wetland science & practice

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FROM THE EDITOR'S DESK

Greetings! Spring is in the air here in New England as it is sunny and in the 50s today. Snow is gone from the valley here, yet higher elevations still have patches of snow and ice-covered ponds. The sugar houses are busy making maple syrup, but still haven't heard any wood frogs or spring peepers. I spent a few weeks in Florida this winter that included visiting several national, state, and county parks. Since I took hundreds of photos, I decided to post a number of them in *Notes from the Field*. I encourage others to submit photos for future issues.

Ralph Tiner
WSP Editor

This issue is largely devoted to articles about constructed floating islands. While attending our Denver conference, I sat in a couple of presentations on this topic and thought it would be of interest to a wider audience so I contacted Mason Bowles, workshop coordinator about getting presenters to write articles for *Wetland Science & Practice*. They responded positively and you'll find all except one published in this issue. The final article is on natural floating islands and we'll publish that in the October issue. Along with these articles, you'll find one by Max Finlayson and others on our Denver Declaration about wetland management and restoration and a student grant research report by Elizabeth Perera and Kathy Young on the hydrology of some Icelandic wetlands. You'll also see Rick Smardon's book review of *Eden Again: Hope in the Marshes of Iraq* by Suzanne Alwash, many wetland wildlife images in *Notes from the Field* and Doug Wilcox's cartoon (*From the Bog*). Thanks again to all contributors.

On the news front, in February the Society and others requested that the US EPA and Corps of Engineers extend the comment period for the review of the proposed definition of "waters of the United States." The agencies have rejected these requests, so comments are due by April 15.

Meanwhile, we'll keep doing our best to maintain and restore wetlands around the globe and to educate the public on wetlands, their functions, values, and threats. Happy Swamping. ■

Note to Readers: All State-of-the-Science reports are peer reviewed, with anonymity to reviewers.

CONTENTS

Vol. 36, No. 2 April 2019

COVER PHOTO:

Limpkin at Rock Springs Run, Orange County, Florida, USA
(Ralph Tiner photo)

SOCIETY OF WETLAND SCIENTISTS
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PRESIDENT'S ADDRESS

Mardi Gras has come and gone in Louisiana, and now I study the long-term weather forecast for Lafayette to find the brief lettuce planting season. The leaves will be on the trees soon, with winter just a chilly memory of a few days of sweater weather. Soon it will be time for brutally hot field work in south Louisiana.

Beth Middleton
U.S. Geological Survey, Wetland and Aquatic Research Center
SWS President

In SWS news, the Board met by conference call on January 20, 2019. Lori Sutter (Treasurer) presented the 2018 end-of-year financials, which were accepted by the Board. Leandra Cleveland (Secretary-General) reported that membership renewals are on track for the year and Arnold van der Valk gave a report on the nominations committee for the SWS elections.

The Board discussed an effort to affiliate with wetland societies outside of the US. It is anticipated that many other national and regional wetland societies will want to link with SWS in the future, and these efforts will give the members of these societies limited access to SWS services. Affiliations with wetland societies around the world will help SWS efforts to internationalize.

A Strategic Planning Committee has been launched as part of a nearly two-year planning effort to examine SWS programs and strategies for the future. Scott Jecker will chair the Committee and there will be opportunities for members to share feedback throughout the planning process.

Nick Davidson and Matthew Simpson have been appointed as SWS observers to the Ramsar Science and Technical Review Panel (STRP). SWS can provide vital support to the Ramsar STRP, through wetland science and management experts. Congratulations to Nick and Matt on their appointments.

Planning is underway for the joint CLRA, SWS, SER meeting, which will be held in Quebec City, Canada June 7-11, 2020. For more information, please visit www.re3-quebec2020.org.

We are looking forward to the SWS 2019 Annual Meeting in Baltimore, Maryland that is just around the corner! The meeting will be held May 28-31, 2019 and there are great opportunities for education and networking. Please be sure to register for the meeting at www.swsannualmeeting.org. I look forward to seeing you in Baltimore! ■

wetland science & practice

Breaking News on U.S. Wetland Regulations

BREAKING NEWS UPDATE: The EPA-Army Corps did not extend the WOTUS comment period, with comments still due on April 15, 2019. Information on the SWS request for the comment period extension is given below.

See "Waters of the United States (WOTUS) Rulemaking" (https://www.epa.gov/wotus-rule). ■

There Is Still Time to Vote in SWS Board Election

SWS continues to grow and remains vibrant thanks to you, our members, and the dedicated leadership of our Board of Directors, committee members, volunteers and staff. It is important to continue this leadership through the election of the 2019 SWS President-Elect.

The President-Elect serves a one-year term, followed by a one-year term as President, and then a final year as Past-President. The elected official will be introduced and take office during the 2019 SWS Annual Meeting in Baltimore, Maryland, USA.

Below are the candidates running for SWS President Elect. The election will run from March 26 - April 16, 2019.

- Loretta Battaglia, Ph.D., Associate Professor, Wetland Ecology, Southern Illinois University (Carbondale, Illinois, USA) https://battaglialab.siu.edu/
- Scott Bridgham, PhD, Professor in the Department of Biology and Environmental Studies Program, University of Oregon (Eugene, Oregon, USA) https://bridghamlab.uoregon.edu/

Take a moment to read the brief profiles for each position and vote for the 2019 President-Elect (https://www.surveymonkey.com/r/6C7JKM9). Please note that the candidate statements are listed in alphabetical order by last name.

All individual SWS members are entitled to one vote, which may be submitted using this electronic ballot. All electronic voting must be completed by 11:59 pm PT on **Tuesday, April 16, 2019.** ■

Call for SWaMMP Mentors

The SWS Multicultural Mentoring Program (SWaMMP - http://www.sws.org/Awards-and-Grants/sws-undergraduate-mentoring-program-swammp.html) is dedicated to increasing diversity in the field of wetland science by offering undergraduate students, from underrepresented groups, full travel awards to the SWS Annual Meeting. SWaMMP is currently seeking mentors for the 2019 program to help guide student award recipients throughout meeting events and activities, including a pre-meeting orientation session on the evening of Tuesday, May 28, and a luncheon on the last day of the meeting, Friday, May 31. Because of this, mentors will be expected to attend the Annual Meeting for its complete duration.

Mentors must have a minimum of two years of graduate experience and must have attended at least two other Annual Meetings. Every effort will be made to pair the students with mentors who share similar interests, such as restoration, hydrology, etc. If you would like to volunteer to be a mentor, please contact Vanessa Lougheed (vlougheed@utep.edu), SWaMMP Coordinator, as soon as possible. ■

In Search of SWS Memorabilia

As SWS prepares to celebrate its 40th anniversary, members are invited to send us pictures of both historical and recent events. Please forward to Beth Middleton at middletonb@usgs.gov.

If anyone has copies of past Board meeting minutes, chapter reports, Bulletin of the SWS (now Wetland Science & Practice), or other materials to help nail down dates at which the various chapters, sections and committees formed, please get in touch with Kathy Ewel (kcewel@cox.net). ■

SWS Chapter Updates

ROCKY MOUNTAIN CHAPTER

The Society of Wetland Scientists (SWS) Rocky Mountain Chapter, in cooperation with the Colorado Riparian Association, is hosting the 2019 Annual Meeting on April 10, 2019, in Golden, Colorado, at the American Mountaineering Center.

