Multipurpose Constructed Treatment Wetlands in the Arid Southwestern United States: Are the Benefits Worth the Risks?[1]

William E. Walton

Department of Entomology, University of California, Riverside, California, 92521, USA
E-mail: walton@mail.ucr.edu

Abstract

Multipurpose constructed treatment wetlands are being used increasingly in the southwestern U.S. to reclaim water, provide habitat for wetlands wildlife, educate the public on issues related to water and wildlife conservation, and fulfill other goals. Whereas, man-made wetlands have proven effective for water treatment, one serious drawback is the potential of some wetlands to produce large numbers of pathogen-transmitting and pestiferous mosquitoes. In regions of rapid human development, the juxtaposition of wetlands, which contain reservoirs and vectors of the causative agents of human disease, and human developments, which may contain avian reservoirs capable of rapid arbovirus amplification, are a concern to public health officials. Population trends of immature and adult mosquitoes differ markedly among wetlands receiving water that differs in quality and differing in coverage by vegetation. Four case studies are discussed in terms of mosquito production and control.

INTRODUCTION

Multipurpose constructed wetland technology offers many potential benefits including water quality improvement/reclamation, creation of wetland habitat, wildlife conservation, recreation, education and research, and amenities to housing developments. As compared to conventional wastewater treatment facilities, the lower construction and annual operational costs make constructed treatment wetlands a potential alternative technology for wastewater treatment (Kadlec and Knight 1996). Constructed wetland technology has a great potential for meeting the wastewater treatment needs of small communities (< 10,000 persons with flows ≤ 1 MGD) in the U.S. during a period of both reduced funding for capital improvements in existing wastewater treatment facilities and greater threats of enforcement for failure to meet wastewater discharge requirements (Bastian 2001). Facilities serving small communities with limited abilities to fund improvements in conventional wastewater treatment plants service about 72% of the U.S. population (Bastian 2001). The advances in the technology (Kadlec and Knight 1996, Vymazal et al. 1998, USEPA 2000) and the marked increase in the number (Cole 1998) of constructed wetlands attest to the utility of the technology for wastewater treatment. Despite the success of many constructed wetlands to attain multiple goals, questions remain concerning the suitability of man-made wetlands as surrogates for wetlands lost to human land use (NRC 2001) and design of treatment wetlands for multiple uses (USEPA 2000).

One drawback to multipurpose constructed wetlands primarily treating municipal wastewater is the production of mosquitoes which can be pestiferous and vectors of pathogens causing disease in humans and companion animals (Walton et al. 1998, CH2M Hill 1999, Russell 1999, Knight et al. 2001). Constructed treatment wetlands in arid regions of the U.S. may enhance and alter the seasonal phenology of mosquito populations in several ways. First, nutrient-rich municipal wastewater may

[1] INTECOL Invited Papers Symposium 30. Disease and Wetlands Thursday, August 10, 2000.

enhance resources for mosquito larvae ultimately increasing adult mosquito production. Second, a continuous source of shallow standing water with emergent vegetation provides developmental sites for immature mosquitoes and resting habitats for adult mosquitoes that might not otherwise exist during particular times of the year in arid regions. Compared to a bimodal annual pattern of mosquito abundance observed for some mosquito species in the arid southwestern U.S. (Durso and Burguin 1988), a continuous supply of municipal wastewater can result in a unimodal annual pattern of mosquito abundance exhibiting (i) an earlier onset of mosquito production during each year which can be further augmented by comparatively warm water derived from bacterial metabolism in the conventional wastewater treatment process, (ii) production during the summer months when mosquito developmental sites are usually dry and mosquitoes would either not be active or occur at low abundance, and (iii) conditions favorable for mosquito production later during the year (Figure 1A). Furthermore, design features of wetlands that create intermittently flooded habitats can also create mosquitoes if standing water persists long enough for mosquitoes to complete immature development.

