

107001

ENTERED



PROCEEDINGS OF THE SECOND INTERNATIONAL
CONFERENCE ON WETLANDS & REMEDIATION

Edited by

Karl W. Nehring
Susan E. Brauning

32176





WETLANDS and REMEDIIATION II

PROCEEDINGS OF THE SECOND INTERNATIONAL
CONFERENCE ON WETLANDS & REMEDIATION

Burlington, Vermont, September 5-6, 2001

EDITORS

Karl W. Nehring and Susan E. Brauning
Battelle



BATTELLE PRESS
Columbus • Richland

v

213

225

rs.

235

it.

243

251

255

263

271

181

89

5

Library of Congress Cataloging-in-Publication Data

International Conference on Wetlands and Remediation (2nd : 2001 : Burlington, Vt.)
Wetlands and remediation II : proceedings of the Second International Conference
on Wetlands and Remediation, Burlington, Vermont, September 5-6, 2001 / edited by
Karl Nehring, Susan E. Brauning.

p. cm.

Includes bibliographical references (p.).

ISBN 1-57477-122-1 (hard cover : alk. paper)

1. Wetland management--Congresses. 2. Wetland conservation--Congresses.
I. Nehring, Karl, 1949-- II. Brauning, Susan E., 1956-- III. Title.

QH87.3 .I57 2001
333.91'8153--dc21

2001056620

Printed in the United States of America

Copyright © 2002 Battelle Memorial Institute. All rights reserved. This document, or
parts thereof, may not be reproduced in any form without the written permission of
Battelle Memorial Institute.

Battelle Press
505 King Avenue
Columbus, Ohio 43201, USA
614-424-6393 or 1-800-451-3543
Fax: 1-614-424-3819
Internet: press@battelle.org
Website: www.battelle.org/bookstore

For information on future environmental conferences, write to:

Battelle
Environmental Restoration Department, Room 10-123B
505 King Avenue
Columbus, Ohio 43201-2693
Phone: 614-424-7604
Fax: 614-424-3667
Website: www.battelle.org/conferences

CONTENTS

Foreword

vii

213

Remediation of Wetlands Contamination

225

**Remediating Chlorinated Solvents in Wetlands: Natural Processes or an
Active Approach?** *J.H. Pardue*

1

235

**Efficiency of Natural Attenuation of Chlorinated Solvents in Two
Freshwater Wetlands.** *M.M. Lorah, D.R. Burris, and L.J. Dyer*

9

**Phytobuffering of Chlorobenzenes via Willows at a Louisiana Superfund
Site.** *W.D. Constant and P.B. Jones*

17

43

Fate of TCE in Constructed and Natural Wetland Mesocosms.
G.R. Kassenga and J.H. Pardue

25

51

**Effect of Sampling Method on Measured Porewater Concentrations in a
Wetland Contaminated by Chlorinated Solvents.** *L.J. Dyer, M.M. Lorah,
and D.R. Burris*

33

55

**Biphasic Desorption of Hydrophobic Organic Contaminants in Highly
Organic Wetland Soils.** *W.S. Shin and J.H. Pardue*

41

13

Bioavailability of Nonionic Organics to Wetland Plants. *C. Gomez and
J. Pardue*

49

1

**Study of Natural Attenuation Processes in a Hydrocarbon-Impacted
Wetland.** *B.J. Moore, R.R. Dupont, W.J. Doucette, J.E. Armstrong, and
J.V. Headley*

57

**Remediating Wetlands with Mercury Contamination at the Nyanza
Superfund Site.** *A. Kabir, G. Morin, J.M. Penko, C. Turek, D. Ellis, and
K. Thomson*

65

Modeling Cesium Partitioning in the Rhizosphere. *L.S. Siegel,
A.N. Alshawabkeh, and M.A. Hamilton*

73

Investigation and Distribution of Selenium at Soda Lake, Wyoming.
D.J. Berlin and T. Thompson

83

**Isolation and Performance of a Wetland-Associated Perchlorate-Reducing
Bacterium.** *M.A. Ives, R.A. Gearhart, and W.J. Snible*

