



THE ROLE OF WETLANDS IN WATERSHED MANAGEMENT LESSONS LEARNED

SECOND CONFERENCE ON THE USE OF
WETLANDS FOR WASTEWATER TREATMENT
AND RESOURCE ENHANCEMENT

CONFERENCE CO-CHAIRS
ROBERT A. GEARHEART
BRAD A. FINNEY

CONFERENCE COORDINATOR
BARBARA SMITH

PROCEEDINGS EDITORS
SHERI WOO
BARBARA SMITH
BRAD A. FINNEY

MAY 18 – 19, 2000

HUMBOLDT STATE UNIVERSITY

Table of Contents

The State of the Art and the Artistic Statement of Constructed Wetlands Engineering	1
<i>Sheri Woo</i>	
Case Study: Success and Failure of First-Generation Municipal Treatment Wetlands in the Pacific Northwest	5
<i>Gregory Zentner</i>	
Innovative Stormwater Detention/Treatment Wetland Facility Benefits Regional Salmon & Wildlife.....	17
<i>Keith MacDonald</i>	
EPA Web Accessible Constructed Wetlands Descriptive and Performance Data Base.....	23
<i>Brad A. Finney</i>	
Multi-County Wetland Projects for the Improvement of Surface Waters and Groundwater Recharge	29
<i>Stephen R. Lyon</i>	
Design of Constructed Wetlands – Lessons Learned.....	35
<i>Ronald W. Crites</i>	
An Innovative Onsite Treatment and Disposal System for Restaurant Strength Wastewater	41
<i>Jeffrey K. Anderson</i>	
The Impact of Emergent Vegetation on Water Quality Improvement and Mosquito Production in a Wastewater Treatment Wetland.....	45
<i>William E. Walton, James J. Sartoris, Joan S. Thullen, and Larry B. Barber</i>	
Data from Reference Wetlands Optimizes Treatment System Design and Operation	53
<i>Keith MacDonald</i>	
Emergent Macrophyte Density in a Constructed Wetland System for Wastewater Treatment	61
<i>Sophie Lagacé, Robert A. Gearheart, and Curtis Miller</i>	
Terrestrial Plant Carbon Amendments for Denitrification in an Open Water Shorebird Mitigation Wetland.....	69
<i>Noah Hume and Alex Horne</i>	
Phosphorus Retention Capacity of two Filter Media for use in Constructed Wetlands: Preliminary Investigations	75
<i>Margaret G. Forbes</i>	
Vector Control at the Tres Rios Demonstration constructed Wetland Project	81
<i>Roland Wass and Paul Kinshella</i>	
Understanding Tidal Marsh Conversion in South San Francisco Bay	91
<i>Neal Van Keuren</i>	
Shore-Protection Planning of Wetlands Located near Navigation Channels	99
<i>Adele Militello and Nicholas C. Kraus</i>	
A Wet Pond as a Stormwater Runoff BMP – Case Study.....	109
<i>Scott M. Taylor and Brian Currier</i>	

Update on the Role of Constructed Wetlands in Meeting Wastewater Discharge Requirements	117
<i>Robert K. Bastian</i>	
Reef Protection and Mangrove Restoration through Constructed Wetlands Treatment of Urban Stormwater	125
<i>Steven McHaney, Fred Smith, and Ignacio Cabrera</i>	
Performance of High Elevation Aerated Lagoons and Treatment Wetlands at Ouray, Colorado	137
<i>Richard H. Bowman</i>	
A Review of Treatment Kinetics for Constructed Wetlands	147
<i>George Tchobanoglous, Ron Crites, Bob Gearheart, and Woody Reed</i>	
Comparison of Design Approaches to Constructed Wetland Generalized Plug Flow Reactor Model	159
<i>Robert A. Gearheart and Jeff Anderson</i>	
Metals Removal and Accumulation in the Sacramento Demonstration Wetlands.....	171
<i>Blake Tresan</i>	
Nitrogen Farming: A Market Based Solution to a Variety of Chronic Environmental Problems	181
<i>Donald L. Hey</i>	
Middle Egypt Instream Treatment Wetlands Pilot Testing.....	183
<i>J.H. Hendrich and W.P. Saunders</i>	
A Quantitative Study of Periphyton Colonized on Artificial Substrates at the City of Arcata's Marsh Pilot Project.....	191
<i>Taku Tojimbara</i>	