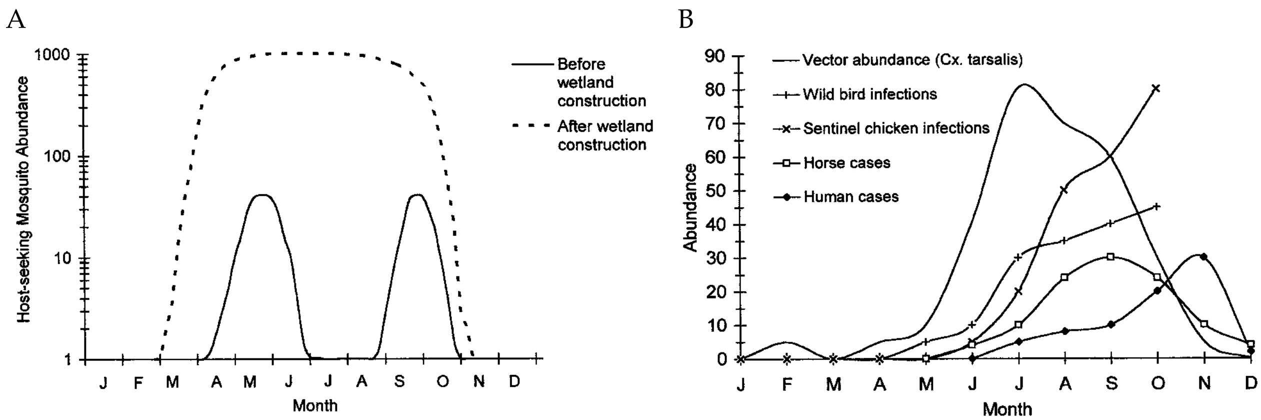

FIGURE 1
(A) HYPOTHETICAL CHANGE IN MOSQUITO ABUNDANCE IN AN ARID REGION OF THE SOUTHWESTERN U.S. FOLLOWING OPERATION OF A WETLAND PROCESSING MUNICIPAL WASTEWATER. (B) PHENOLOGY OF A WESTERN EQUINE ENCEPHALOMYELITIS OUTBREAK IN CALIFORNIA [REDRAWN FROM CH2M HILL (1999)]

Even though annual abundance patterns of mosquitoes inhabiting arid regions of the U.S. are not always bimodal (Bohart and Washino 1978), a continuous supply of nutrient-rich water cannot only increase abundance and favor enhanced activity of adult mosquitoes by providing mosquito-friendly habitat during periods of natural inactivity or low activity, it might also alter mosquito life histories (e.g., natural selection for a reduction in diapause intensity in adult mosquitoes, enhanced survivorship of adult mosquitoes). Such changes in seasonal abundance patterns and life histories can have important consequences on the potential for pathogen transmission by mosquitoes of public health significance.

The implications for public health in regions of rapid urban and suburban development are particularly acute where wetlands lie in proximity to human development. Wetland birds are reservoirs for arboviruses in an enzootic cycle involving mosquito vectors. Mosquitoes which have fed on wetland birds and acquired arbovirus infections can migrate into the surrounding region and subsequently feed and infect humans directly or infect susceptible peridomestic birds, such as house finches (*Carpodacus mexicanus*) and house sparrows (*Passer domesticus*) (Reeves 1990). Mosquitoes taking blood meals from viremic peridomestic birds can then potentially infect humans.

A typical outbreak of western equine encephalomyelitis in California would exhibit virus activity in the vector population (*Culex tarsalis*), seroconversions in susceptible wild birds and then in chickens used as sentinels for virus activity (Figure 1B). An increased incidence of avian infections would be followed by virus activity in horses and humans. The size of the vector population, the survival of infected adult mosquitoes to permit multiple blood meals, and the propensity of mosquitoes to feed on different vertebrate host species are among the important factors influencing the dynamics of disease outbreaks. Constructed treatment wetlands in arid regions have the potential to significantly influence the first two of these characteristics. An enhancement of summer mosquito populations during the period of accelerating pathogen activity has the potential to create disease outbreaks.

Mosquito populations have been studied in relatively few treatment wetlands (CH2M Hill 1999, Knight et al. 2001). This paper will highlight mosquito-related issues at four constructed treatment wetlands in California and Arizona. The difficulties for mosquito abatement posed by dense emergent vegetation used as part of the treatment process, the potential effects of water quality on mosquito abundance and the estimated costs for mosquito abatement will be briefly discussed.