93

Investigation of Wetland Characteristics Using Finite Element Method. <i>L. Yilmaz</i>	101
 <i>Wetlands for Wastewater Treatment</i>	
Wetland Technologies for Water and Wastewater Management: Inside the Black Box. <i>B.G. Warner</i>	107
Assessment of a Reconstructed Wetland for Remediation of Chlorinated Solvents. <i>D.E. Richard, K.P. England, D. Connell, J.J. Berns, and P.J. Hirl</i>	117
On-Site Remediation of Petroleum Contact Wastes Using Subsurface-Flow Wetlands. <i>S.D. Wallace</i>	125
Treatment of Acid Mine Drainage by a Natural Wetland. <i>S.N. Groudev, K. Komnitsas, I.I. Spasova, and I. Paspaliaris</i>	133
Column Study of Organic Substrates: Passive Acid Mine Drainage Treatment. <i>P.A. Hagerty and S.M. Furjanic</i>	141
Distribution of Metal Precipitates in a Metal-Contaminated Wastewater Treatment Reactor. <i>Z.-X. Quan, H.-J. La, Y.-G. Cho, and S.-T. Lee</i>	153
Treating Landfill-Contaminated Groundwater Using Surface-Flow Wetlands. <i>D. Novak, D. Plomb, and W. Allen</i>	161
Treatment of Diffuse-Source Pollution with Small-Scale Constructed Wetlands. <i>K. Frankowski</i>	169
Constructed Wetlands for Airport Runoff — The London Heathrow Experience. <i>P. Worrall, D.M. Revitt, G. Prickett, and D. Brewer</i>	177
Sustainable Management of Aircraft Anti/De-Icing Process Effluents Using a Subsurface-Flow Treatment Wetland. <i>J.D. Karrh, J. Moriarty, J.J. Kornuc, and R.L. Knight</i>	187
Treatment of Cheese-Processing Waste Using Subsurface-Flow Wetlands. <i>S.D. Wallace</i>	197
Treating Dairy Parlor Wastewater Using Subsurface-Flow Constructed Wetlands. <i>P. Mantovi, S. Piccinini, N. Marmiroli, E. Maestri, and S. Tagliavini</i>	205

A Full-Scale System with Wetlands for Slaughterhouse Wastewater Treatment. <i>H.M. Poggi-Varaldo, A. Gutiérrez-Saravia, G. Fernández-Villagómez, P. Martínez-Pereda, and N. Rinderknecht-Seijas</i>	
Treatment of Septic Tank Effluent Using Vertical-Flow Constructed Wetlands. <i>L. Cui, S.-M. Luo, X.-Z. Zhu, and Y.-H. Liu</i>	
Microbial Biomass and Activity in Soil Fed with Different Wastewaters. <i>M. Schwarz, S. Fuchs, and H.H. Hahn</i>	
 <i>Wetlands Design, Construction, and Operation</i>	
Developing a Constructed Wetland Center at the University of Vermont. <i>D.H. Whitney, N.J. Hayden, W.C. Hession, and M. Tignor</i>	
Wetlands Creation Filtering Runoff from an Army Vehicle Test Course. <i>N. Cavallaro</i>	
Field Studies of Enhanced Phosphorus Removal from Constructed Wetland Effluents. <i>N. Calder and B.C. Anderson</i>	
Nitrification/Denitrification: Full-Scale Subsurface-Flow Constructed Wetlands Using Airlift Pumps. <i>A. Hanson, L.E. Mimbela, R. Polka, and W. Zachritz</i>	
An Assessment of the Role of Reeds, <i>Phragmites australis</i>, in the Treatment of Wastewaters Using Simulated Wetlands. <i>A. Pervez</i>	
Unplugging the Bed of a Subsurface-Flow Wetlands Using H₂O₂. <i>A. Hanson, L.E. Mimbela, R. Polka, and W. Zachritz</i>	
Atmospheric Oxygen Diffusion Rates in Constructed Wetlands. <i>M.-Y. Wu, E.H. Franz, and S. Chen</i>	
Influence of Ionic Tracer Selection on Wetland Mixing Characterization Studies. <i>R.C. Jamieson, T.S. Jamieson, R.J. Gordon, G.W. Stratton, and A. Madani</i>	
 <i>Wetlands Ecology and Restoration</i>	
Use of Ecological Services to Scale Compensation for Wetlands Impacts. <i>J.A. Weier, M.L. Rockel, K. Parker Brown, B.E. Smith, and D.R. Jordan</i>	

