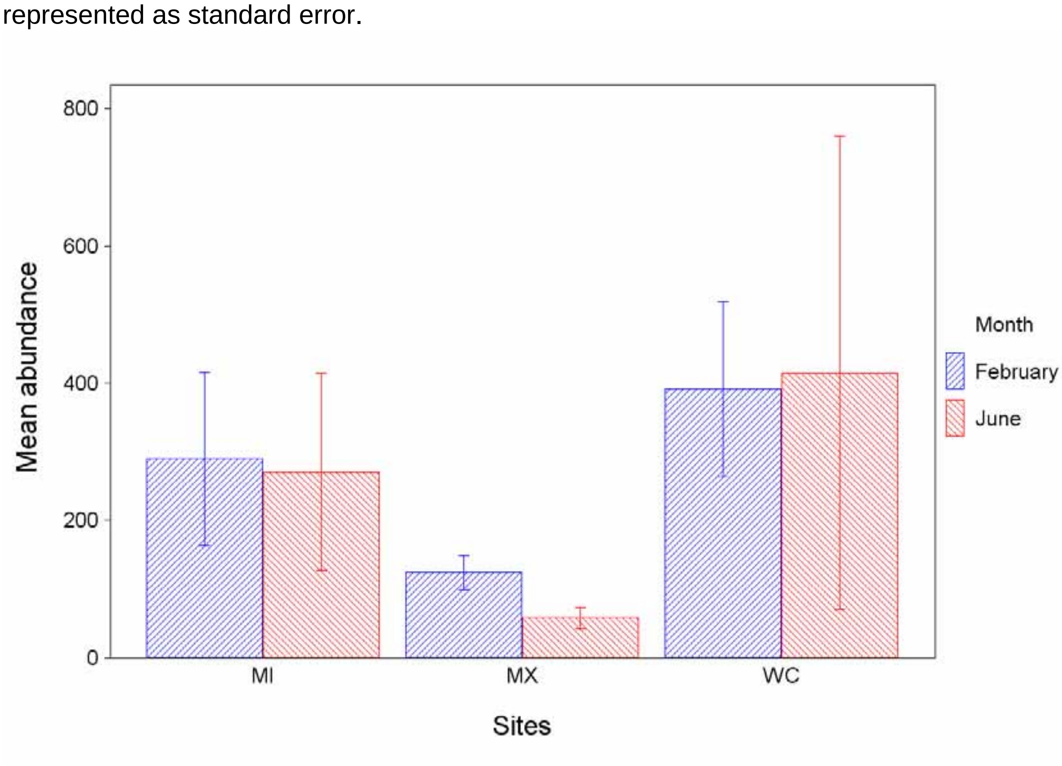

Figure 8. Mean invertebrate abundance at groups of wetland sites in February and June. Variance is represented as standard error.

Table 2. Weighted correlation matrix showing relationship between species axes and environmental variables. High correlations associated with a given variable are shown in **bold.**

Variable	Axis			
	1	2	3	4
Dissolved oxygen-surface	**-0.3545**	-0.2663	-0.2791	0.1978
% cover	-0.0040	**0.7088**	0.0152	0.4326
Conductivity	**0.6086**	-0.5880	0.0598	-0.1099
Depth	**0.2931**	0.1214	-0.2674	-0.0572
Vegetation height	-0.2332	**0.5290**	0.0202	-0.4351
Water temperature	0.3929	0.0394	**-0.4809**	0.3002

of the first axis (Figure 9, Table 2) (water temperature was most highly correlated with Axis 3 which is not presented in the figure). Dissolved oxygen was negatively associated with Axis 1 (Figure 9). Conductivity was almost equally weighted along Axis I and Axis II (Table 2).

Paired *t*-tests suggested that water temperature changed with season at sites, and there were significant differences between February and June ($T= -13.20$, $p<0.0001$) temperatures. Average February temperatures were 10.3 $\pm$ SE 0.4 ^{o}C, while in June temperatures averaged 20.7 $\pm$ SE 0.6 ^{o}C. Other variables associated with the positive portion of Axis 1 did not appear to differ with sampling occasion, and no significant differences were found using paired *t*-tests (depth, $T=2.06$, $p=0.0558$ and conductivity, $T=0.31$, $p=0.7620$). These two variables were likely associated with intrinsic site differences rather than season.