THE IMPACT OF EMERGENT VEGETATION ON WATER QUALITY IMPROVEMENT AND MOSQUITO PRODUCTION IN A WASTEWATER TREATMENT WETLAND

William E. Walton¹, James J. Sartoris², Joan S. Thullen² and Larry B. Barber³

¹ Dept of Entomology, University of California, Riverside
Riverside, California

² U. S. Geological Survey, Denver, Colorado

³ U.S. Geological Survey, Boulder, Colorado

SUMMARY

In summer 1994, a 9.9 ha multipurpose wetland was constructed and planted with two species of bulrush (*Schoenoplectus californicus* and *S. acutus*) at Eastern Municipal Water District's Hemet/San Jacinto Regional Water Reclamation Facility in southern California. The wetland system was designed to polish an average of 3,785 m³ d⁻¹ of secondary-treated effluent with nitrogen removal as the primary objective. Weekly monitoring of inflow and outflow water quality was supplemented with biannual synoptic surveys of water quality at 45 stations throughout the wetland, vegetation surveys using standard quadrat measurements and color infrared photography, and routine monitoring of aquatic insect populations, particularly mosquitoes.

Temporal and spatial distribution patterns of the nitrogen series (total ammonia, nitrite, nitrate, and organic nitrogen), total organic carbon, and ultraviolet absorbance at 254 nm within the wetland, indicated that the system's nitrogen dynamics were influenced by variations in nitrogen loading from the effluent and by the degree of coverage and age of the emergent vegetation.

Spatial trends of mosquito production were highly correlated with Total Organic Carbon (TOC) concentrations in the wetland. Three years after beginning operation, summer host-seeking mosquito populations increased approximately one order of magnitude per year, reaching nearly 40,000 females per trap per night by 1997. Attempts to reduce the mosquito populations during 1997 were either unsuccessful or minimally effective because thick emergent vegetation hindered the contact of control agents with the mosquitoes.

In order to improve the efficiency of nitrogen transformations in the wetland, and to reduce mosquito production, the wetland was reconfigured to reduce the proportion of surface area that is capable of supporting emergent vegetation. Prior to reconfiguring the wetland, dried emergent vegetation was burned. Although burning has drawbacks (such as impact on air quality and destruction of the organic carbon pool for denitrifying bacteria), burning saved approximately \$80,000 over mechanical removal and disposal of bulrush. We evaluated the effects of three vegetation management strategies, which included burning, on mosquito production, vegetation regrowth and water quality in replicated experimental wetlands. A

reduction of emergent vegetation significantly improved the wetlands' capacity to improve water quality by increasing dissolved oxygen, and by reducing nutrient loading caused by the breakdown of plant biomass.

STUDY SITES

Demonstration wetland

Our studies were carried out at the Multipurpose Wetlands Research and Demonstration Project located at Eastern Municipal Water District's Hemet/San Jacinto Regional Wastewater Reclamation Facility (RWRF) in San Jacinto, California (33°48'N, 117°1'W, 454 m ASL). A 9.9 ha multipurpose wetland was primarily designed to remove nitrogen from secondary-treated effluent from a nearby treatment plant. Ancillary uses for the wetland included providing habitat for wildlife, and siting public education in water and wildlife conservation. The wetland comprised five inlet marshes (inlet marshes 1-5), a comparatively deep (1 ha, maximum depth = 1.8 m) central pond and two polishing marshes (outlet marshes A and B) (Sartoris et al. 2000). Water depth in the inlet and polishing marshes was 50-70 cm during spring through autumn. Inlet marshes had aspect ratios of 2:1 or 3:1, and consisted of bands of emergent vegetation interspersed with 2-4 bands of open water. Three central marshes drained into a connecting marsh before entering the central pond; two outside marshes drained directly into the central pond. The wetland was planted with hardstem bulrush [*Schoenoplectus acutus* (G.H.E. Muhlenberg ex J. Bigelow)] and California bulrush [*S. californicus* (C.A. Meyer)] in September 1994. The planting and flooding of the demonstration wetland are described in detail by Sartoris et al. (2000). After 15 months of continuous inundation, the wetland was incorporated into the RWRF treatment chain. The RWRF is an activated sludge process plant producing $2.84 \times 10^4 \text{ m}^3 \text{ d}^{-1}$ of secondary-treated effluent. Approximately 13 to 26% of the effluent (3,785 to 7,570 $\text{m}^3 \text{ d}^{-1}$) was routed to the wetlands for polishing.

Research cells

The effects of three vegetation management strategies on vegetation regrowth, mosquito production, and water chemistry were studied in eight 0.1 ha experimental wetlands (14 m by 69 m research cells) at the San Jacinto research facility. The research cells were reconfigured from having either a single deep pond or no deep pond to each research cell having 2 deep ponds (depth ~ 2 m). One pond was adjacent to the inflow weir and a second pond was located approximately 2/3 of the distance between inflow and outflow weirs. Shallow regions (depth ~ 0.5 m) were situated between the two ponds and between the second pond and the outlet weir.