Investigations into Wetland Carbon Sequestration as Remediation for Global Warming. <i>R.M. Thom, S.L. Blanton, A.B. Borde, G.D. Williams, D.L. Woodruff, and M.H. Huesemann</i>	311
TOC Fluctuations in a Wetland Under Restoration, Wainfleet Bog, Ontario, Canada. <i>D.R. Van Stempvoort and A.S. Crowe</i>	321
Environmental Monitoring During Construction of a Subaqueous Sand Cap. <i>K. Cunningham, T. Thompson, C.E. Houck, L. Mortensen, and K. Smayda</i>	329
Wetlands Mitigation/Protection During an Asbestos Disposal Site Cleanup. <i>C.A. Merritt</i>	337
Patterns of Nitrate Attenuation in Riparian Wetlands. <i>A.-C. Cosandey, V. Maître, C. Guenat, and J.-C. Védy</i>	347
N-15 Signals of Nitrogen Source and Fate in a Semiarid Wetland. <i>J.M. Heikoop, D.D. Hickmott, D. Katzman, P. Longmire, and R.S. Beers</i>	355
Riparian Wetland Function in Channelized and Natural Streams. <i>J. Magner</i>	363
Total N, Total P, and Organic Matter Content in Floodplain Soils in Xianghai Natural Reserve, China. <i>W. Deng, J. Zhai, Heyan, Yuguoying</i>	371
Author Index	381
Keyword Index	385

device. This study is part of a European project called NICOLAS: Nitrogen Landscape Structures in Agricultural Environments, which was backed by the Environment & Climate Directorate of the European Union, n° 7-0395.

CES

d), 1998. *A sound reference base for soils*. Collection techniques et NRA editions, Paris.

A.J. Gold, P.M. Groffman and P.A. Jacinthe, 1999. "Ground water nitrate in the subsoil of forested and mowed riparian buffer zones." *Journal of Environmental Quality*. 28: 962-970.

A.C., C. Guenat, M. Bouzelboudjen, V. Maître and R. Bovier, 2001. "The modeling of functional units of soil process based on a three-soil-horizon cartography: an example applied to denitrification in a forest." *Geoderma*.

A.C., C. Guenat, V. Maître and J.C. Védry, 2001, submitted-b, "Temporal patterns in different horizons of two riparian wetland soils." *European soil science*.

A., D. Fitzgerald, A.R. Hill and R. Aravena, 2000. "Nitrate dynamics in a riparian zone: hydrology and hydrologic flow path in a river riparian zone." *Journal of Environmental Quality*. 29: 1075-1084.

1989. *Carte mondiale des sols. Légende révisée*. Unesco, Rome, 106 pp.

1996. "Nitrate Removal in Stream Riparian Zones." *Journal of Environmental Quality*. 25: 743-755.

., N.K. Kaushik, J.T. Trevors and H.R. Whiteley, 1999. "Review: Nitrate dynamics in temperate climate riparian zones." *Water, Air, Soil Pollution*. 111: 1-10.

1997. T.P. Burt, 2001. NICOLAS: Nitrogen Control by Landscape Structures. Project: 1997-2000 ENV4-CT97-0935. Final Report, European Commission DGXII.

and D.L. Brakensiek, 1989. "Estimation of soil water retention and hydraulic properties." In: H.J. Morel-Seytoux (Ed.), *Unsaturated Flow in Hydrologic Engineering and Practice*. Kluwer Academic, pp. 275-300.

., and R. Knowles, 1976. "Acetylene inhibition of nitrous oxide by soil bacteria." *Biochemistry, Biophysics Research Communication*. 69: 705-708.

N-15 SIGNALS OF NITROGEN SOURCE AND FATE IN A SEMIARID WETLAND

Jeffrey M. Heikoop, Donald D. Hickmott, Danny Katzman, Patrick Longmire and Robert S. Beers (Los Alamos National Laboratory, Los Alamos, New Mexico)

ABSTRACT: Nitrogen isotope measurements of plants and waters are being used to identify nitrogen fluxes and transformations occurring in a natural cattail marsh in Sandia Canyon at Los Alamos National Laboratory (LANL). The marsh receives inputs of treated sewage wastewater, containing nitrate enriched in ^{15}N ($\delta^{15}\text{N}$ of 32.4 ‰, concentrations up to 30 mg/L). Cattails growing near the head of the primary wetland have $\delta^{15}\text{N}$ values up to 37.8 ‰, suggesting that sewage nitrate is their main source of nitrogen with in-situ denitrification leading to further enrichment of the wetland nitrate pool. These cattails also have lower molar C/N ratios, relative to other cattails in the system, with values around 16. These results suggest that nitrogen is both lost from the system via denitrification and stored in plant material. Cattails growing near the distal end of the wetland, in more strongly reducing sediments that potentially have higher denitrification rates, were enriched in ^{13}C . This is due to decreased isotopic fractionation during uptake and assimilation of CO_2 , resulting from partial closure of stomata under physiological redox stress. These cattails were enriched in ^{15}N , relative to cattails growing in central portions of the wetland. Natural abundance level isotopic measurements of wetland plants and waters could provide an effective technique to identify spatial gradients in nitrogen inputs, outputs, and transformation, in both natural and constructed wetlands.