CASE STUDY SITES

San Jacinto Demonstration Wetland

The 9.9 ha multipurpose demonstration wetland is located in San Jacinto, California and the site is described in detail by Sartoris et al. (2000). The wetland was configured as a marsh-pond-marsh system. The marshes were planted with *Schoenoplectus {=Scirpus} californicus* and *S. acutus* in autumn 1994 with 3 or 4 zones (12 m wide) of open water in each 0.5 m deep marsh. The central pond was 1.02 ha and 1.8 m deep. The wetland was incorporated into the Eastern Municipal Water District's Hemet/San Jacinto Regional Water Reclamation Facility's treatment train in January 1996 and, during the two year period discussed here, mean daily total inflow volume was 4542 m^3 d^{-1} of secondary treated effluent from the activated sludge process plant. Hydraulic retention time was 9-14 days. Mean concentration for constituents in the inflow water were total N 19.93 mg L^{-1} (organic N 3.3 mg L^{-1}, NH_4-N 14.5 mg L^{-1}, NO_3-N 0.6 mg L^{-1}), total P 2.5 mg L^{-1}, BOD (summer 1997 only) 46.1 mg L^{-1}. NH_4-N loading rates during the period of annual mosquito activity (1 April – 1 November) increased 3-fold in 1997 (1996: 57.5 kg d^{-1}; 1997: 152.9 kg d^{-1}). The primary functions of the wetland are nitrogen removal and fecal coliform bacteria reduction from wastewater.

Prado Wetlands

The 186 ha Prado Wetlands is located north of Corona, California in western Riverside County and consists of 50 ponds divided among three types categorized by intended vegetation cover (60, 40, 0% of surface covered by emergent vegetation) and water depth (0.45, 0.6, 2.4 m, respectively). This multipurpose wetland is operated by the Orange County Water District and the primary function of the wetlands is to remove nitrate from Santa Ana River water prior to recharge of a groundwater basin. Half of the flow (1.8 - 2.4 m^3 s^{-1}) of the Santa Ana River is diverted through the wetlands. Hydraulic retention time is 5-7 days during the summer and during this period nitrate concentration declines from approximately 10 mg L^{-1} to non-detectable levels across the wetland. Ammonium nitrogen levels are low (circa 0.12 mg L^{-1}) and phosphate-P is around 1.2 mg L^{-1}. The wetlands were rebuilt in 1997, but were scoured by high flows caused by El Niño rains in early 1998 (Keiper et al. 1999). The dominant vegetation in the wetlands is *S. californicus* and *Typha* spp.

Tres Rios Demonstration Constructed Wetlands

The Tres Rios Demonstration Constructed Wetland Project is located in Tolleson, Arizona and is operated by the City of Phoenix, Water Services Department. The major function of the wetlands was to evaluate the applicability of constructed wetland technology for large-scale wetlands for habitat enhancement. Between August 1995 and late 1998, the project received approximately 7600 m^3 d^{-1} of municipal wastewater from the 91st Avenue Wastewater Treatment Plant which utilizes an activated sludge process. During 1995 through 1998, the project consisted of three sites totaling approximately 5 ha of surface flow wetlands divided into deep open-water zones (> 1 m deep) and shallow (< 50 cm) marshes containing emergent vegetation, primarily *Schoenoplectus {=Scirpus} validus* and *S. olneyi*. The Cobble Site had a paired 0.9 ha basins located in the Salt River channel. The Hayfield Site had two 1.3 ha basins located above the Salt River channel. Each basin had 20% of its surface area as deep open-water zones. The Research Cell Site consisted of twelve 1200m^2 ponds located within the treatment plant. The basins were initially configured with varying amounts (11 to 35% of the surface area) of open water but were rapidly filled by bulrushes. Median values for constituents in the inflow water to the Hayfield and Cobble sites were total N 5.7-8.1 mg L^{-1} (organic N 1.2 mg L^{-1}, NH_4-N 2 mg L^{-1}, NO_3-N 2.4 mg L^{-1}), PO_4-P 3.3 mg L^{-1}, COD 37 mg L^{-1}, BOD 3 mg L^{-1}, TOC 8.6 mg L^{-1} (USBR 2001).