METHODS

Demonstration wetland studies

Weekly inflow and outflow water samples and biannual synoptic water quality surveys (carried out in May and September 1996 and 1997) were analyzed for concentrations of total ammonia nitrogen, total Kjeldahl nitrogen, nitrite nitrogen, and nitrate nitrogen using standard methods (American Public Health Association (APHA) 1995). Synoptic water quality samples were collected at 45 stations throughout the wetland in less than 4 h (Sartoris

et al. 2000). TOC and ultraviolet absorbance (UV_{254}) of unfiltered samples were measured using methods described by Sartoris et al. (2000). Water inflow and outflow were measured daily using flow meters.

Vegetation cover was estimated from aerial photographs taken 2 to 3 times annually, at approximately 450 m above the water surface. The proportion of the wetland surface as open water or covered by each of the two bulrushes was determined after image processing of the photographs and was plotted using ARC/INFO software (Sartoris et al. 2000). Vegetation density was measured several times per year using 1 m² or 0.25 m² quadrats assigned randomly throughout the vegetated regions in the wetland.

Immature and adult mosquito populations were surveyed using the methods described by Walton et al. (1998a). Host-seeking mosquitoes were collected using three carbon dioxide-baited suction traps. Emerging adults were collected using eighty-four 0.25 m² emergence traps (Walton et al. 1999a). Immature mosquitoes were sampled by dipping (Service 1993) along three transects in each marsh of the wetland. On each date, 105 dips were taken throughout the wetland. Mosquitofish (*Gambusia affinis*) were not present in the wetland from 1994 through 1998.

Research cell studies

In November 1997, the dried emergent vegetation (bulrush, *Schoenoplectus californicus*) in the research cells was burned prior to reconfiguration for the vegetation management study. Burning quickly consumed the aboveground bulrush biomass; however, the below ground roots were not adversely affected. Following burning, a rock bucket attached to a backhoe was used to reduce bulrush root densities in the shallow zones of five research cells by approximately 50%. In the shallow regions of two of these cells, hummocks (approximately 4m x 2m x 1m, LWH), were constructed with the backhoe. By restricting vegetation to the hummocks, vegetation coverage in the shallow zones was expected to be reduced by approximately 50%. The three remaining cells were left unmanipulated after burning. The three vegetation management practices will be referred to as R (burning and rock bucket), H (burning, rock bucket and hummocks) and C (control: burning only).

Flooding of the research cells with secondary-treated effluent began on July 13, 1998. In order to examine the effects of burning on levels of metal contaminants and water quality of the first outflow event, water levels in the research cells were maintained to avoid overflow through the outlet weir for approximately one month. Thereafter, water residence time was 13 to 18 d. Water quality was measured weekly using standard methods for wastewater analyses (APHA 1995). Dissolved oxygen concentration, ammonia nitrogen, nitrate nitrogen, nitrite nitrogen, total Kjeldahl nitrogen, total phosphorus, Biochemical Oxygen Demand (BOD), total suspended solids, and total coliform bacteria in the inlet and outlet water were measured in the field or at the water district's laboratory.

Vegetation density was measured several times per year using 0.25 m² quadrats assigned randomly throughout the vegetated regions of each research cell. Data on other vegetation characteristics (surface cover, plant height, stem diameter, biomass, etc.) were also collected during two surveys per year.

Temporal and spatial trends of mosquito production from the research cells were determined using 0.25 m² emergence traps (Walton et al. 1999a). Four traps were placed in each of the two marshes of each cell on July 21 or 22. Emerging insects were collected weekly from July 29 through September 29. A group of samples also was collected on October 13. Details of the sampling protocol are described by Walton et al. (1999b).

Immature mosquitoes were sampled weekly by combining three or five 350 ml dip samples at 16 stations positioned equidistantly along the research cell periphery and at 4 stations along each of two transects through the cell interior. Developmental stage and abundance of immature mosquitoes were determined at 25X and 50X magnification using a stereo dissecting microscope.