INTRODUCTION

Biogeochemical cycling of nitrogen in wetlands is an important factor in ecosystem structure and function, water quality and long-term sequestration of fixed nitrogen. Treatment wetlands, both natural and constructed, are effective systems at naturally attenuating nitrogen inputs. Nitrogen and carbon isotopic measurements of wetland plants and waters can potentially be used to identify nitrogen sources to wetlands (e.g. McClelland et al., 1997; McClelland, J.W. and Valiela, I., 1998), and to identify spatial gradients in nitrogen attenuating processes (see Kendall et al., 1997).

Various anthropogenic sources of nitrogen input to wetlands have distinct nitrogen isotope signatures. The ratio of the heavy isotope of nitrogen, ^{15}N , to the light isotope of nitrogen, ^{14}N , is reported as $\delta^{15}\text{N}$, where;

$$\delta^{15}\text{N} = ((R_{\text{sample}}/R_{\text{standard}})-1)*1000; R = ^{15}\text{N}/^{14}\text{N}; \text{units of } \text{‰}.$$

The international standard is atmospheric N_2 . Fertilizer nitrogen typically has values close to 0 ‰, whereas manure/sewage nitrogen typically has values of 10-

20 ‰ or higher (Heaton, 1986). Nitrogen from atmospheric deposition (NO_x , NH_3^+ , organic nitrogen) may have values less than 0 ‰. Nitrogen transforming processes, such as denitrification or ammonia volatilization, result in products enriched in ^{14}N . By mass balance, residual nitrogen source pools must be enriched in ^{15}N . Denitrification, for example, produces nitrogen gas that is up to 35 ‰ depleted relative to source nitrate, leaving residual nitrate pools highly enriched in ^{15}N (Heaton, 1986). Natural abundance level nitrogen isotope measurements have been used to identify sewage uptake by plants in freshwater and marine settings (e.g. Jordan et al., 1997; Costanzo et al., 2001), including ponds, marshes and coastal wetlands (McClelland et al., 1997; McClelland and Valiela, 1998; Cole et al., 2001; Heikoop et al., 2001). The United States Geological Survey is using plant-based isotope techniques to identify areas in the Everglades that are strongly reducing, where methylation of atmospheric mercury sources may occur (Kendall et al., 1997).

Carbon isotopes in plants have been used as an indicator of water stress. Plants under water stress partially close their stomata to avoid excessive losses of water as a result of transpiration. This limits exchange of CO_2 between internal plant pools of CO_2 and the external atmospheric pool. The net effect is that isotopic fractionation (preferential incorporation of ^{12}C) is reduced (Farquhar et al., 1982). Many wetland plants have a similar physiological response to redox stress in which they partially close their stomata under more strongly reducing conditions. *Typha domingensis*, for instance, has been shown to have significantly reduced stomatal conductance at an eH of -200 mV, while still maintaining relatively high rates of photosynthesis (Pezeshki et al., 1996). Carbon isotopes, therefore, are potentially useful in identifying redox gradients in wetlands that may be accompanied, for instance, by gradients in denitrification potential.

A small cattail marsh in Sandia Canyon, at Los Alamos National Laboratory (New Mexico, USA), receives inputs of nitrogen, mainly in the form of nitrate (concentrations up to 30 mg/L as nitrate), from Laboratory treated sewage wastewater. This wastewater is strongly enriched in ^{15}N , with $\delta^{15}\text{N}$ of 32.4 ‰ (Longmire, unpublished data). Background nitrate from meteoric precipitation has $\delta^{15}\text{N}$ of ~ 0 ‰ and concentrations of ~1 mg/L (Longmire, unpublished data). Waters discharged from the wetland have background concentrations of nitrate. The combination of isotopically distinct nutrient sources, and the presence of a nutrient attenuation gradient, make this an ideal setting to test the hypothesis that $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ of wetland plants reflect nutrient sources, and nutrient attenuating processes.