Sweetwater Wetlands

The Sweetwater Wetlands is located northwest of Tucson, Arizona and is operated by the City of Tucson Water Department. The wetlands were constructed during 1996 and shallow zones were planted with bulrush during April-May 1997. The site contains four settling basins (total surface area: 0.7 ha), two surface flow wetlands (6 ha) and four groundwater recharge basins (5.7 ha). The two 3 ha wetlands contained a mixture of open water (< 50%) and shallow emergent marshes supporting predominantly *Typha domingensis*, *S. validus* and *S. olneyi*. The primary function of the wetlands is to treat backwash water from filters used to process secondary effluent from the Roger Road Wastewater Treatment Plant. Therefore, the wetlands receive secondary treated effluent that has a high suspended solids content. The wetlands received a mixture of secondary effluent and backwash water between April and October 1998. During this time, the proportion of backwash effluent was gradually increased until only backwash water entered the wetlands after October 1998. Flow during summer 1999 was approximately 605 m^3 d^{-1}. Mean concentrations for selected constituents in the inflow water during summer 1999 were Kjeldahl N 11.9 mg L^{-1}, NO_3-N 1.0 mg L^{-1}, PO_4-P 12.9 mg L^{-1}, and BOD 117.3 mg L^{-1}.

MOSQUITO PRODUCTION AND CONTROL

The abundance of mosquitoes actively seeking blood meals at the treatment wetlands increased annually after beginning operation. Host-seeking mosquito populations were initially small because emergent vegetation was sparse and nutrient loading rates were typically low during the period that vegetation was being established. As emergent vegetation filled in the shallow zones of treatment wetlands and loading rates were increased when the wetlands were incorporated into the treatment train, mosquito abundance increased concomitantly.

At the San Jacinto demonstration wetland, host-seeking mosquito (*Culex* spp.) abundance during early summer increased approximately ten-fold annually to nearly 40,000 $trap^{-1}$ $night^{-1}$ by the third year of operation (Figure 2A). Host-seeking mosquito abundance (integrated on an annual basis:

mosquito days) increased 6-fold annually. Mean larval abundance in dip samples during summer 1997 was nearly 10 larvae dip^{-1} (Walton et al. 1998).

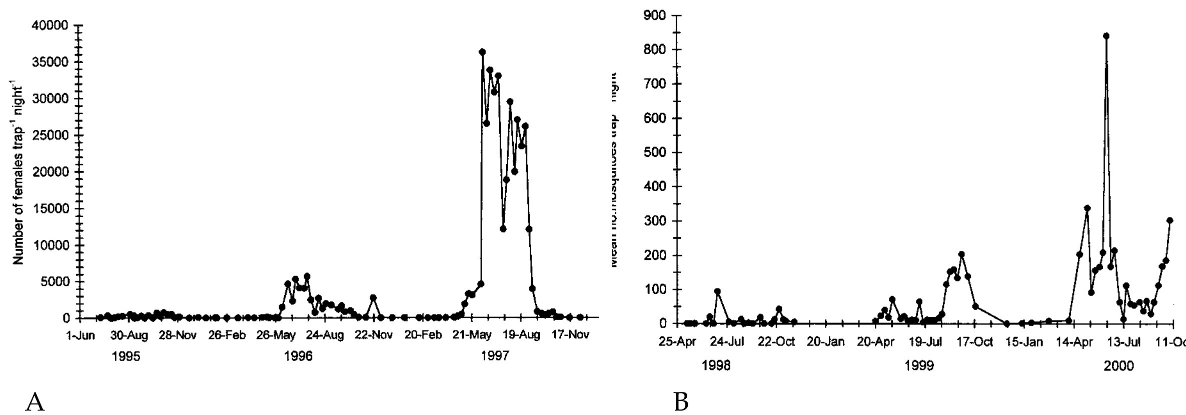

FIGURE 2
ABUNDANCE OF HOST-SEEKING MOSQUITOES COLLECTED BY CARBON DIOXIDE-BAITED SUCTION TRAPS AT THE (A) SAN JACINTO DEMONSTRATION WETLAND 1995-97 AND (B) PRADO WETLANDS 1998-2000 IN SOUTHERN CALIFORNIA