RESULTS AND DISCUSSION

Demonstration wetland studies

Nitrogen loading rates increased three-fold from January 1996 (total N: 4.83 kg ha⁻¹ d⁻¹) to September 1997 (15.40 kg ha⁻¹ d⁻¹) and total nitrogen removal efficiency declined from about 60% during 1996 to 27% during 1997 (Sartoris et al. 2000). Ammonia nitrogen and organic nitrogen were 55 to 75% and 11 to 25%, respectively, of the inflow nitrogen. While the percentage of nitrate nitrogen increased nearly ten-fold (3 to 31%) across the wetland during spring 1996, the proportion of nitrate to total nitrogen in inflow versus outflow waters, did not change appreciably thereafter, indicating a decline of nitrification within the wetlands (Sartoris et al. 2000).

Bulrush areal coverage increased nearly 18-fold (0.18 to 3.22 ha) during the first year, 2.25-fold during the second year, and only 1.1-fold during the third year of operation, covering 90% of the colonizable shallow zones by September 1997 (Sartoris et al. 2000). In addition to rapidly filling in the shallow zones in the wetland, bulrush culm densities also increased asymptotically. Bulrush culm densities increased nearly two orders of magnitude between spring 1995 and autumn 1996. Thereafter, mean culm densities changed very little; however, *S. acutus* culm densities exhibited greater annual variation than did *S. californicus* culm densities because the above-substrate biomass of *S. acutus* mature stands died off annually beginning in January 1997. The rapid regrowth of hardstem bulrush was indicated by the equivalence of culm densities of both bulrushes by July 1997.

TOC concentrations in areas dominated by *S. acutus* were generally higher than in areas dominated by *S. californicus*. The ratio of U₂₅₄: TOC was used to provide an indication of the relative contribution of humic substances to the TOC pool. TOC and dissolved organic carbon (DOC) levels were approximately equal (Sartoris et al. 2000). Although U₂₅₄: TOC declined downstream of the inlets during spring 1996, high TOC values in inlet marshes dominated by *S. acutus* may have contributed to this trend. The U₂₅₄: TOC values progressively increased as water moved through the inlet marshes in September 1997.

In areas with *S. acutus*, production of adult *Culex tarsalis* was 3 to 4 times greater than in inlet marshes containing predominantly *S. californicus*. This mosquito is a great public

health concern because it is the predominant vector of St. Louis encephalitis and western equine encephalomyelitis viruses in California. Production and abundance of immature stages of this mosquito were associated with high TOC concentrations. The abundance of mosquito larvae increased approximately one order of magnitude per year from ca. 0.1 larva dip⁻¹ in 1995, to 1-3 larvae dip⁻¹ in 1996 to ca. 10 larvae dip⁻¹ in 1997. Increases in larval numbers were associated with increased vegetation coverage and nutrient loading rates.

Culex erythrothorax larvae are associated with vegetation and are difficult to sample adequately by standard methods (Walton and Workman 1998, Workman and Walton 2000); consequently, this species was rarely collected in larval surveys. However, this adult mosquito was prevalent in the adult host-seeking mosquito collections, often exceeding *Cx. tarsalis* abundance by 10-fold or more. The numbers of adult host-seeking populations at the wetland during the summer increased about an order of magnitude per year from ca. 500 females trap⁻¹ night⁻¹ during 1995 to nearly 40,000 females trap⁻¹ night⁻¹ in 1997. Unlike *Cx. tarsalis* which dispersed > 2 km per night from the wetland, *Cx. erythrothorax* rarely moved more than 1 km from the wetland, and often returned to the wetland after feeding on hosts in the surrounding farmland (Walton et al. 1998b). When annual abundance was integrated across each year, adult abundance increased approximately 6-fold per year. *Culex erythrothorax* is thought not to represent a significant public health concern, but adult females feed preferentially on mammals and will feed during the day if disturbed from wetland vegetation.

Attempts to reduce mosquito populations using environmentally friendly, mosquito-specific bacterial larvicides were either unsuccessful or minimally successful (Walton et al. 1998a). Dense emergent vegetation inhibited penetration of the bacterial larvicides to the water surface, and the most significant declines in mosquito abundance occurred towards the end of the annual period of mosquito activity (approximately April through October) in conjunction with natural declines of adult mosquito populations.

Research cell studies

Bulrush recolonized slowest in the H cells 9 (cells burned, scraped with a rock bucket, with hummocky) and fastest in the C cells (cells with the control burn only). Bulrush densities (culms m⁻²) in the C and R cells (cells burned and scraped) increased 6 times between July and October 1998; however, bulrush densities in the R cells were approximately one-half that in the C cells. Bulrush densities increased only 2-fold in H cells during 1998. Bulrush densities in C and R cells did not differ significantly during 1999 (F-test, $P > 0.05$). Bulrush densities and coverage increased in the H cells between years and during 1999. Even though the interiors of the H cells contained about 50% the vegetation in the interiors of the cells in other treatments, bulrush became dense along the gently sloping perimeters of the H cells.