Site Description. The Sandia wetland is a ~ 1km long cattail (*Typha latifolia*) marsh developed on sediments deposited by runoff into the canyon during early (ca. 1950's) construction activities in the head of the watershed. These deposits, along with the stratigraphy of the underlying volcanic tuff, have resulted in a low gradient canyon reach suitable for wetland development. The climate is semi-arid and seasonally cold, with monsoonal rainfall occurring in July and August. Perennial water supply is provided by discharge from a wastewater treatment plant outfall. The outfall discharge is seasonally augmented by runoff from

snowmelt and monsoonal precipitation. In 1998 the outfall was relocated from a hillslope location at the head of the wetland to a location 0.4 km upcanyon. This has resulted in lowering of the water table and has possibly increased geomorphic instability in the upstream half of the wetland system, which had developed on terraces adjacent to the main channel. Several subsequent high-intensity flood events have caused incision and consequently partial dewatering of this upper portion of the wetland, resulting in reduced cattail growth. The downstream portion of the wetland (referred to as the primary wetland) remains perennially saturated and supports lush cattail growth.

MATERIALS AND METHODS

The upper 30 cm of cattail leaves were collected from cattails growing along the longitudinal axis (i.e. main surface water flow path) of the primary wetland. Additional samples were collected from the wetland periphery and from upstream terraces. Reference samples were collected from a nearby reservoir. Samples were homogenized to a fine powder and ~ 2-3 mg aliquots were analyzed by Elemental Analyzer – Continuous Flow – Isotope Ratio Mass Spectrometry, which provides N and C concentrations as well as $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values. Precision (1 σ) on 6 replicate analyses was 0.2 ‰ for $\delta^{15}\text{N}$, 0.15 ‰ for $\delta^{13}\text{C}$; 0.7 ‰ for [C] and, 0.07 ‰ for [N].

RESULTS AND DISCUSSION

The average $\delta^{15}\text{N}$ of reference cattails and cattails from the longitudinal axis and periphery of the primary Sandia Canyon wetland are shown in Figure 1. Reference cattails have low $\delta^{15}\text{N}$, whereas cattails from the main longitudinal axis of the marsh are highly enriched in ^{15}N , with average values of ~25 ‰, reflecting the importance of sewage nitrate. Cattails from the periphery of the wetland have intermediate values reflecting a

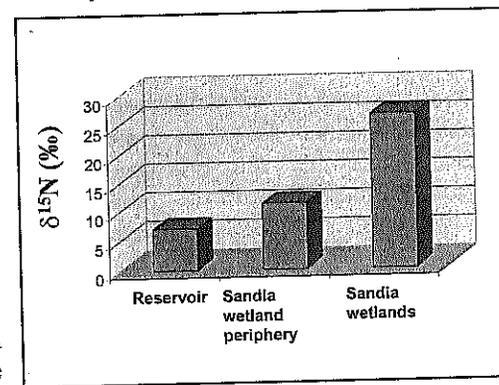


FIGURE 1. Mean $\delta^{15}\text{N}$ of reference cattails from a local reservoir, and of cattails from the Sandia Canyon wetland periphery and longitudinal axis.

mixture of sewage and background nitrogen inputs. The trend in $\delta^{15}\text{N}$ versus distance along the longitudinal axis is shown in Figure 2. Several cattails near the head of the wetland are highly enriched in ^{15}N , with values up to ~38 ‰. These are the highest reported $\delta^{15}\text{N}$ values for plants that we are aware of. The high values reflect the high $\delta^{15}\text{N}$ of the sewage nitrate source plus further enrichment of the wetland nitrate pool resulting from in-situ denitrification.

The curvilinear trend in $\delta^{15}\text{N}$ (Figure 2) is believed to reflect the decreasing importance of ^{15}N -enriched sewage nitrate with distance downstream along the longitudinal axis of the wetland, countered by increasing rates of

denitrification in more reducing downstream sediments. Sewage nitrate will be taken up by cattails at the head of the wetland and will also be eliminated by denitrification in waterlogged sediments. Sediments are reducing throughout the wetland, but the upstream portion of the wetland is characterized by a mix of gravel and organic matter (eH of +188 mV), while downstream sediments are composed of more strongly reducing organic-rich mud (eH of -240 mV).

The trend in molar C/N ratios is shown in Figure 3. Cattails at the head of the wetland have the highest N contents, suggesting that plant uptake is a direct factor in sewage wastewater nitrogen attenuation, in addition to the influence of denitrification mentioned previously.

Cattail $\delta^{13}\text{C}$ increases with distance downstream (Figure 4). $\delta^{13}\text{C}$ of atmospheric CO_2 will be constant over the length of the wetland. Since the wetland soils are saturated along the entire length of the primary wetland, the $\delta^{13}\text{C}$ signal is most likely a function of redox stress. In this sense, with detailed laboratory and field calibration, $\delta^{13}\text{C}$ of wetland plants could potentially be developed as a redox proxy, which could in turn be used to infer redox gradients that might be responsible for gradients in denitrification potential within wetlands. Plant-based $\delta^{13}\text{C}$ records could potentially be used to deconvolute the contributions of denitrification from nutrient source signals to $\delta^{15}\text{N}$ of wetland plants.