Organisms that appeared to be associated with seasonal patterns included *Cyzicus californicus*, an endemic crustacean associated with vernal pools and found in Figure 9 in the negative portion of Axis I. This species and members of the Class Ostracoda were mostly associated with MI-4 and MI-5 locations that were dried by the second sampling occasion in June. *Tropisternus lateralis* was associated with the positive portion of Axis I, and abundance of this single generation beetle has been found to peak in June in other California studies (Zalom et al. 1980). The mayfly, *Callibaetis*, has also been found to increase in abundance in ephemeral ponds over time (Moorhead et al. 1998), and this may partially explain its presence in the extremely positive portion of Axis I. Several midges (e.g., *Chaetocladius, Limnophyes*, *Micropsectra*, *Psectrocladius*, and *Psectrotanypus*) appeared to be important in the diagram and may be associated with hydroperiod. In a study of prairie ponds, Driver (1977) found *Pscetrotanypus* to be characteristic of semi-permanent ponds, similar to those in the present study. This genus was most common at MI-7, MI-8, MI-9, WC-1, and WC-5 in June. It appeared that seasonal differences were related both to wetlands having different hydroperiods and the natural history phenology of some invertebrates. The documented (Yee et al. 2000) high-pH sensitive organism, *Hyalella azteca,* was present in MI-3 and MI-6 in February (4 and 13 individuals, respectively) and in MI-3, MI-6, and MI-7 (90, 2, and 2 individuals, respectively) in June, also providing evidence that differences in assemblages between sampling periods were caused by something other than jet grouting impacts.

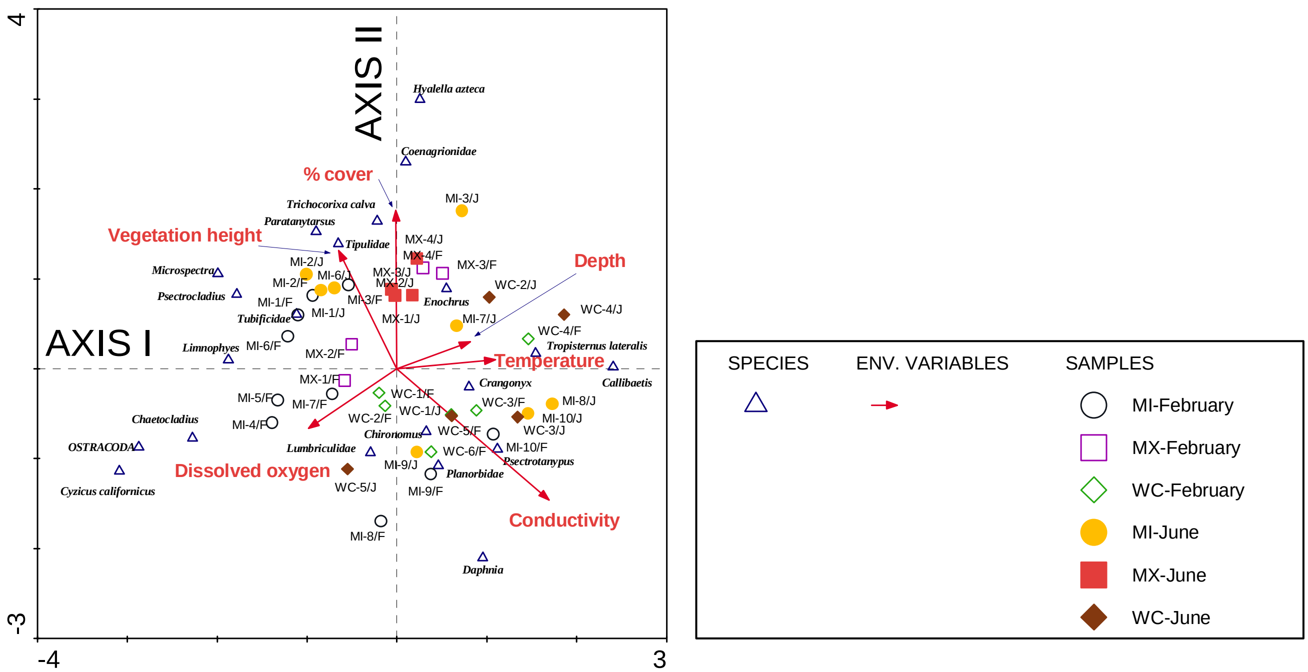

Figure 9. Taxon conditional triplot based on a CCA of wetland macroinvertebrate data with respect to environmental variables. Taxa are represented as small triangles. Only taxa whose fit to the diagram is > 5 percent are shown.