Mosquito abatement using bacterial larvicides (2 applications of *Bacillus thuringiensis* var. *israelensis* (Bti), 5 applications of *B. sphaericus* (Bs)) and an adulticide (2 applications of Pyrenone®; 6.0% pyrethrins, 60% piperonyl butoxide) was carried out by helicopter between August and mid-November 1997 (Walton et al. 1998). Early afternoon applications combining Bti and Pyrenone did not demonstrably reduce the mosquito populations during mid-August. The first treatment of *B. sphaericus* also appeared to have little effect on the mosquitoes. During late August, adult mosquito emergence across the wetland indicated that mosquito mortality in the inlet marshes was much greater than in the outlet (polishing) marshes (Walton et al. 1998). Because the bacterial larvicides were applied to the entire wetland, this mortality was unlikely to have been caused by the larvicide. Mosquito populations declined almost two orders of magnitude during September due in part to larvicides. In 1998, the wetland was reconfigured to improve water quality performance and reduce mosquito abundance.

At the Prado wetlands, mosquito populations also increased annually (Figure 2B) following damage caused by flooding from El Niño rains during early 1998. Even though the surface area of the Prado wetlands is ~20 times that of the San Jacinto wetland, mosquito abundance was considerably lower at the Prado wetlands (cf. Figure 2A and 2B). The comparatively small host-seeking mosquito population at the Prado wetlands was likely caused by the interaction of several factors such as the comparatively high water quality of the Santa Ana River, low coverage by emergent vegetation, high rates of water flow, mosquito predators occurring naturally within the river, and an excellent working relationship between wetland managers and vector control personnel which promotes immediate attention to potential mosquito problems. The compartmentalization and redundancy built into the wetland system, as well dikes that can accommodate mosquito control equipment, facilitate environmentally friendly vector control focused on small areas rather than more expensive, basin-wide applications of mosquito control agents. Mosquito production is however greatly enhanced following vegetation management (Keiper and Walton, unpublished data) and by autumnal flooding of seasonal wetlands adjacent to the Prado wetlands. Many *Culex* species readily colonize recently inundated habitats; such habitats are made more attractive to mosquitoes when harvested and dead vegetation is inundated.

Mosquito production at the two Arizona treatment wetlands followed the aforementioned interannual trends. At the Tres Rios wetlands, host-seeking mosquito populations increased appreciably during the second year of operation. By late spring 1997, host-seeking mosquito abundance was > 1400 individuals trap^{-1} night^{-1} at several trap sites (CH2M Hill 1999). Between June and August 1997, > 80,000 mosquitoes were collected over 12 nights at the three sites within the Tres Rios complex (R. Wass, personal communication). Mosquito abatement measures using mosquito-specific bacterial larvicides were implemented during 1998 and mosquito abundance was reduced but was still high (> 39,800 mosquitoes collected over 14 nights from June through August 1998). Source reduction and other mosquito abatement measures outlined in CH2M Hill (1999) were carried out in 1999 and summer host-seeking mosquito collections declined to < 4,300 females (R. Wass, personal communication).

Monthly mean host-seeking mosquito abundance (< 100 individuals trap^{-1} night^{-1}) at the Sweetwater wetlands was low during the period when emergent vegetation was being established and loading rates were low (Figure 3). During late spring 1998, mosquito abundance increased dramatically to > 5500 females trap^{-1} night^{-1}. Mosquito abatement, primarily using larvicides, began in summer 1998. Monthly mean mosquito abundance was reduced to between 500-2,000 females trap^{-1} night^{-1}, but arbovirus activity was detected in the vicinity of the wetland during autumn 1998. To reduce mosquito abundance and arbovirus activity, mosquito abatement was begun early in 1999 (Figure 3). A rotation of three larvicides at approximately biweekly intervals was carried out using a remote-controlled helicopter during spring 1999. Two mosquito-specific bacterial larvicides, (Bti and Bs), and an insect growth regulator, methoprene, were used. The rotation of the bacterial agents is a strategy to reduce the rapid evolution of resistance in mosquitoes to the more effective agent in organically enriched waters, *B. sphaericus*. Weekly applications of the bacterial agents were carried out during the summer and autumn. Malathion was applied once in August (Figure 3). Additional adulticiding was carried out weekly and then semiweekly (Figure 3: single- and double-headed arrows, respectively) using the synthetic pyrethroid sumithrin 2+2. Despite mosquito abatement efforts, arboviral activity was detected during the autumn.