The few remaining relict cattails growing on a dewatered upstream terrace also had higher $\delta^{13}\text{C}$, relative to cattails growing in the adjacent channel (-26 = versus -27.6 ‰, $p < 0.01$). In this case, the higher $\delta^{13}\text{C}$ is due to water stress as

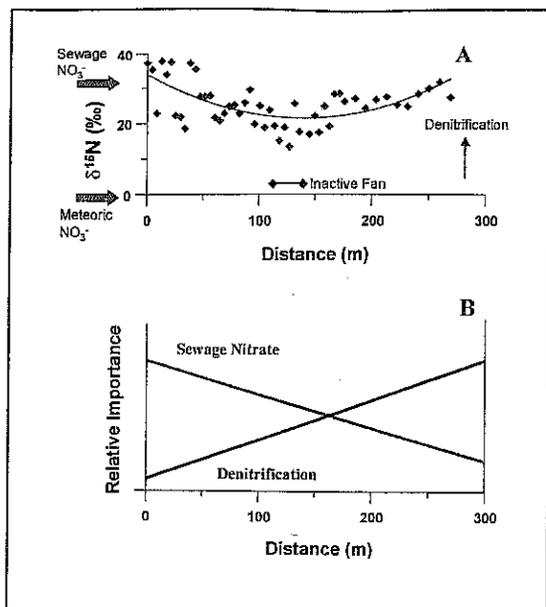


FIGURE 2. A. $\delta^{15}\text{N}$ of cattails versus distance along the longitudinal axis of the primary wetland. Values for sewage and meteoric nitrate are shown, as is the isotopic effect of denitrification. The curvilinear trend is significant at $p < 0.001$, with $R^2 = 0.40$. Location of an inactive alluvial fan is shown. This fan may preferentially deliver surface and subsurface side slope flow (with low $\delta^{15}\text{N}$ of nitrate) to the wetland. Groundwater has been observed at levels higher than the wetland, in holes augured into this fan following precipitation events. B. Qualitative model explaining the trend in cattail $\delta^{15}\text{N}$ (see text).

opposed to redox stress. Since higher eH values will tend to occur in less saturated soils, the physiological effects of water stress on carbon isotope fractionation during photosynthesis could mask $\delta^{13}\text{C}$ signals associated with redox conditions. Plant-based $\delta^{13}\text{C}$ redox signals, therefore, will be best applied in wetland soils that are constantly saturated during plant growing seasons. $\delta^{15}\text{N}$ of cattails growing on this upstream terrace have values intermediate to sewage and meteoric nitrogen sources. The main source of new nitrogen will be meteoric inputs (the cattails are rooted well above the current water table), but mineralization of older (prior to relocation of the outfall) cattail detritus would provide a source of recycled heavy nitrogen. When alive, the older cattails would have been at the head of a more extensive wetland receiving sewage input from the hillslope outfall, prior to its being moved upstream.

Combined, these results allow us to develop a simple conceptual model of nitrogen sources, sinks and transformations occurring in the primary Sandia wetland (Figure 5). New nitrogen will be delivered to the subsurface rooting zone via diffusion of nitrate from surface waters. Both plant uptake and denitrification will reduce nitrate levels in the subsurface, creating this diffusion gradient (Mitsch and Gosselink, 1993). Significant transport of nitrate in alluvial groundwater is unlikely for these same reasons. There are only low levels of ammonia in outfall waters, and horizontal

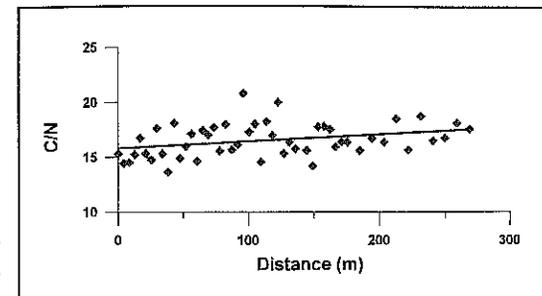


FIGURE 3. Molar C/N ratios of cattails versus distance along the longitudinal axis of the primary wetland; $p = 0.02$, $R^2 = 0.11$.