The second CCA axis appeared to be largely vegetation associated, with percent cover and vegetation height located high in the positive portion of Axis II (Figure 9). *Hyalella azteca* was located in Figure 9 high on Axis II. Edwards and Cowell (1992) found *H. azteca* densities associated with larger emergent macrophyte densities in a Florida lake and suggested that there were greater amphipod food resources and refuge from fish predators at these locations. In the present study it appeared that highest abundance of *H. azteca* was found at sites with highest percent cover which was sometimes associated with emergent vegetation. *Daphnia* were in the highly negative portion of Axis II (Figure 9) and, in some studies, this genus has been found to prefer more pelagic environments and to avoid areas with dense plants (Meerhoff et al. 2006). Burks et al. (2001) also found decreased *Daphnia* densities with increasing macrophyte density, and reported a relationship between the presence of odonates and declines in *Daphnia* density. Odonates in the family Coenagrionidae were found in the CCA diagram high on Axis II and were associated with increased vegetation height and percent cover and were opposite of the sites containing the highest abundance of *Daphnia*. There also appeared to be a difference in wetland types along Axis II with flood plain wetlands at MX sites along with drainage ditch and swale-type wetlands (MI-1, MI-2, and MI-6) found high on Axis II while the more semi-permanent pond sites at MI and WC were found low on Axis II in association with higher conductivities.

Sites from the various locations tended to be mixed together, although there was some tendency for MX sites to cluster together. It did not appear that differences in macroinvertebrate assemblages along either Axis I or Axis II were associated with grouting activities and pH was not a significant variable in the model.

Discussion

Construction activities involving jet grouting did not seem to impact either surface or groundwater pH chemistry. Increased pH values from February to June appeared to be related to temporal patterns that occurred regionally. In a study of the impact of grouting on groundwater in the City of Berlin, Eiswirth et al. (1999) detected no significant changes in groundwater chemistry. This was in a highly porous aquifer, and it was suggested that NaOH, which leached out of the grout, quickly became immobile through buffering reactions with the groundwater. Impacts of jet grouting on water chemistry at MIAD also appear to be limited in extent.

While changes in macroinvertebrate taxa richness were not detected, there were some changes in the makeup of macroinvertebrate assemblages between sampling periods; however, these were likely associated with natural seasonal changes, and pH was not a significant variable in the CCA model. Aside from seasonal changes, macroinvertebrate assemblages, in large part, were associated with wetland characteristics that were independent of jet grouting activities such as dissolved oxygen, vegetation height, and percent cover. Spatial and temporal variability in wetland macroinvertebrate assemblages among the 20 study sites was likely unaffected by jet grouting, but instead merely a response to natural environmental factors along with life history patterns. High alkalinity wetlands in Wisconsin were found to contain characteristic taxa which included isopods, physid snails, and pygmy backswimmers (Pleidae) (Lillie 2003). This sort of assemblage was not found in wetlands at the MIAD and along with the presence of taxa sensitive to high pH suggests a lack of jet grouting impacts.

We believe that the absence of a detectable effect of jet grouting on macroinvertebrates likely reflects the lack of short-term biologically meaningful impacts to this nearby potential environmental stressor. It might be anticipated that some wetland types would be unaffected by altered groundwater chemistry. Vernal wetlands might not be expected to be affected by localized groundwater impacts because of the typically limited exchange with those water sources (e.g., Hanes and Stromberg 1998). Direct precipitation is usually the dominant source of water in this type of wetland (Hanes and Stromberg 1998). However, jet grouting with large amounts of water and pressure could result in the development of a hydraulic gradient that moves toward wetlands that are lower in the landscape, and there are a variety of types of wetlands at MIAD. The assumption in this discussion is that changes in macroinvertebrate assemblages could be observed during this initial impact, if one occurred. Further sampling would be needed if it was expected that impacts would occur upon refilling of wetlands during the winter months. Typically, the types of stressors that exhibit lagged responses are long-term stressors that result in habitat fragmentation and restricted movement between populations of species (e.g., Findlay and Bourdages 2000). These sorts of stressors may not be detectable during short timeframes. It seems unlikely that jet grouting, in the way it was used at MIAD, would result in this type of response. However, monitoring should be extended to ensure this is the case.