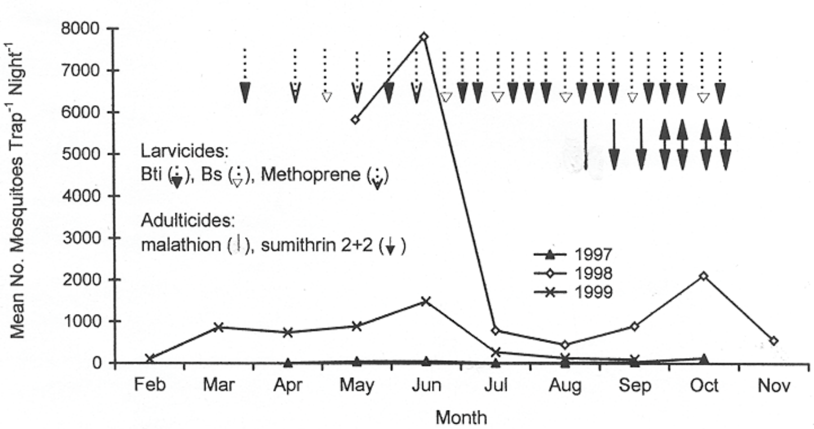

FIGURE 3
HOST-SEEKING MOSQUITO ABUNDANCE AT THE SWEETWATER WETLANDS, TUCSON ARIZONA DURING 1997-1999 AND MOSQUITO ABATEMENT CARRIED OUT DURING 1999. MOSQUITO ABUNDANCE WAS BASED ON FEMALE MOSQUITOES COLLECTED BY CARBON DIOXIDE-BAITED SUCTION TRAPS

DISPERSAL OF MOSQUITOES

Adult mosquitoes produced at a wetland can disperse in significant numbers several kilometers into the surrounding region. Mosquitoes differ appreciably in their dispersal tendencies; some container-breeding mosquitoes move < 200 meters from larval development sites whereas other mosquitoes associated with wetlands often disperse en masse tens of kilometers in search of hosts (Service 1993).

Two species commonly found at treatment wetlands in the southwestern U.S. show either strong developmental site fidelity (the tule mosquito, *Culex erythrothorax*) or a tendency to disperse (nearly 1-2 km $night^{-1}$; the western encephalitis mosquito, *Culex tarsalis*). More than 50% of blood-engorged *C. erythrothorax* females collected at the San Jacinto wetland contained cattle blood indicating that the mosquitoes had fed on hosts in the surrounding region and returned to the wetland to develop eggs (Walton et al. 1999). Mark-release-recapture studies (Walton et al. 1999) found that > 99% of *C. erythrothorax* were collected within 0.5 km of the wetland. The distributions of unmarked and marked individuals in a 23 km^2 region of the San Jacinto Valley were similar and showed a distinct concentration at the wetland (Figure 4A).

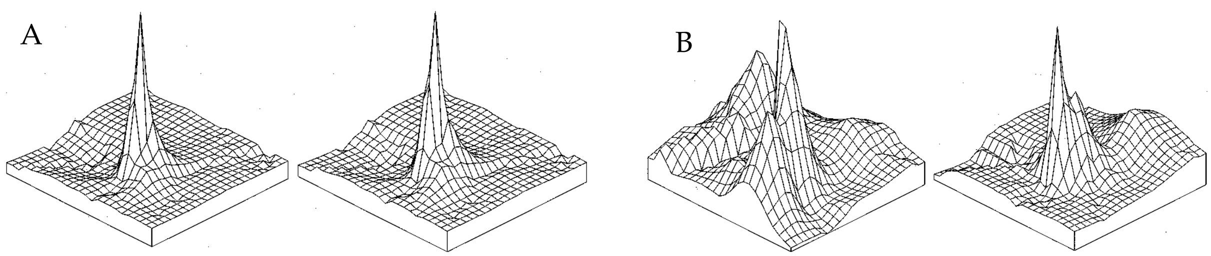

FIGURE 4
SPATIAL DISTRIBUTION OF HOST-SEEKING (A) *CULEX ERYTHROTHORAX* AND (B) *CULEX TARSALIS* IN A 23 KM^2 AREA OF THE SAN JACINTO VALLEY DURING SEPTEMBER 13-15, 1995. THE RELATIVE ABUNDANCE OF ALL INDIVIDUALS COLLECTED IN 26 CARBON DIOXIDE-BAITED SUCTION TRAPS IS SHOWN IN THE LEFT PANEL AND THE RELATIVE ABUNDANCE OF RECAPTURED INDIVIDUALS RELEASED AT THE SAN JACINTO DEMONSTRATION WETLAND (LOCATED AT THE CENTRAL PEAK IN ALL DIAGRAMS) IS SHOWN IN THE RIGHT PANEL FOR EACH MOSQUITO SPECIES