During 1998, adult mosquito production from H cells and R cells was 2% and 25%, respectively, of adult mosquito production from the C cells. The number of *Culex* spp. emerging per square meter of vegetated surface from the C cells was 100- and 10-times greater than from the H and R cells, respectively, during the second week after flooding. Thereafter, emerging mosquitoes were not collected from the H cells during 1998. Adult production declined during the four to six weeks after flooding in the C and R treatments and

remained at a low level of emergence (< 2 individuals m^{-2}) through mid-October 1998. The abundance of mosquito larvae in dip samples showed trends among the treatments similar to those observed in the emergence traps, except declines of abundance occurred one week earlier than those observed for emerging adults.

During 1999, larval abundance and adult production per square meter of vegetated water surface differed very little among the treatments on most dates; however, on a per pond basis, adult mosquito production remained lowest in the H cells because vegetation cover was also lowest.

The effectiveness of nutrient removal and reduction of suspended particulates did not differ significantly among the three vegetation management treatments. Greater nitrification of the high ammonia concentrations from the influent was achieved in the H cells than in the other treatments because dissolved oxygen concentrations and pH were highest in the H cells.

The hummocks showed considerable promise as a method for slowing the proliferation of bulrush growth and significantly reducing mosquito production during the two years after vegetation management practices were carried out. Larvivorous fish, such as the mosquitofish (*Gambusia affinis*), were not added to the cells in this study, but would be expected to reduce mosquito populations in the comparatively open H cells to an extent greater than was observed in the fishless wetlands during 1999.

In the arid southwestern United States, constructed treatment wetlands that utilize emergent vegetation to polish wastewater with high reduced nitrogen concentrations can present significant public health concerns. Nutrients supplied by wastewater and comparatively mild environmental conditions (e.g., a long, warm growing season and continuous water supply) facilitate the rapid proliferation of emergent vegetation and its concomitant increase in mosquitoes, that potentially vector disease causing pathogens.

Large populations of resident and migratory birds that utilize wetlands serve as potential pathogen reservoirs. In the Southwest, where human neighborhoods often develop near wetlands, large mosquito populations present a significant public health problems. Greater attention to land use surrounding constructed treatment wetlands merits more consideration than it is presently given. Wetland design and management practices that diminish the surface area covered by dense, emergent vegetation, will help reduce mosquito production and conflicts between public health agencies and wetlands operators. Such practices may also enhance the nutrient removal capabilities of this wetland.

REFERENCES

- American Public Health Association. (1995). Standard Methods for the Examination of Water and Wastewater. 19th ed. American Public Health Association. Washington, D.C.
- Sartoris, J. J., Thullen, J. S., Barber, L. B. and Salas, D. E. (2000). Investigation of nitrogen transformations in a southern California constructed wastewater treatment wetland. Ecological Engineering 14: 49-65.

- Service, M. W. (1993). *Mosquito Ecology: Field Sampling Methods*. 2nd ed. Chapman and Hall, London. 988 pp.
- Walton, W. E., Chan, K., Gould, L. H. and Keiper, J. B. (1999b). Mosquito production from three vegetation management practices for constructed treatment wetlands in southern California: preliminary findings. *Proc. Mosq. Vector Control Assoc. CA.* 67: In press.
- Walton, W. E. and Workman, P. D. (1998). Effect of marsh design on the abundance of mosquitoes in experimental constructed wetlands in southern California. *Journal of the American Mosquito Control Association* 14: 95-107.
- Walton, W. E., Workman, P. D. and Keiper, J. B. (1999a). An inexpensive collapsible pyramidal emergence trap for the assessment of wetland insect populations. *Proc. Mosq. Vector Control Assoc. CA.* 67: In press.
- Walton, W. E., Workman, P. D., Randall, L. A., Jiannino, J. A. and Offill, Y. A. (1998a). Effectiveness of control measures against mosquitoes at a constructed wetland in southern California. *Journal of Vector Ecology* 23: 149-160.
- Walton, W. E., Workman, P. D. and Tempelis, C. H. (1998b). Dispersal, survivorship, and host selection of *Culex erythrothorax* associated with a constructed wetland in southern California. *Journal of Medical Entomology* 36: 30-40.
- Workman, P. D. and Walton, W. E. (2000). Emergence patterns of *Culex* mosquitoes at an experimental constructed treatment wetland in southern California. *Journal of the American Mosquito Control Association* 16(2): In press.