Acknowledgments

We thank Deb Martin (Entrix) for accompanying us in the field. Sampling was performed under permit with the California Department of Fish and Game (SC-009310), Reclamation's Dam Safety Program provided funding. We'd also like to thank Shawn Oliver (Central California Area Office - Folsom) for his reviews and tireless support of the project.

Literature

Burks, R.L., E. Jeppesen, and D.M. Lodge. 2001. Pelagic prey and benthic predators: impact of odonate predation on *Daphnia*. J. N. Am. Benthol. Soc. 20(4):615-628.

Driver, E.A. 1977. Chironomid communities in small prairie ponds: some characteristics and controls. Freshwater Biology 7:121-133.

Edwards, T.D. and B.C. Cowell. 1992. Population dynamics and secondary production of *Hyalella azteca* (Amphipoda) in *Typha* stands of a subtropical Florida lake. J. N. Am. Benthol. Soc. 11(1):69-79.

Eiswirth, M., R. Ohlenbusch, and K. Schnell. 1999. Impact of chemical grout injection on urban groundwater. Impacts of Urban Grouth on Surface Water and Groundwater Quality (Proceedings of IUGG99 Symposium HS5, Birmingham, July 1999). IAHS Publ. no. 259.

Findlay, C.S. and J. Bourdages. 2000. Response time of wetland biodiversity to road construction on adjacent lands. Conservation Biology 14(1):86-94.

Hanes, T. and L. Stromberg. 1998. Hydrology of vernal pools on non-volcanic soils in the Sacrament valley. Pages 38-49 in: C.W. Witham, E.T. Bauder, D.Belk, W.R. Ferren Jr., and R. Ornduff (Editors). Ecology, Conservation and Management of Vernal Pool Ecosystems-Proceedings from a 1996 Conference. California Native Plant Society, Sacramento, CA.

Lillie, R.A. 2003. Macroinvertebrate community structure as a predictor of water duration in Wisconsin wetlands. Journal of the American Water Resources Association 39(2):389-400.

Mayes, W.M., A.R.G. Large, and P.L. Younger. 2005. The impact of pumped water from a de-watered Magnesian limestone quarry on an adjacent wetland: Thrislington, County Durham, UK. Environmental Pollution 138(3):443-454.

Meerhoff, M., C. Fosalba, C. Bruzzone, N. Mazzeo, W. Noordoven, and E. Jeppesen. 2006. An experimental study of habitat choice by *Daphnia*: plants signal danger more than refuge in subtropical lakes. Freshwater Biology 51:1320-1330.

Moorhead, D.L., D.L. Hall, and M.R. Willig. 1998. Succession of macroinvertebrates in playas of the southern high plains, USA. J. N. Am. Benthol. Soc. 17(4):430-442.

Murarka, I.P., T.E. Bailey, and J.R. Meiers. 2002. Water quality at a coal ash filled surface coal mine pit in Indiana. Proceedings of Coal Combustion By-Products and Western Coal Mines: A Technical Interactive Forum, April 16-18. Golden, CO.

Roadcap, G.S., W.R. Kelly, and C.M. Bethke. 2005. Geochemistry of extremely alkaline (pH>12) ground water in slag-fill aquifers. Ground Water 43(6):806-816.

Sutter, G. and R. Francisco. 1998. Vernal pool creation in the Sacramento valley: a review of the issues surrounding its role as a conservation tool. Pages 190-194 in: C.W. Witham, E.T. Bauder, D.Belk, W.R. Ferren Jr., and R. Ornduff (Editors). Ecology, Conservation and Management of Vernal Pool Ecosystems-Proceedings from a 1996 Conference. California Native Plant Society, Sacramento, CA.

USEPA. 1986. Quality Criteria for Water. Office of Water Regulations and Standards. EPA 440/5-86-001. Washington. DC 20460.

USEPA. 2006. National Recommended Water Quality Criteria. Office of Water. Office of Science and Technology (4304T).