In contrast to the spatial distribution of *C. erythrothorax*, the spatial distribution of *C. tarsalis*, the predominant vector of arboviruses in the region, indicated that this species disperses widely (i.e., to the edge of the trapping grid in a single night) and occurs at three additional sites in the valley (Figure 4B). Whereas, the central peak in the *C. tarsalis* distribution is indicative of host-seeking females collected at the demonstration wetland in September 1995, as the number of host-seeking mosquitoes increased nearly two orders of magnitude during the next two years (Figure 1A) it is readily evident that the wetland would be the primary source of western encephalitis mosquitoes in region.

COST OF MOSQUITO ABATEMENT

Cost-benefit analyses for constructed treatment wetlands (Kadlec and Knight 1996) do not include the costs associated with mosquito abatement. If mosquito abatement must be carried out by helicopter, or remote-controlled helicopter, costs increase markedly. Dense emergent vegetation creates penetration problems for aerial and water-based applications of standard mosquito control agent formulations because larvicides will remain on the vegetation or vagaries in flow through vegetation often result in insufficient doses of mosquito control agents contacting or being ingested by mosquito larvae.

Annual costs for application of mosquito control agents to constructed treatment wetlands containing dense emergent vegetation ranged between $5,250 and $6,665 ha^{-1} (Table 1). Despite these expenditures and comparatively reduced adult mosquito populations, pathogen transmission and disease outbreaks are still possible. Source reduction (i.e., harvesting emergent vegetation) can be effective, but is expensive (e.g., ~ $100,000 for 9 ha) and may be contraindicated for water quality improvement.

TABLE 1
COSTS OF MOSQUITO ABATEMENT FOR THREE CONSTRUCTED TREATMENT WETLANDS IN THE SOUTHWESTERN UNITED STATES

Demonstration Wetland San Jacinto, CA (1997)		Tres Rios Wetlands Phoenix, AZ (1998)		Sweetwater Wetlands Tucson, AZ (1999)	
Larvicides	$13,664	Larvicides	$ 6,538	Larvicides	$18,500
Adulticides	$ 406	Application	$ 4,500	Adulticiding	$ 2,000
Helicopter	$12,000			Helicopter	$27,700
Total (~½ yr)	$26,070	(~½ yr)	$11,038		$48,200
Cost ha^{-1} yr^{-1}	$ 5,266		$ 5,250		$ 6,665

CONCLUSIONS

Multipurpose constructed treatment wetlands offer many potential benefits; however, production of pestiferous and pathogen-transmitting mosquitoes is one drawback. Mosquito production typically increases as water quality declines and coverage by inundated vegetation increases. Problems related to mosquito production can be acute in the arid southwestern U.S. where rapid human development, a susceptible populace unaccustomed to the presence of mosquitoes, endemic activity of arboviruses, and the presence of competent mosquito vectors of the causative agents of human diseases combine to create public health concerns. Mosquito activity is not restricted to the area circumscribed by a wetland; large-scale land use patterns should be given greater attention. Long-term planning for maintenance and mosquito abatement have been discussed in detail elsewhere (CH2M Hill 1999, Russell 1999, Knight et al. 2001) and need to be incorporated into designs and operations for multipurpose constructed treatment wetlands in order to minimize mosquito production and maximize the benefits of this important technology.