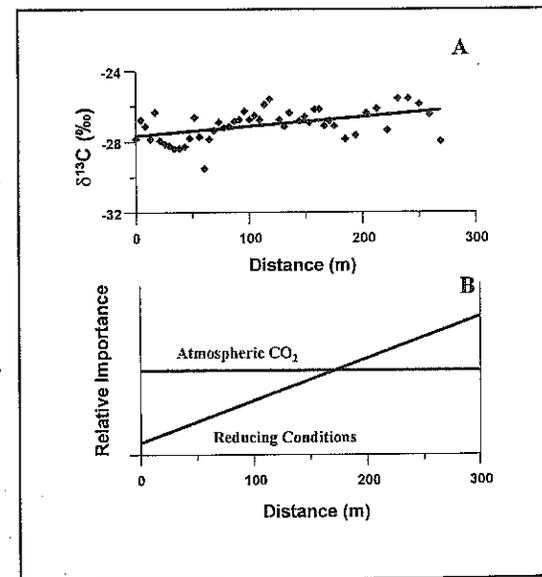


FIGURE 4. A. $\delta^{13}\text{C}$ of cattails versus distance along the longitudinal axis of the primary wetland; $p = 0.001$, $R^2 = 0.23$. B. Qualitative model explaining trend in $\delta^{13}\text{C}$ (see text).

advection of ammonia in groundwaters is unlikely due to immobilization of ammonia on negatively charged soil particles (Mitsch and Gosselink, 1993). Ammonia, therefore, is likely to be recycled close to organic detritus from which it is derived.

Nitrate that is not attenuated within the wetland will be transported away from the wetland in surface waters, and to a lesser extent, in alluvial groundwaters. Nitrate that diffuses into the subsurface can be taken up by plants or can be denitrified and released as nitrogen gas or NO_2 . We are also using nitrogen isotopes to assess the possibility that ^{15}N -enriched nitrate is being lost to underlying aquifers.

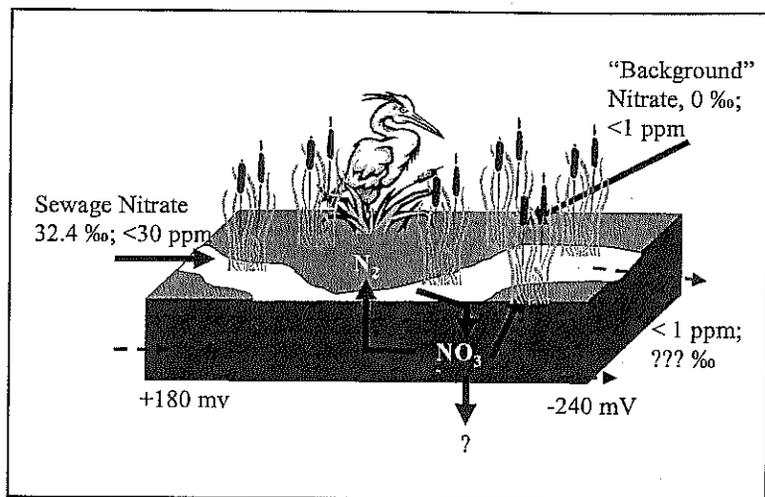


FIGURE 5. Conceptual model of nitrogen dynamics in Sandia wetland. Nitrogen source $\delta^{15}\text{N}$ and concentrations are shown, along with the prevailing redox gradient. Various nitrogen fluxes are illustrated including diffusion of nitrate into the subsurface, loss to underlying groundwaters, horizontal advection, plant uptake and denitrification.

The importance of new sewage nitrate is greatest towards the head of the wetland, while background sources become progressively more important downstream. The redox gradient within the wetland ensures that new nitrogen diffusing in from surface waters towards the end of the wetland is more completely denitrified, leading to greater isotopic enrichment of the residual subsurface nitrate pool available for plant uptake. Plant nitrogen contents are highest at the head of the wetland where nitrate-enriched treated sewage wastewater first enters the system. Despite significant downstream trends, there is considerable unexplained variability in $\delta^{15}\text{N}$, $\delta^{13}\text{C}$ and C/N ratios. This likely reflects the heterogeneous nature of wetland sediments, hydrology, rooting depths etc.

These concepts are being investigated further by studying the Martin Canyon wetland at LANL. This wetland receives inputs of nitrate derived from

high explosives. This nitrate presumably has low $\delta^{15}\text{N}$ as fertilizer nitrate is used in the production of high explosives. Nitrate levels in this wetland (e.g. 0.51 mg/L) are significantly lower than nitrate levels in Martin Spring (e.g. 15.2 mg/L). Martin Spring is located upstream of the wetland and is the primary source of water in the canyon. This wetland was burned during the Cerro Grande Fire in May 2000, affording an opportunity to study nutrient dynamics during recovery. Though new nitrogen sources (high explosive nitrate and background meteoric nitrogen) will likely not be distinct isotopically, denitrification could still impart an isotopic trend to cattails growing in the wetland.