Williams, D.D. 2005. Temporary forest pools: can we see the water for the trees? Wetlands Ecology and Management 13:213-233.

Yee, K.A., E.E. Prepas, P.A. Chambers, J.M. Culp, and G. Scrimgeour. 2000. Impact of $Ca(OH)_2$ treatment on macroinvertebrate communities in eutrophic hardwater lakes in the Boreal Plain region of Alberta: in situ and laboratory experiments. Can. J. Fish. Aquat. Sci. 57:125-136.

Zalom, F.G., A.A. Grigarick, and M.O. Way. 1980. Habits and relative population densities of some hydrophilids in California rice fields. Hydrobiologia 75:195-200.

Appendix A

Macroinvertebrates Collected From Folsom Wetlands in February and June 2007

Folsom CA/February 2007																				
Site	MI-1	MI-2	MI-3	MI-4	MI-5	MI-6	MI-7	MI-8	MI-9	MI-10	MX-1	MX-2	MX-3	MX-4	WC-1	WC-2	WC-3	WC-4	WC-5	WC-6
Date (2007)	2/6	2/6	2/6	2/6	2/6	2/6	2/6	2/6	2/6	2/6	2/7	2/7	2/7	2/7	2/6	2/6	2/6	2/6	2/6	2/6
COLLEMBOLA				1										1						
EPHEMEROPTERA																				
Baetidae																				
Callibaetis sp.														1						
Centroptilum sp.	10																			
Fallceon quilleri																				
ODONATA																				
Aeshnidae																				
Anax sp.												1		6						
Coenagrionidae			58			11					1	7	1	10						
Argia sp.	3																			
Libellulidae			1																	
Erythemis sp.																				
Pachydiplax longipennis																				
Plathemis lydia																				
HETEROPTERA																				
Corixidae																				
Corixidae larvae												11		1						
Hesperocorixa laevigata			1	3	1			3												
Sigara sp.					1															
Trichocorixa calva												2								
Gerridae larvae																				
Macroveliidae																				
Macrovelia hornii																				
Mesoveliidae																				
Mesovelia mulsanti																				
Notonectidae																				
Notonecta kirbyi				3																
Notonecta undulata																				
Saldidae																				
Saldula sp.																				
TRICHOPTERA																				
Limnephilidae							6													
Limnephilus sp.					2															
COLEOPTERA																				
Dytiscidae																				
Acilius abbreviatus															1					
Agabus sp.				9	8				2											
Colymbetes sp.					3															
Dytiscus sp.					1												1			

Folsom CA/February 2007																				
Site	MI-1	MI-2	MI-3	MI-4	MI-5	MI-6	MI-7	MI-8	MI-9	MI-10	MX-1	MX-2	MX-3	MX-4	WC-1	WC-2	WC-3	WC-4	WC-5	WC-6
Date (2007)	2/6	2/6	2/6	2/6	2/6	2/6	2/6	2/6	2/6	2/6	2/7	2/7	2/7	2/7	2/6	2/6	2/6	2/6	2/6	2/6
Hydroporinae																				
Hydroporus sp.						1	1	1	1											
Liodessus obscurellus																				
Neoclypeodytes ornatellus							9													
Rhantus sp.																				
Sanfilippodytes sp.				4	4										1					
Haliplidae																				
Peltodytes callosus						1														
Hydraenidae																				
Hydraena sp.					1							1								
Hydrophilidae																				
Anacaena sp.																				
Cymbiodyta sp.													1							
Enochrus californicus				1			2			1										
Enochrus sp.																				
Helochares normatus																				
Paracymus sp.															1	2				
Tropisternus lateralis										1										
Scirtidae																				
Cyphon sp.																				
Staphylinidae																				
DIPTERA																				
Ceratopogonidae																				
Ceratopogoninae						3														
Bezzia/Palpomyia																				
Dasyhelea sp.																				
Chironomidae																				
Orthocladiinae																				
Chaetocladius sp.			2	53	3	1	129													
Corynoneura sp.				3	2															
Cricotopus sp.	2												4							
Eukiefferiella sp.				1																
Limnophyes sp.	2		1	1	2	3	18			1										
Parametriocnemus sp.	8																			
Paraphaenocladius sp.						2														
Psectrocladius sp.	1		40	7	1															
Rheocricotopus sp.						1														
Smittia sp.							1													
Thienemanniella sp.																				
Chironominae																				
Apedilum sp.	1																			
Chironomus sp.	1		23	8	3	125				1					2					
Dicrotendipes sp.						1							1	2						