ACKNOWLEDGEMENTS

This work was supported in part by Special Funds for Mosquito Research from the Division of Agriculture and Natural Resources of the Univ. of California, U.S.D.I. Cooperative Agreement No. 1445-CA09-0011, U.S.D.A. funding to the Agricultural Experiment Station at U.C.-Riverside and the Research Foundation of the MVCAC. The cooperation of the U.S.G.S., Eastern Municipal Water District, Orange County Water District, Northwest MVCD and the Riverside County Dept. of Health is appreciated. This paper also summarizes material presented to the Mosquito Control Association of Australia; the hospitality of M. Brown, B. Kay and especially R. Russell during the Australian conference is most appreciated. I thank B. Baharie, J. Beehler, C. Crother, R. Knight, C. Levy, W. Reisen, R. Russell, J. Sartoris, L. Smith and J. Thullen for discussions and K. Chan, L.H. Gould, J. Jiannino, J. Keiper, H. Murray, L. Randall, M. Sanford and P. Workman for assistance with aspects of the work summarized here. For providing data and permission to cite data, I thank R. Wass and E. Stiles (Tres Rios Demonstration Wetlands), and B. Prior and M. Light (Sweetwater Wetlands).

LITERATURE CITED

Bastian, R.K. 2001. Update on the role of constructed wetlands in meeting municipal wastewater discharge requirements. *In:* R. Gearheart (ed.) Conference on the "Role of Wetlands in Watershed Management - Lessons Learned." Humboldt State Univ. Arcata, CA. May 2000. In press.

Bohart, R.M. and R.K. Washino. 1978. Mosquitoes of California. Publ. No. 4084. Univ. Calif. Press, Berkeley, CA.

CH2M Hill. 1999. A Mosquito Control Strategy for the Tres Rios Demonstration Constructed Wetlands. City of Phoenix, Water Serv. Dept. CH2M Hill, Tempe, AZ.

Cole, S. 1998. The emergence of treatment wetlands. Environ. Sci. Tech. 32: 218-223.

Durso, S.L. and M.J. Burguin. 1988. Mosquito abundance and arboviral activity in the Coachella Valley - 1987. Proc. Calif. Mosq. Vector Control Assoc. 56: 20-25.

Kadlec, R. H. and R. L. Knight. 1996. Treatment Wetlands. CRC Press, Boca Raton, FL.

Keiper, J.B., J. Jiannino, J. Beehler and W.E. Walton 1999. Distribution and abundance of Culicidae and Chironomidae (Diptera) following storm damage in a southern California constructed wetlands. Proc. Mosq. Vector Control Assoc. Calif. 67: 47-54.

Knight, R.L., W.E. Walton, G. O'Meara, W.K. Reisen, and R. Wass. 2001. Design strategies for effective mosquito control in constructed treatment wetlands. Water Sci. Tech. In press.

National Research Council (NRC) 2001. Compensating for Wetland Losses Under the Clean Water Act. www.nap.edu/books/0309074320/html

Reeves, W.C. (ed.) 1990. Epidemiology and Control of Mosquito-borne Arboviruses in California, 1943-1987. CMVCA, Sacramento, CA.

Russell, R.C. 1999. Constructed wetlands and mosquitoes: health hazards and management options - An Australian perspective. Ecol. Eng. 12: 107-124.

Sartoris, J.J., J.S. Thullen, L.B. Barber and D.E. Salas. 2000. Investigation of nitrogen transformations in a southern California constructed wastewater treatment wetland. Ecol. Eng. 14: 49-65.

Service, M.W. 1993. Mosquito Ecology. 2nd ed. Chapman and Hall. London, U.K.

U.S. Bureau of Reclamation (USBR). 2001. Tres Rios Demonstration Wetlands, Project Status and Water Quality Data Analysis Report, Phase I-1995 to 1998. USBR. Denver, CO.

U.S. Environmental Protection Agency (USEPA). 2000. Constructed Wetlands Treat-ment of Municipal Wastewaters. EPA/625/R-99/010. Office Res. Dev. Cincinnati, OH.

Vymazal, J., H. Brix, P.F. Cooper, M.B. Green and R. Haberl (eds.). 1998. Constructed Wetlands for Wastewater Treatment in Europe. Backhuys Publishers, Leiden, The Netherlands.

Walton, W.E., P.D. Workman, L.A. Randall, J.A. Jiannino, and Y.A. Offill. 1998. Effectiveness of control measures against mosquitoes at a constructed wetland in southern California. J. Vector Ecology 23: 149-160.

Walton, W.E., P.D. Workman, and C.H. Tempelis. 1999. Dispersal, survivorship, and host selection of *Culex erythrothorax* (Diptera: Culicidae) associated with a constructed wetland in southern California. J. Medical Entomology 36: 30-40.