More information can be found at http://www.sws.org/rocky-mountain-chapter. ■

EUROPE

The SWS-Europe chapter will hold its 2019 annual meeting with WETPOL from June 17-21, 2019 in Aarhus, Denmark. SWS-Europe will be having a special symposium "Wetlands and ecosystem services: water quality improvement, climate regulation and flood control." Visit the meeting website at http://wetpol.com/. ■

PACIFIC NORTHWEST

Celebrate Pacific Northwest wetlands with SWS PNW Chapter members at a month of wetland events during the month of May! Come learn about the background of each wetland restoration site and discuss the steps necessary for each site to meet the desired objectives. To register or for more information on an event, please email the contacts noted. To register, please provide your name, email and phone number. The group leaders will get back to you with specific field trip information.

Bellingham

Sunday, May 5th – 10:30am – 3:30pm.
Port Susan Bay restoration project and Skagit Bay's Craft Island marsh tour. FREE. Led by Katrina Poppe, NW Ecological Services, WWU
Followed by a social at Brandywine Kitchen in Bellingham
Please register by emailing Katrina and Erin at katrina@nwecological.com and epage@co.whatcom.wa.us

Seattle

Friday, May 3rd – 3:00pm – 6:00pm.
Kingfisher Natural Area and Thornton Creek Confluence restoration project tour. FREE. Led by Katherine Lynch SPU, Clay Antineau, SPU and Marti Louther, Sound Transit
Followed by a social at the Fiddler's Inn in NE Seattle
Please register by emailing Lizbeth and Maki at lsee461@ecy.wa.gov and Maki.Dalzell@hdrinc.com

Leavenworth

Saturday, May 11th – 10:00am – 3:00pm.
Upper Wenatchee wetland and floodplain restoration project tour. $25 – includes transportation and lunch from the Local Yokel. Led by Nate Hough-Snee (Meadow Run Environmental) and Josh Wozniak (Parametrix) and local agency and restoration experts.
Followed by an ad hoc social in Leavenworth. Pre-trip happy hour/seminar Friday May 10th at 6pm at Leavenworth (TBD). Please register - A registration link will be available soon on PNW chapter page.
Questions can be directed to Nate and Josh at nate@natehough-snee.org and Jwozniak@parametrix.com

Portland, OR

Friday, May 24th – 11:00am – 3:00pm.
Crystal Springs Creek Restoration and Foster Floodplain Natural Area. FREE. Led by Kaitlin Lovell and Marie Walkiewicz (Portland Bureau of Environmental Services).
Followed by an ad hoc social at the 13 Virtures Brewery (6410 SE Milwaukie Ave, Portland, OR 97202)
Please register by emailing Yvonne at Vallette.yvonne@epa.gov

Please join us for the social after each event! ■

2019 Wetlands Ambassador

Congratulations to Priyanka Sarkar, who has been selected as SWS Wetland Ambassador for 2019! http://www.sws.org/Awards-and-Grants/wetland-ambassadors-graduate-research-fellowship.html

BIOGRAPHY

Priyanka is currently working on her Ph.D. as a UGC-BSR Senior Research Fellow in the Department of Ecology and Environmental Science, Assam University, Silchar (AUS), India. She completed her Master's degree with a specialization in Environmental Monitoring and Assessment from the Department of Ecology and Environmental Science, AUS. Previously, she studied the potential for concurrent rice-fish culture in the wetlands of Assam, Northeast India by analyzing the important physico-chemical water parameters; besides, qualitative and quantitative estimation of phyto- & zooplankton communities. Currently, Priyanka is studying the ecosystem services and economic valuation of Chatla floodplain wetland of Assam, northeast India with an aim to enlighten the stakeholders and influence the policymakers to adopt scientific and sustainable management strategies for Chatla, and similar wetlands in India.

RESEARCH INTERESTS

Priyanka's specific research interests include: carbon sequestration in wetland soil and vegetation, nitrogen and phosphorus dynamics in wetlands, assessing regulating ecosystem service (water purification potential of wetlands) and provisioning ecosystem services (wetland goods) of wetlands, economic valuation of wetland ecosystem services, and management/restoration of wetlands. Moreover, she is also interested in understanding how various ecological aspects of floodplain wetlands in the tropics are related to socio-economic dimensions, livelihood sustenance, and human well-being.

The title of Priyanka's Wetland Ambassador Fellowship project is "Can biochar increase carbon sequestration in wetland restoration projects?" She will be carrying out my Wetland Ambassador Fellowship at Drexel University in Pennsylvania, USA, under the mentorship of Dr. Elizabeth Watson. ■

Take Full Advantage of Your Membership Through SWS' Monthly Webinar Series

Participate in outstanding educational opportunities without leaving your desk! SWS is pleased to provide its monthly webinar series that addresses a variety of wetland topics. The convenience and flexibility of SWS webinars enables you to educate one or a large number of employees at once, reduce travel expenses, and maintain consistent levels of productivity by eliminating time out of the office.

SWS webinars are free for members. Additionally, every quarter, one of our monthly webinars is open to the public. These free quarterly webinars are offered in March, June, September and December.

WEBINAR ARCHIVES

If you're unable to participate in the live webinar, all webinars are recorded and archived for complimentary viewing by SWS members.

The SWS Webinar Committee is excited to announce that our past webinars are available on YouTube. Non-members may access webinars that are three months or older on the SWS YouTube channel. As always, SWS members enjoy complimentary access to live webinars, and exclusive access to the all the previously recorded webinars.

SUBTITLED WEBINARS

Webinars are also viewable with subtitles on YouTube, allowing SWS supporters around the world to watch the webinars with subtitles in their native language.

SPANISH-LANGUAGE SWS WEBINAR SERIES

The SWS International Chapter is starting a series of webinars in Spanish (http://www.sws.org/About-SWS/proximos-seminarios-web-de-sws-en-espanol-nonmembers-2.html). This series will generally be a prerecorded presentation, broadcast at a specific time each month. If you would like to view the webinars in your language, you can view them on our YouTube Channel three months after the initial broadcast. ■

2019 SWS Annual Meeting - Register Today!

Themed *The Role of Wetlands in Meeting Global Environmental Challenges: Linking Science, Policy, and Society*, the SWS 2019 Annual Meeting will be held May 28-31 in Baltimore, Maryland (USA). Be sure to visit the meeting website at swsannualmeeting.org, and join us on Facebook at https://www.facebook.com/events/2132311983690685/. ■

REGISTRATION

Are you excited to reserve your spot for the 2019 Annual Meeting? Please visit the registration web page (https://www.swsannualmeeting.org/register/) for more information. Rates increase May 1, so register today!

SUPPORT THE SWS ANNUAL MEETING

See information about sponsorship, exhibiting and donating to the silent auction on the following pages. Thank you for investing in the future of wetland science!