CONCLUSIONS

Plant-based isotopic proxies of nitrogen sources, and nitrogen transforming processes, could provide a valuable additional tool for the study of nutrient dynamics in natural and treatment wetlands in which inorganic nitrogen attenuation is a goal. This technique will need to be carefully calibrated in individual wetlands, but could supplement traditional instrumental techniques and water-based measurements. Each plant in a wetland can be thought of as a monitoring well sampling the sediments in which it is growing. If the chemistry of a wetland plant faithfully reflects the sediment porewater chemistry, then valuable information can be derived from the plants themselves. This information can be garnered with simple, quick field sampling and with easy, relatively inexpensive analytical techniques. Plant-based chemical information can be obtained without disturbing wetland sediments, and hence wetland function. The signals obtained are time-integrated, thus smoothing out high frequency temporal variations. Data can be obtained at whatever spatial precision is desired. Properly developed, these techniques could help us to monitor spatial variation in treatment wetland performance, and to monitor this performance through time, helping us to see inside the "black box" with non-invasive techniques.

ACKNOWLEDGEMENTS

We wish to thank Zachary Sharp and Viorel Atudorei for helping to analyze these cattail samples at the University of New Mexico. Ryan Davis, Jim Jerden, Gary Luedemann and Dale Counce all provided valuable assistance with field work in Sandia Canyon. This work was supported by a LANL Director's Funded Post Doctoral Fellowship to the senior author.

REFERENCES

- Cole, M. L., Kroeger, K. D., and I. Valiela. 2001. "Stable Isotopic Tracers of Wastewater Nitrogen in Aquatic Ecosystems." *American Society of Limnology and Oceanography 2001 Aquatic Sciences Meeting Abstract Book*: 37.
- Costanzo, S. D., O'Donohue, M. J., Dennison, W. C., Loneragan, N. R., and M. Thomas. 2001. "A New Approach for Detecting and Mapping Sewage Impacts." *Mar. Poll. Bull.* 42(2): 149-156.

- Farquhar, G. D., O'Leary, M. H., and J. A. Berry. 1982. "On the Relationship Between Carbon Isotope Discrimination and the Inter-cellular Carbon Dioxide Concentration in Leaves." *Aust. J. of Plant. Phys.* 9: 121-137.
- T. H. E. Heaton. 1986. "Isotopic Studies of Nitrogen Pollution in the Hydrosphere and Atmosphere: A Review." *Chem. Geol. (Isot. Geosci. Sec.)* 59: 87-102.
- Heikoop, J. M., Hickmott, D. D., and P. Longmire. 2001. "Nitrogen-15 Signals of Treated Sewage Wastewater Uptake and Transformation in a Cattail Marsh." American Society of Limnology and Oceanography 20001 Aquatic Sciences Meeting Abstract Book: 67.
- Jordan, M. J., Nadelhoffer, K. J., and B. Fry. 1997. "Nitrogen Cycling in Forest and Grass Ecosystems Irrigated with ¹⁵N-Enriched Wastewater." *Ecol. Appl.* 7(3): 864-881.
- Kendall, C., Silva, S., Steinitz, D., Wise, E., Chang, C., Stober, J. and M.Meyer. 1997. "Mapping Spatial Variability in Marsh Redox Conditions Using Biomass Stable Isotopic Compositions." <http://sflwww.er.usgs.gov/publications/posters/atl-mtg/>.
- McClelland, J. W., and I. Valiela. 1998. "Linking Nitrogen in Estuarine Producers to Land-Derived Sources." *Limnol. Oceanog.* 43(4): 577-585.
- McClelland, J. W., Valiela, I., and R. H. Michener. 1997. "Nitrogen-Stable Isotope Signatures in Estuarine Food Webs: A Record of Increasing Urbanization in Coastal Watersheds." *Limnol. Oceanog.* 42(5): 930-937.
- Mitsch, W. J., and J. G. Gosselink. 1993. *Wetlands*. 2nd ed. John Wiley and Sons, Inc., New York, NY.
- Pezeshki, S. R., DeLaune, R. D., Kludze, H. K., and H. S. Choi. 1996. "Photosynthetic and Growth Responses of Cattail (*Typha domingensis*) and Sawgrass (*Cladium jamaicense*) to Soil Redox Conditions." *Aquat. Bot.* 54(1): 25-35.