Folsom CA/February 2007																				
Site	MI-1	MI-2	MI-3	MI-4	MI-5	MI-6	MI-7	MI-8	MI-9	MI-10	MX-1	MX-2	MX-3	MX-4	WC-1	WC-2	WC-3	WC-4	WC-5	WC-6
Date (2007)	2/6	2/6	2/6	2/6	2/6	2/6	2/6	2/6	2/6	2/6	2/7	2/7	2/7	2/7	2/6	2/6	2/6	2/6	2/6	2/6
Endochironomus sp.																				
Glyptotendipes sp.																				
Paratendipes sp.													4							
Phaenopsectra sp.						2							2							
Polypedilum sp.						11							1							
Pseudochironomini																				
Pseudochironomus sp.																				
Tanytarsini																				
Micropsectra sp.	10		1	1		15	3													
Paratanytarsus sp.			6			14									1					
Rheotanytarsus sp.													2							
Tanytarsus sp.	2			1									1							
Tanypodinae																				
Ablabesmyia sp.																				
Alotanypus sp.						4														
Larsia sp.	2																			
Procladius sp.																				
Psectrotanypus sp.						5														
Tanypus sp.													2							
Zavrelimyia sp.																				
Culicidae							1													
Anopheles sp.																				
Culex sp.																				
Dixidae																				
Dixella sp.																				
Ephydridae												1								
Simuliidae																				
Simulium sp.	1												1							
Stratiomyidae																				
Odontomyia sp.																				
Tabanidae				2																
Tipulidae	1			1																
Limnophila sp.						2														
Limonia sp.			2											4						
Tipula sp.																				
TURBELLARIA							1								1	4				
OLIGOCHAETA																				
Enchytraeidae						1														
Lumbricidae											1					7				
Lumbriculidae	3			4		35	6	9	27	14					1	9				
Naididae																				
Tubificidae	4			3	1	20			3				8			1				
HIRUDINEA																				

Folsom CA/February 2007																				
Site	MI-1	MI-2	MI-3	MI-4	MI-5	MI-6	MI-7	MI-8	MI-9	MI-10	MX-1	MX-2	MX-3	MX-4	WC-1	WC-2	WC-3	WC-4	WC-5	WC-6
Date (2007)	2/6	2/6	2/6	2/6	2/6	2/6	2/6	2/6	2/6	2/6	2/7	2/7	2/7	2/7	2/6	2/6	2/6	2/6	2/6	2/6
Erpobdellidae													1							
Glossiphoniidae																				
Helobdella stagnalis						2														
CLADOCERA																				
Chydoridae																				
Eurycercus sp.																				
Daphniidae																				
Daphnia sp.										4					5			10	9	104
Simocephalus sp.				7	16															
COPEPODA				1																
OSTRACODA	16			897	776															
SPINICAUDATA																				
Cyzicidae																				
Cyzicus californicus				77	140	1														
AMPHIPODA																				
Crangonyctidae																				
Crangonyx sp.											71	119	58	80	934	93	166	326	297	253
Hyalellidae																				
Hyalella azteca			4			13						10	4	70						
DECAPODA																				
Cambaridae	5		1		2	4	4		77	2	1	1		4			1	1	11	2
ACARI																				
Pionidae																				
Piona sp.										1										
GASTROPODA																				
Lymnaeidae																2				
Physidae		2	6			8	2	3							54	34				
Planorbidae						1									2	7				
BIVALVIA																				
Sphaeriidae																				
Sphaerium sp.																	5			
Total number of taxa	17	1	13	22	18	26	13	4	5	8	4	9	15	10	11	9	4	3	3	3
Total number of organisms	72	2	146	1088	967	287	183	16	110	25	74	153	91	179	1003	159	173	337	317	359