RIDESHARE AND ROOMMATE MATCH

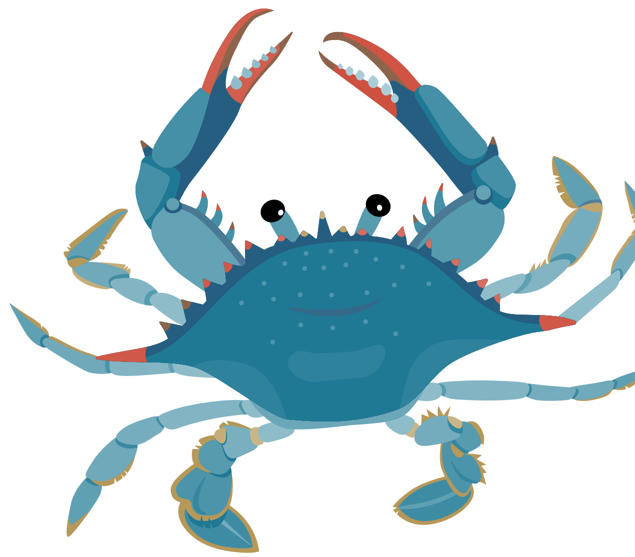
Are you looking to share transportation and/or lodging costs with fellow wetland scientists at the SWS 2019 Annual Meeting? Connect with your peers here (https://www.facebook.com/events/304844836939822/) to coordinate the details of your trip on Facebook!

FIELD TRIPS

The SWS 2019 Annual Meeting will offer unique opportunities for field trip enthusiasts! All field trips will be guided, include transportation, park fees and meals/snacks. Registration for field trips is limited. For more information: https://www.swsannualmeeting.org/field-trips/

2019 PROGRAM

Clawd wants you to know that the Program Committee is a little behind schedule releasing the presentation schedule as a result of the multiple abstract submission deadline extensions due to the government shutdown earlier this year. SWS expects to release the program the week of April 8, so please be watching for that information soon!



Planning Underway for 2020

Planning is underway for the joint Québec RE3 Conference, *From Reclaiming to Restoring and Rewilding*. SWS is excited to join the Canadian Land Reclamation Association (CLRA) and the Society for Ecological Restoration (SER) in Quebec from June 7-11, 2020. Mark your calendar, check out the website, and follow the event on Twitter and Facebook. **#QuebecRE3** ■

SWS 2019 | Annual Meeting | May 28 - 31

The Role of Wetlands in Meeting Global Environmental Challenges: Linking Wetland Science, Policy, and Society

Baltimore, Maryland

Sponsorship Opportunities

A variety of sponsorship levels are available on a first-come, first-selected basis and are sure to provide international exposure among leaders in wetland science. Not sure which sponsorship opportunity to choose? Construct your own sponsorship package to fit your unique needs and goals.

CONTRIBUTING LEVEL — $500

Help make the SWS 2019 Annual Meeting a success by making a general contribution.

BRONZE LEVEL — $1,000

- **DAILY PLENARY SPEAKER.** The 2019 Annual Meeting will feature two renowned plenary speakers who will share research findings and new perspectives. Two opportunities available. **SOLD**
- **DAILY MORNING & AFTERNOON REFRESHMENTS.** Attendees will enjoy light snacks and beverages during daily morning and afternoon refreshments. Six opportunities available.

SILVER LEVEL — $2,500

- **POSTER SESSION & SILENT AUCTION.** The 2019 Poster Session Reception will showcase the latest wetland research and provide an opportunity to meet with experts to learn about their scientific studies. The Mid-Atlantic Chapter will also be hosting a silent auction to help fund Chapter activities.
- **STUDENT MIXER.** A great opportunity for student attendees to mingle, exchange ideas and learn about opportunities for involvement in SWS.
- **ATTENDEE PEN.** Attendees will receive a meeting-themed pen in their attendee bag which will feature the sponsor's logo. **SOLD**

GOLD LEVEL — $5,000

- **HOTEL ROOM KEY.** All guests will receive a custom hotel key card as they check in under the SWS hotel block which will feature the sponsor's logo.
- **ATTENDEE BAG.** Meeting-branded attendee bags will be distributed to all participants containing important meeting materials. The sponsor's logo will be featured on each bag.
- **LANYARDS.** Meeting-themed lanyards will be distributed to each attendee at registration which will feature the sponsor's logo.
- **WATER BOTTLE.** Attendees will receive a meeting-themed water bottle in their attendee bag which will feature the sponsor's logo.

PLATINUM LEVEL — $7,500

- **WELCOME RECEPTION.** The 2019 Annual Meeting will kick off with a special Welcome Reception providing attendees the chance to network with friends, old and new, over hors d'oeuvres and cocktails.
- **MOBILE APP.** Attendees will be able to access the daily programming, general meeting information and connect with fellow attendees via their smart phones and the web. The sponsor's logo will be featured on the homepage of the app.
- **WIFI.** Internet access will be available at the meeting venue. The sponsor's logo will be featured on the landing page with the option to customize the WIFI network and password.

BENEFITS OF SPONSORSHIP	$500	$1,000	$2,500	$5,000	$7,500
Logo + hyperlink featured on meeting website	★	★	★	★	★
Logo featured on onsite sponsor signage	★	★	★	★	★
Special recognition during sponsored event		★	★		★
One marketing item dropped in attendee bag			★	★	★
One complimentary registration to the SWS Annual Meeting				★	
Two complimentary registrations to the SWS Annual Meeting					★
One complimentary exhibit booth at the SWS Annual Meeting					★

**Prices in U.S. dollars.*

To discuss sponsorship opportunities for your company, contact Jenny Frey, jfrey@sws.org, 608-310-7853.

Silent Auction Donor Form

Donation Instructions

Thank you for your generous contribution to the SWS 2019 Annual Meeting silent auction! Please complete one form for each item being donated and send via email to Jenny Frey at jfrey@sws.org. All items should be received at the address below by April 30, 2019.

Society of Wetland Scientists
Attention: Jenny Frey
22 N Carroll St, Ste 300
Madison, WI 53703 USA
(608) 310-7853

Donor Contact Information

Name	
Organization	
Address	
Phone	
Email	

Include in silent auction materials: ❑ Name only ❑ Organization only ❑ Both

Donation Information

Item/service	
Description	
Approximate value (USD)	$

Please check one: ❑ I will ship the item to the address above ❑ I will bring the item to the meeting

Do you need a receipt for your donation? ❑ Yes ❑ No

The Denver Declaration on the Management and Restoration of Wetlands

C.M. Finlayson[1], G.T. Davies[2, 3], N.C. Davidson[1,4] and W.R. Moomaw[3]

ABSTRACT

Following the release of the San Juan Statement on Climate Change and Wetlands by the Society of Wetland Scientists in 2017 the *Denver Declaration on the Management and Restoration of Wetlands* was produced and signed by approximately 200 delegates at the 2018 annual meeting of the Society. The Declaration recognised the importance of wetlands and their significance as carbon sinks and the opportunities to sequester additional quantities of carbon. It further highlighted the need to maintain and restore wetlands, including those in mountain regions, for their biodiversity and ecosystem services, including climate resiliency. The Declaration was supported by a special symposium on *Wetlands in a Changing Climate: Science, Policy and Management*. These activities were placed within the context provided by the *World Scientists' Warning to Humanity: A Second Notice* and by the *Global Wetlands Outlook* produced by the Ramsar Convention on Wetlands.

INTRODUCTION

In 2017 approximately 200 individual attendees at the Society of Wetland Scientists' (SWS) 38th annual meeting (conference) in San Juan, Puerto Rico, signed the San Juan Statement on Climate Change and Wetlands. The statement focussed on encouraging "policy makers in all countries to continue collaborative efforts to develop and implement international policies, such as the Paris Climate Agreement, to mitigate global climate change" (Finlayson et al. 2017a). It also represented an active step by the SWS to encourage members to address the alarming state and trends for wetlands globally (Ramsar Convention 2018), as called for in an article on the Second Warning to Humanity and Wetlands (Finlayson et al. 2018). The later was developed by the same team of authors that had prepared an overview of scientific, policy and management issues associated with wetlands in a changing climate (Moomaw et al. 2018) and represented concern over the fate of wetlands globally under global change.

1. Corresponding author contact: mfinlayson@csu.edu.au, Institute for Land, Water & Society, Charles Sturt University, Albury, NSW, Australia
2 BSC Group, Inc., Worcester, MA 01720, USA
3 Global Development and Environment Institute, Tufts University, Medford, MA, USA
4 Nick Davidson Environmental, Queens House, Ford Street, Wigmore HR6 9UN, UK

In line with these activities and to maintain momentum for engaging with the wetland researchers and practitioners that attend SWS annual conferences a further statement was issued by attendees at the 39th conference in Denver, Colorado, USA in June 2018. This was presented as the *Denver Declaration on the Management and Restoration of Wetlands* and was supported by a special interest symposium on *Wetlands in a Changing Climate: Science, Policy and Management* within the conference.

The Denver Declaration is presented below along with a summary of the special symposium held during the conference.

THE DENVER DECLARATION

The Denver Declaration (Figure 1) was signed by approximately 200 delegates to indicate their support for the collaborative efforts that were encouraged in the San Juan Statement to develop and implement international policies to mitigate global climate change as well as to stress the importance of wetlands for their biodiversity and ecosystem services, including as carbon sinks.

The Denver conference was located at the foot of the Rocky Mountains, which is an inspiring place for the discussion of future carbon conservation. Field trips enabled delegates to investigate riparian wetlands on the high plains at approximately 1,600 meters above sea level, all the way up to high-altitude peatland fens at approximately 3,050 meters. The delegates recognized the immense ecological, economic, cultural, and spiritual significance of high-altitude wetlands and the key roles they play in the hydrology and ecology of major rivers on continents around the world.

As with the San Juan Statement, the Denver Declaration also requested all wetland managers and scientists to share the statement and to encourage policy makers to support local to global efforts to combat the loss of all wetlands for the betterment of humankind.

As outlined in the paper about the Second Warning to Humanity and Wetlands (Finlayson et al. 2018), signing such a Declaration at a conference may not in itself be a profound action, but it does demonstrate that the signatories "are aware of the importance of wetlands for maintaining a supportive climate and the importance of making the best use of international policy mechanisms."

It can also be seen as one of the many steps identified in the World Scientists' Warning to Humanity http://scientistswarning.forestry.oregonstate.edu/ that can be taken to initiate changes in policy and environmental outcomes through discourse and the sharing of information (Ripple et al. 2017).

The importance of influencing policy makers who may not be fully aware of the importance of wetlands for mitigating climate change cannot be under-estimated, especially given existing discrepancies in the international policy platforms for wetlands when it comes to climate change (Finlayson et al 2017b; Moomaw et al. 2018).

SYMPOSIUM ON WETLANDS IN A CHANGING CLIMATE: SCIENCE, POLICY AND MANAGEMENT

The symposium was arranged at the SWS 2018 Denver conference to enable the presentation of recent research that had been published in Moomaw et al. (2018), including a synthesis of recent research on the status and climate vul-

FIGURE 1. The Denver Declaration on the Management and Restoration of Wetlands.

The following participants at the Society of Wetland Scientists 2018 Annual Meeting affirm their support for the "San Juan Statement on Climate Change and Wetlands" that was signed by more than 200 participants at the Society's 2017 Annual Meeting.

The San Juan Statement encouraged all countries to continue their collaborative efforts to develop and implement international policies to mitigate global climate change.

In 2018, participants stress the importance of:

i) recognizing that all types of wetlands, including those underlain by permafrost and coastal wetlands, are among the most productive ecosystems on the planet;

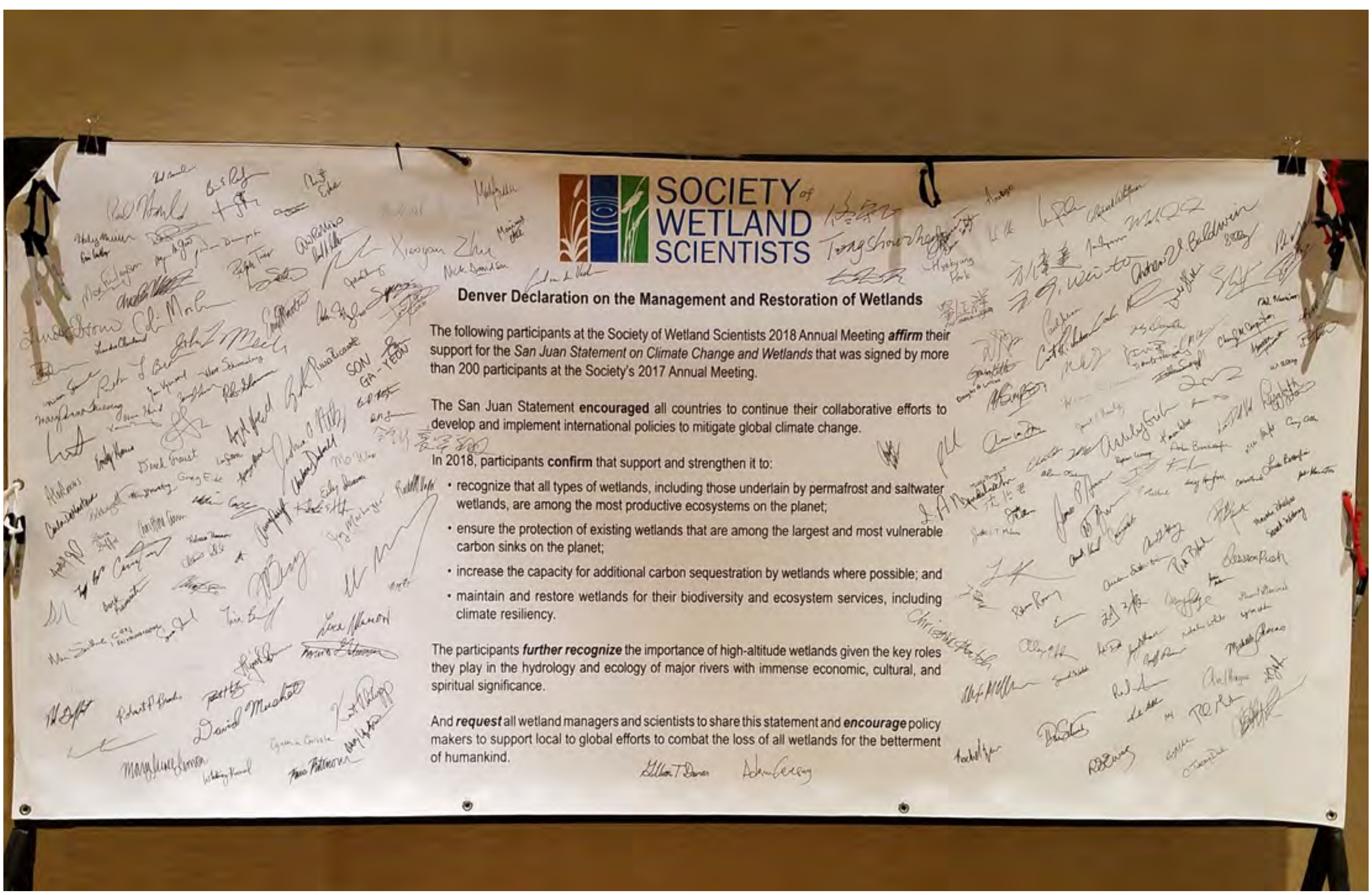
ii) ensuring the protection of existing wetlands that are among the largest and most vulnerable carbon sinks on the planet;