Folsom CA/June 2007				dry	dry															dry
Site	MI-1	MI-2	MI-3	MI-4	MI-5	MI-6	MI-7	MI-8	MI-9	MI-10	MX-1	MX-2	MX-3	MX-4	WC-1	WC-2	WC-3	WC-4	WC-5	WC-6
Date (2007)	6/12	6/12	6/12	6/12	6/12	6/12	6/12	6/12	6/12	6/12	6/13	6/13	6/13	6/13	6/13	6/13	6/13	6/13	6/13	6/13
COLLEMBOLA																		1		
EPHEMEROPTERA																				

Folsom CA/June 2007						dry	dry															dry
		Site	MI-1	MI-2	MI-3	MI-4	MI-5	MI-6	MI-7	MI-8	MI-9	MI-10	MX-1	MX-2	MX-3	MX-4	WC-1	WC-2	WC-3	WC-4	WC-5	WC-6
		Date (2007)	6/12	6/12	6/12	6/12	6/12	6/12	6/12	6/12	6/12	6/12	6/13	6/13	6/13	6/13	6/13	6/13	6/13	6/13	6/13	6/13
	Baetidae																					
		Callibaetis sp.			17				4	63	5	49	8				12		3			
		Centroptilum sp.																				
		Fallceon quilleri	9																			
ODONATA																						
	Aeshnidae				1											1	1					
		Anax sp.																				
	Coenagrionidae		4		80			1	23			11		2		3						
		Argia sp.																				
	Libellulidae																					
		Erythemis sp.			2																	
		Pachydiplax longipennis			4																	
		Plathemis lydia													1							
HETEROPTERA																						
	Corixidae																					
		Corixidae larvae								6				15		1						
		Hesperocorixa laevigata						8	4													
		Sigara sp.														1						
		Trichocorixa calva						2						25	1	6	1				1	
	Gerridae larvae																2		1			
	Macroveliidae																					
		Macrovelia hornii																		1		
	Mesoveliidae																					
		Mesovelia mulsanti			1											2						
	Notonectidae																					
		Notonecta kirbyi																	1			
		Notonecta undulata							1													
	Saldidae																					
		Saldula sp.			1																	
TRICHOPTERA																						
	Limnephilidae																					
		Limnephilus sp.																				

Folsom CA/June 2007						dry	dry															dry
		Site	MI-1	MI-2	MI-3	MI-4	MI-5	MI-6	MI-7	MI-8	MI-9	MI-10	MX-1	MX-2	MX-3	MX-4	WC-1	WC-2	WC-3	WC-4	WC-5	WC-6
		Date (2007)	6/12	6/12	6/12	6/12	6/12	6/12	6/12	6/12	6/12	6/12	6/13	6/13	6/13	6/13	6/13	6/13	6/13	6/13	6/13	6/13
COLEOPTERA																						
	Dytiscidae																					
		Acilius abbreviatus																				
		Agabus sp.																				
		Colymbetes sp.																				
		Dytiscus sp.																				
		Hydroporinae	1		1																	
		Hydroporus sp.							15													
		Liodessus obscurellus															1					
		Neoclypeodytes ornatellus							2													
		Rhantus sp.																			1	
		Sanfilippodytes sp.			1				3								1					
	Haliplidae																					
		Peltodytes callosus																				
	Hydraenidae																					
		Hydraena sp.							3													
	Hydrophilidae																					
		Anacaena sp.							3													
		Cymbiodyta sp.							11	1												
		Enochrus californicus			2				1													
		Enochrus sp.	6		4							7										
		Helochares normatus																12				
		Paracymus sp.			1																	
		Tropisternus lateralis			8				3								65					
	Scirtidae																					
		Cyphon sp.	1		1																	
	Staphylinidae				2				2				2	1	1							
DIPTERA																						
	Ceratopogonidae											4										
		Ceratopogoninae																				
		Bezzia/Palpomyia									3											
		Dasyhelea sp.										18										