iii) increasing the capacity for additional carbon sequestration by wetlands where possible; and

iv) maintaining and restoring wetlands for their biodiversity and ecosystem services,including climate resiliency.

The participants also recognize the immense ecological, economic, cultural, and spiritual significance of high-altitude wetlands and the key roles they play in the hydrology and ecology of major rivers.

And request all wetland managers and scientists to share this statement and encourage policy makers to support local to global efforts to combat the loss of all wetlands for the betterment of humankind.



nerability of freshwater and saltwater wetlands, and their contributions to addressing climate change (carbon cycle, adaptation, and resilience). It further explored the policy and management realm for wetlands from international to national, subnational and local levels to identify strategies and policies reflecting an integrated understanding of both wetland and climate change science.

Based on information presented in Moomaw et al. (2018), the symposium highlighted:

- Wetlands as a major carbon reservoir recognizing that peatlands sequester approximately as much carbon as global forest biomass, and along with vegetated coastal ecosystems are among the most carbon rich on the planet;
- The importance of securing estimates of current wetland carbon storage and the future for carbon sequestration potential as temperatures warm and create emission feedback vulnerabilities from thawing and drying wetlands - especially permafrost - triggered by rising temperature and other disturbances;
- The case for preventing further loss of existing wetlands which is significant but is often not included in assessing limits on future emissions to meet climate goals; and
- The intersection of climate and wetland policy and management from the international to national, subnational and local levels.

Specific recommendations were discussed that captured the synergies between wetlands and carbon cycle management, climate adaptation and resiliency to further enable researchers, policy makers and practitioners to protect wetland carbon and climate adaptation/resiliency ecosystem services as we move forward in a world with a changing climate. The talks that were presented are outlined in Table 1, and the associated abstracts are presented in the October 2018 issue of Wetland Science & Practice (Volume 35, No. 3; https://issuu.com/societyofwetlandscientists/docs/2018_special_issue).

The relevance of the Denver Declaration to the members of SWS and wider society is shown through the key messages presented in the Global Wetland Outlook (GWO) (Ramsar Convention 2018), launched at the 13th Conference of the Ramsar Convention on Wetlands in October 2018. The key messages in the Global Wetland Outlook, based on recently compiled data about changes in the ecological character of wetlands, provide poignant reading (see Figure 2). The Outlook also provided information on

TABLE 1: Summary of presentations included in the special symposium on Wetlands in a Changing Climate: Science, Policy and Management

Title	Author	Address
Future Opportunities to Incorporate Wetlands Science and Policy into Climate Solutions	William Moomaw	Center for International Environment and Resource Policy, The Fletcher School of Law and Diplomacy and Global Development and Environment Institute, Tufts University, Medford, MA, USA
Polar Wetlands of the Past and their Utility for Predicting the Future	Ben LePage	Pacific Gas and Electric Company, San Ramon, CA, USA and Academy of Natural Sciences, Philadelphia, PA, USA
Climate Change Impacts on Northern Wetlands and Feedbacks to Global Climate	Sue Natali	Woods Hole Research Center, Woods Hole, MA, USA
Coastal Wetlands and Climate Change: Threats, Opportunities, and Policy Recommendations	Ariana E. Sutton-Grier	MD/DC Chapter of The Nature Conservancy, Bethesda, MD, USA and Earth System Science Interdisciplinary Center, University of Maryland, College Park, MD, USA
Effects of Precipitation Extremes on Stressed Coastal Vegetation	Beth Middleton	USGS, Wetland & Aquatic Research Center, Lafayette, LA, USA
International Wetland and Climate Policy – The Huff, Puff and Bluff and Stormy Times Ahead?	C. Max Finlayson	Institute for Land, Water & Society, Charles Sturt University, Albury, New South Wales, Australia & IHE Delft, Delft, Netherlands
What's a Practicing Wetland Scientist to Do? Policy and Management Tools, Strategies and BMPs in Light of Climate Change	Gillian T. Davies	BSC Group, Inc., Worcester, MA, USA and Global Development and Environment Institute, Tufts University, Medford, MA, USA
Restoring Coastal Wetlands: A Nature-based Solution to Cope with Sea Level Rise and Enhance Biodiversity. a Mediterranean Example	Patrick Grillas	Tour du Valat, Research Centre for the Conservation of Mediterranean Wetlands, Arles, France

FIGURE 2. Key messages from the Global Wetland Outlook (Ramsar Convention 2018)

Key Messages

Healthy, functioning natural wetlands are critical to human livelihoods and sustainable development.

Although still covering a global area almost as large as Greenland, wetlands are declining fast, with 35% losses since 1970, where data are available.

A quarter of wetland animal and plants species are at risk of extinction.

Quality of remaining wetlands is also suffering, due to drainage, pollution, invasive species, unsustainable use, disrupted flow regimes and climate change.

Wetland ecosystem services, ranging from food security to climate change mitigation, are enormous, far outweighing those of terrestrial ecosystems.

The Ramsar Convention promotes wetland conservation and wise use and is at the centre of efforts to halt and reverse wetland loss.

Key steps in conserving and regaining healthy wetlands include:

- Enhancing the network of Ramsar Sites and other wetland protected areas
- Integrating wetlands into planning and the implementation of the post-2015 development agenda
- Strengthening legal and policy arrangements to conserve all wetlands
- Implementing Ramsar guidance to achieve wise use
- Applying economic and financial incentives for communities and businesses
- Ensuring participation of all stakeholders in wetland management
- Improving national wetland inventories and tracking wetland extent.

the drivers of change as well as recommended responses based on the Convention's Strategic Plan. The Outlook is supported by a set of technical notes providing supporting information to each of its sections, namely: introduction to the report (Gardner et al. 2018a); status and trends of wetlands (Finlayson and Davidson 2018); drivers of change in wetlands (van Dam 2018); and responses from the *Ramsar Strategic Plan 2016-2020* (Gardner et al. 2018b).

So as to further bring the key messages from the SWS's recent work on wetlands and climate change to the attention of policy makers, in October 2018 at the Ramsar Convention's COP13, SWS organized a side-event during the COP on "Climate management, adaptation and key legal issues for Ramsar wetlands." The event was jointly organised by SWS, the Australian Department of Environment and Energy, Stetson University School of Law, and the Institute for Land Water & Society at Charles Sturt University. Presentations covered: the role of wetlands in climate change: consequences and solutions; the importance of coastal wetlands for "blue carbon"; and key legal issues in the COP13 draft Resolutions on climate change.

The SWS side-event was designed to inform and support Ramsar Contracting Parties' negotiations during COP13 on five climate change-related resolutions, as listed here.

- Guidance on identifying Wetlands of International Importance (Ramsar Sites) for global climate change regulation as an additional argument to existing Ramsar criteria;
- Restoration of degraded peatlands to mitigate and adapt to climate change and enhance biodiversity;
- Promote conservation, restoration and sustainable management of coastal blue carbon ecosystems;
- Recognize cultural values, indigenous peoples and local communities, and climate change mitigation and adaptation in wetlands; and
- Support sustainable urbanization, climate change and wetlands.

After negotiations and agreed changes all five were adopted by COP13. The final text of each of these Resolutions is available in the three languages (English, French and Spanish) of the Convention (https://www.ramsar.org).

CONCLUSION

Delegates at the 2018 annual meeting of the Society of Wetland Scientists recognized through the *Denver Declaration on the Management and Restoration of Wetlands* the immense ecological, economic, cultural, and spiritual significance of high-altitude wetlands and the key roles they play in the hydrology and ecology of major rivers on continents around the world. This included an emphasis on the opportunity for wetlands to sequester carbon to mitigate the impact of climate change on humanity. As with the San Juan Statement issued by the Society in 2017 the Denver Declaration also requested all wetland managers and scientists to share the statement and to encourage policy makers to support local to global efforts to combat the loss of all wetlands for the betterment of humankind. A symposium on *Wetlands in a Changing Climate: Science, Policy and Management* further emphasized the role of wetlands in mitigating climate change and the need for adaptation, including restoration, to ensure that the biodiversity and ecosystem services, including climate resiliency, from wetlands were maintained and extended. ■

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Initial Surface Hydrology Characteristics of Icelandic, Drained, Patchy Wetlands

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Northern wetlands with a high organic content comprise a large portion of Earth's wetlands (Arnalds et al. 2016). Icelandic inland wetlands are mostly fens (Figure 1) that contain varying amounts of inorganic and organic material (Arnalds et al. 2016). The distinctive geology in Iceland affects wetland soils. It is populated with several glaciers and about 30 active volcanoes, fed by a mantle plume under the island, erupting on average every 4-5 years (Bird and Gísladóttir 2014). Aeolian and tephra distribution from these volcanoes is deposited throughout the island, creating variable soil conditions with lower organic content nearer to volcanoes and major dust sources, such as large sandar (Arnalds et al. 2016). The primary region for this study is within the lowlands in southern and western Iceland, the largest area of topogenous fens here. Combining these geographic characteristics creates three wetland soil types, as defined by the Icelandic classification system: histosols, histic andisols, and gleyic andisols (Arnalds et al. 2016).

Permafrost makes up about 22% of the land surface in the Northern Hemisphere, defined as frozen soil found at a temperature at or below 0°C for a minimum of two years (Woo 2012). Infiltration can occur into frozen soil as meltwater from the snow reaches the ground surface (Woo 2012). Permafrost has a tendency of being thinner in maritime climates due to their proximity to the oceans rather than further inland. Thus, interior wetlands in Iceland may contain sporadic permafrost but it likely does not occur along the coastline of the island (Arnalds and Kimble 2001; Woo 2012; Arnalds et al. 2016). If the surface soil has a high water content that freezes, concrete frost can develop (Dingman 2015). This is affected by the amount of vegetation in the soil (Orradottir et al. 2008; Dingman 2015). Good conditions for concrete frost formation are rainfall or snowmelt in warmer weather followed by below zero temperatures. Based on prior research concrete frost tends to develop in open soils which have high soil water content under such conditions (Orradottir et al. 2008). The hydraulic conductivity of permafrost or concrete frost is significantly lower than that of unfrozen soils, an important factor in controlling soil draining and the extent and distribution of wetlands (Eugster et al. 2000). Infiltration is highly variable, and is affected by rainfall amounts and intensity, antecedent soil moisture conditions, and varying soil properties (Dingman 2015). Infiltration capacity is described by Horton's equation as:

$$f_p = f_c + (f_0 - f_c)e^{-kt} \qquad (1)$$

where f_p is the infiltration capacity at time t; k is a constant representing the rate of decrease in f capacity; f_c is a final or equilibrium capacity, and f_0 is the initial infiltration capacity

FIGURE 1. Icelandic fen at the Agricultural University of Iceland, Hvanneyri, Iceland (Source: E. Perera, taken 4 July 2018; permission granted).

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(Viessman and Lewis 2003). Soil factors affect infiltration based on the presence of organic matter in soils, soil compaction, or human modification (Dingman 2015).

Soil moisture exhibits a high spatiotemporal variability (Loew et al. 2013). It can differ spatially within an ecosystem, decreasing downslope and vertically above the water table, or locally due to small scale changes in microtopography (Petrone et al. 2004; Woo 2012). At daily to interannual timescales, variation can also be high, making soil moisture difficult to measure (Loew et al. 2013). Soil moisture has a long-term memory, storing interannual precipitation anomalies in cold, arid climates with frozen soils, making it an important factor for seasonal climate forecasts (Shinoda and Nandintsetseg 2011; Loew et al. 2013). Icelandic soils have high organic and mineral content, with high water retention and porosity characteristic of both peatlands and volcanic soils (Neris et al. 2012; Arnalds et al. 2016).

These soil properties provide an important control on surface vegetation and, to some extent, climate (Rouse 2002). Wetland patches with higher water contents can lead to a greater net solar energy input, so their microclimates will vary depending on surface water content (Sumner et al. 2011). The albedo of a bare soil tends to increase with lower water content, however, soil texture and vegetation cover affect surface radiation, adding complexity to this relationship (Graser and Van Bavel 1982; Jensen 2007). The presence of surface water and dark surfaces can lower ground albedo, enhancing radiation absorption in those areas, and aiding in wetland evaporation losses (Sumner et al. 2011). Surface soil moisture is also affected in Icelandic soil cover under vegetated surfaces by the hummocky ground (thufur) (Jones et al. 2009). This feature, along with the root structure of grasslands here, allows for porous concrete soil frost and patchy ice cover in winter (Orradottir et al. 2008; Jones et al. 2009). The presence of permafrost in Iceland is restricted to higher elevations (Jones et al. 2009) and interior wetlands as mentioned above. Good water conductivity and large water retention capacity allow for seasonal frost in Icelandic andisols, which can reach down to 0.5 m depth, while the hummocky surface features can be seen 0.1-0.5 m into the soil profile (Jones et al. 2009).