Folsom CA/June 2007				dry	dry															dry
Site	MI-1	MI-2	MI-3	MI-4	MI-5	MI-6	MI-7	MI-8	MI-9	MI-10	MX-1	MX-2	MX-3	MX-4	WC-1	WC-2	WC-3	WC-4	WC-5	WC-6
Date (2007)	6/12	6/12	6/12	6/12	6/12	6/12	6/12	6/12	6/12	6/12	6/13	6/13	6/13	6/13	6/13	6/13	6/13	6/13	6/13	6/13
Chironomidae																				
Orthocladiinae																				
Chaetocladius sp.																				
Corynoneura sp.											1									
Cricotopus sp.	1									1										
Eukiefferiella sp.																				
Limnophyes sp.		1																		
Parametriocnemus sp.	2																			
Paraphaenocladius sp.																				
Psectrocladius sp.									1											
Rheocricotopus sp.																				
Smittia sp.																				
Thienemanniella sp.													1							
Chironominae																				
Apedilum sp.																				
Chironomus sp.						4	103		301	44					786				1	
Dicrotendipes sp.													1							
Endochironomus sp.									1	6										
Glyptotendipes sp.										1										
Paratendipes sp.													4							
Phaenopsectra sp.																				
Polypedilum sp.		1								2		2								
Pseudochironomini																				
Pseudochironomus sp.										45										
Tanytarsini																				
Micropsectra sp.		4											6						1	
Paratanytarsus sp.	16						1			2	1	1	2							
Rheotanytarsus sp.																				
Tanytarsus sp.										1							1			
Tanypodinae																				
Ablabesmyia sp.										11										
Alotanypus sp.							1								5					

Folsom CA/June 2007				dry	dry															dry
Site	MI-1	MI-2	MI-3	MI-4	MI-5	MI-6	MI-7	MI-8	MI-9	MI-10	MX-1	MX-2	MX-3	MX-4	WC-1	WC-2	WC-3	WC-4	WC-5	WC-6
Date (2007)	6/12	6/12	6/12	6/12	6/12	6/12	6/12	6/12	6/12	6/12	6/13	6/13	6/13	6/13	6/13	6/13	6/13	6/13	6/13	6/13
Larsia sp.										36										
Procladius sp.														1						
Psectrotanypus sp.			2			1	44	6	57	3					420	1	3		13	
Tanypus sp.						1	2													
Zavrelimyia sp.	1																			
Culicidae																				
Anopheles sp.										1		1								
Culex sp.																	10		8	
Dixidae																				
Dixella sp.	1	2																		
Ephydridae										22							1			
Simuliidae																				
Simulium sp.		1																		
Stratiomyidae																				
Odontomyia sp.										2										
Tabanidae																				
Tipulidae																				
Limnophila sp.	1																			
Limonia sp.	38									10										
Tipula sp.											1									
TURBELLARIA															2					
OLIGOCHAETA																				
Enchytraeidae																				
Lumbricidae											2									
Lumbriculidae						1									7	11				
Naididae									2					1				1		
Tubificidae							2						2							
HIRUDINEA																				
Erpobdellidae																				
Glossiphoniidae																				
Helobdella stagnalis							1								6					
CLADOCERA																				
Chydoridae																				

Folsom CA/June 2007						dry	dry															dry
		Site	MI-1	MI-2	MI-3	MI-4	MI-5	MI-6	MI-7	MI-8	MI-9	MI-10	MX-1	MX-2	MX-3	MX-4	WC-1	WC-2	WC-3	WC-4	WC-5	WC-6
		Date (2007)	6/12	6/12	6/12	6/12	6/12	6/12	6/12	6/12	6/12	6/12	6/13	6/13	6/13	6/13	6/13	6/13	6/13	6/13	6/13	6/13
		Eurycercus sp.									3		1									
	Daphniidae																					
		Daphnia sp.									869	5										
		Simocephalus sp.																				
COPEPODA											3											
OSTRACODA														1	13							
SPINICAUDATA																						
	Cyzicidae																					
		Cyzicus californicus																				
AMPHIPODA																						
	Crangonyctidae																					
		Crangonyx sp.											5	21	58	21	342	35	37	20	113	
	Hyalellidae																					
		Hyalella azteca			90			2	2							10						
DECAPODA																						
	Cambaridae																					
ACARI														2								
	Pionidae																					
		Piona sp.																				
GASTROPODA																						
	Lymnaeidae																					
	Physidae				2				1					3		1	91	7				
	Planorbidae																49					
BIVALVIA																						
	Sphaeriidae																					
		Sphaerium sp.																				
		Total number of taxa	12	5	18	0	0	8	22	4	10	21	8	11	11	11	16	5	8	4	7	0
		Total number of organisms	81	9	220	0	0	20	232	76	1245	281	21	74	90	48	1791	66	57	23	138	0