PATCHY WETLANDS IN ICELAND

Wetland ecosystems are vulnerable to changes in hydrology on a global scale – modeled and observed precipitation trends have shown that precipitation in the Arctic has continuously exceeded the global average increase in precipitation (Erwin 2009; Bintanja and Selten 2014). Responses to changes in climate could include differences in the distribution and vegetation types in high-latitude regions (Beringer et al. 2005). Circumpolar Arctic regions experience conditions favorable to patchy wetlands, including the wetlands found in Iceland. Patchy wetlands locally contain tundra vegetation, form niches for the wildlife in those areas, and as ecosystems they are distinctly sensitive to land use disturbance and changes in climate (Woo and Young 2003). The climate in Iceland is influenced by the island's location between warm and cold ocean currents - between the warm North Atlantic Drift and the cold East Greenland Current (Einarsson 1984). Iceland's climate is maritime with mild winters and cool summers, where southern temperatures are between 4-5°C and annual precipitation along the coastline (1,000-1,600 mm) is higher than farther inland (700-1,000 mm) (Einarsson 1984).

In total, Icelandic government subsidies facilitated drainage of approximately 47% of these wetlands after the Second World War, mainly for agricultural production to keep up with the rising population, as well as to help adjust with domestic rural-to-urban migrations (Arnalds et al. 2016). Drainage ditches cover 29,700 km of the area, significantly altering the landscape (Gunnarsson et al. 2006). The efficacy of drainage is relative to the distance between ditches, depth of ditching, and hydraulic conductivity of the peat (Price et al. 2003). The majority of the area impacted in Iceland

TABLE 1. Breeding waders in Iceland of international importance (Gunnarsson et al. 2006).

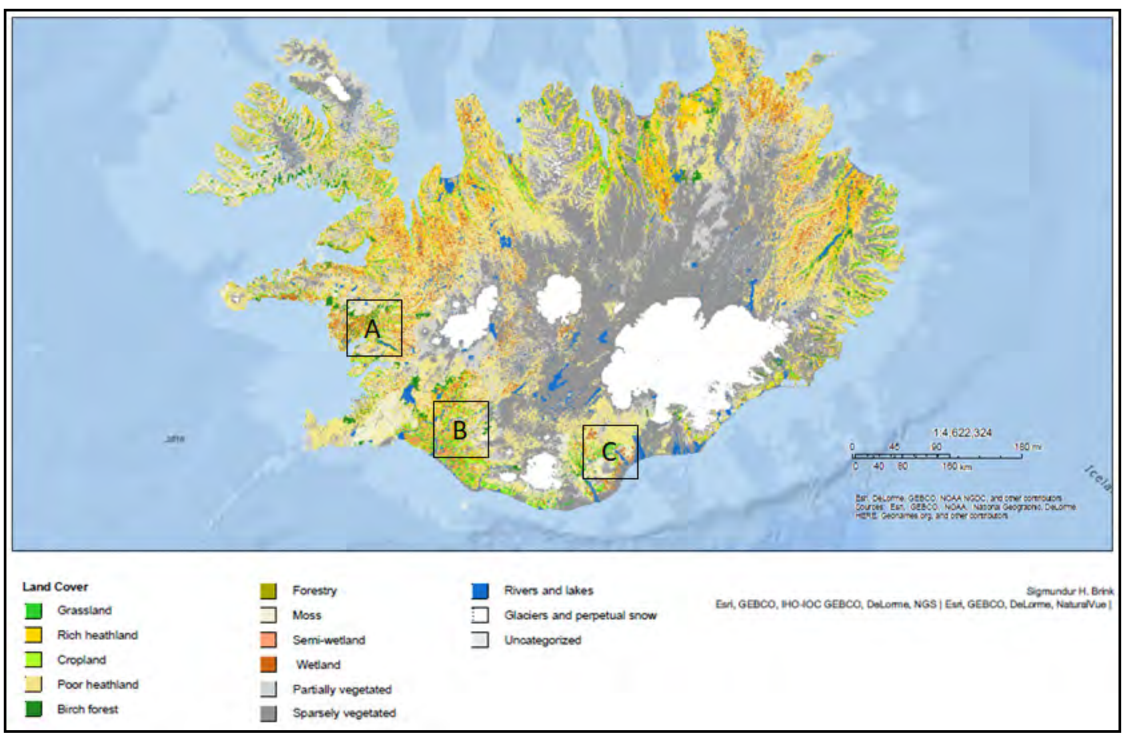
Species	Scientific Name	World population in Iceland (%)	Icelandic population below 200 m a.s.l. (%)
Oystercatcher	*Haematopus ostralegus*	4	100
Golden Plover	*Pluvialis apricaria*	52	32
Ringed Plover	*Charadrius hiaticula*	32	33
Whimbrel	*Numenius phaeopus*	40	75
Dunlin	*Calidris alpina*	16	49
Purple Sandpiper	*Calidris maritima*	46	19
Snipe	*Gallinago gallinago*	6	62
Redshank	*Tringa totanus*	19	97
Black-tailed Godwit	*Limosa limosa*	10	97
Red-necked Phalarope	*Phalaropus lobatus*	6	55

has low ditch density, with about 67% of ditched area at a density of 0.1-0.5 km km^{-2}, and 25% of the ditched areas at a density of 5-10 km km^{-2} (Arnalds et al. 2016). Landscape characteristics such as slope and bedrock hydrology affect the impacts of low ditch densities (Arnalds et al. 2016). Effects from drainage in peatland soils (histosols) are increases in runoff, peak flows, and baseflow relative to natural conditions, although decreases in peak flow have also been observed due to greater available storage capacity in drained soils between storms (Price et al. 2003). With the exception of studying infiltration characteristics in Icelandic lowland andisols, which took place within 15-35 km of the study area in this project (Orradottir et al. 2008), not much else is known about the hydrological characteristics of these wetlands or the impacts from drainage (Arnalds et al. 2016). Most previous studies have covered the soil characteristics, such as the physical properties, and nutrient content of these wetlands and other Icelandic land covers (Arnalds and Kimble 2001; Gudmundsson et al. 2004; Arnalds 2008). Many of the wetland patches were drained for hay making or grazing purposes, however, some were not set aside for specific use, leaving them without a functional purpose (Biological Diversity in Iceland, 2001; Arnalds et al. 2016).

Icelandic coastal inland fens are an important ecosystem providing habitats for about 20 migratory bird species which use these wetlands for food, resting, and nesting. Ten of these are breeding waders, some of which comprise most of the world's population of their species – as such, changes to these fens directly impact the well-being of these birds (Table 1; Gunnarsson et al. 2006). Thusly, afforestation efforts, livestock grazing from sheep and horses, and the prevalence of hydropower in Iceland present continued threats to these populations, which tend to prefer the open spaces of wetlands and grasslands (Gunnarsson et al. 2006; Arnalds et al. 2016). While wetland patches smaller than 3 ha should not be disturbed under current law, this reference size should likely be smaller (e.g., 0.5 ha) due to the importance of small wetland patches to the overall ecosystem (Arnalds et al. 2016). Currently over 40% of wetland areas in the 1-5 ha patch size fall between 1-2 ha, with about 55% of remaining wetlands unprotected by Icelandic government policy (Arnalds et al. 2016). Though wetland drainage is no longer a concern, as with elsewhere in the Arctic, little is known of climate warming impacts on these drained wetland patches (Erwin 2009; Young and Abnizova 2011).

Varying degrees of carbon in Icelandic inland wetland soils lead to their soil classification into three main groups: histosols (>20% C), histic andisols (12-20% C), and gleyic andisols (<12% C) (Arnalds et al. 2016). In particular, the majority of the active volcanic zone is dominated by gleyic andisols, with a gradient of carbon content gradually increasing with further distance from volcanoes and active dust sources (Arnalds et al. 2016). Both the organic and mineral soils in gleyic andisols have higher water retention than expected as a result of their andic soil properties (Arnalds 2008). Andisols are highly vulnerable to aeolian and water erosion due to a lack of particle cohesion and high soil water retention, leading to further erosion of the soil (Orradottir et al. 2008; Anderson 2013).

FIGURE 2. Land cover classifications delineated across Iceland. Sites are marked by black boxes: to the west is the histosols site at Hvanneyri (A), to the south are histic andisols at Þúfa (B), and in the southeast are gleyic andisols at Prestbakki (C). (Map layers provided by S. Brink, with further edits by M. Chase and E. Perera.)



STUDY OBJECTIVES

This study had three main objectives: 1) to assess the hydrology of these drained, patchy wetlands, through infiltration tests and soil moisture, 2) to evaluate spatial variation throughout these wetlands in soil moisture and albedo measurements, and 3) to improve understanding of the hydrology of these patchy wetlands, so that future impacts from human modification and climate warming may be understood, thusly addressed by policy makers. The research questions are: 1) does infiltration vary between soil type? and 2) how does near surface soil moisture content vary by wetland soil type, along with proximity to drainage ditches?

STUDY AREA AND METHODS

This study took place from 26th June until 5th July, 2018, for a total of 8 days of data collection. For each soil type (histosol, histic andisol, and gleyic andisol) one patch was sampled, for a total of 3 sites. The first site, Þúfa, was in the south (63°58'51.6" N, 20°17'06.4" W), the second, Prestbakki, in the southeast (63°49'51.20" N, 18° 1'59.02" W) and the third site was at the Agricultural University grounds at Hvanneyri, in the west (64°33'37.1" N, 21°45'23.0" W) (Figures 2 and 3). Near each drained patch an intact wetland was also sampled to serve as a "control," based on the proximity of the intact wetlands (Figures 2d and 1). In each site, 4-6 transects were sampled. At Þúfa, 4 transects in the drained patch and 1 transect in the intact wetland were sampled for a total of 5 transects; at Prestbakki, 3 transects in both the drained wetland patch and intact wetland were sampled, for a total of 6 transects; and at Hvanneyri, 3 transects in the drained patch and 1 transect in the wetland were sampled, for a total of 4 transects.

In each drained patch, 2-4 infiltration tests were taken using a double ring infiltrometer, placed within 3

FIGURE 3. Site locations (Photos courtesy of E. Perera):

a - Hvanneyri drained patch (in front of ditch)

b - Þúfa drained patch (facing southeast)

c - Prestbakki drained patch (adjacent to ditch)

d - an intact wetland at Hvanneyri site

meters of the ditch, and about 20 m apart from the previous test (Figure 4). This produced a total of 10 infiltration rates representing the 3 soils. Volumetric soil moisture content (%) was taken with a Theta soil moisture probe, measuring near surface soil moisture at a depth of 0.0-0.06 m. Leading into the patch from the infiltration test, near-surface soil moisture measurements were taken along 50 m transects, every 5 meters, where an average of 3 readings represented a sample. This scheme was also used for albedo measurements read around solar noon. Albedo was taken using a Li-Cor pyranometer to measure incoming and outgoing solar radiation. In total at each drained and wetland patch, 2-4 transects were sampled, except for the intact wetland at Þúfa (1 transect). Hvanneyri was more limited in scope, being smaller in size compared to the other sites. In drained patches, along each transect at the 10 m mark and at the 25 m mark, a soil pit was dug down to 0.60 m (Figure 5). For each soil pit, the soil was described for each visible horizon and a sample collected for laboratory analysis. Temperature and soil moisture were recorded by using a soil thermometer for vertical temperature profiles, a Theta soil moisture probe for vertical soil moisture profiles, and a Hobo SmartSensor 10HS for recording both temperature and moisture as a comparison.

Lastly, at the beginning (0 m), middle (25 m), and end (50 m) of each transect, 2-4 vegetation quadrats (0.25 x 0.25 m) were sampled for an overview of the surrounding vegetation at the different sites. Meteorological data, including wind speed, relative humidity, and temperature, were recorded daily using a Kestrel, and supplemented with Hobo temperature and relative humidity data loggers, and nearby weather station data when available.

RESULTS AND DISCUSSION

Preliminary results indicate elevated soil moisture conditions from the preceding May, which had a recorded precipitation of over 125 mm for the month (Iceland Monitor 2018). These antecedent moisture conditions contributed a greater distribution of soil moisture frequency in the southeast at Prestbakki (Figure 6) compared to the south at Þúfa and the west at Hvanneyri. More variation in soil moisture content may possibly be attributed to greater amounts of observed tephra and lower organic content in gleyed andisols vs. histic andisols and histisols.

Analysis of variance indicated that near surface soil moisture was significantly different between drained sites: t-test results revealed values of $p < 0.001$ between Prestbakki in the southeast and Hvanneyri out west, $p < 0.005$ between Þúfa in the south and Hvanneyri, and $p < 0.05$ for Þúfa and Prestbakki. Also, soil moisture content was statis-

FIGURE 4. Infiltration tests were conducted using a double ring infiltrometer; typically placed between hummocks.

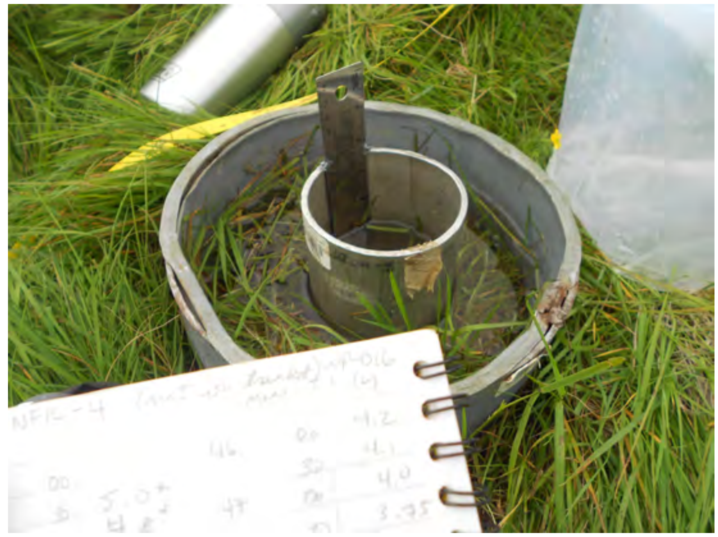


FIGURE 5. Soil pit dug down to 0.60 m depth; tephra layers are black, indicated here by dashed lines. (Photo courtesy of A. Aggarwal, taken 1 July, 2018.)

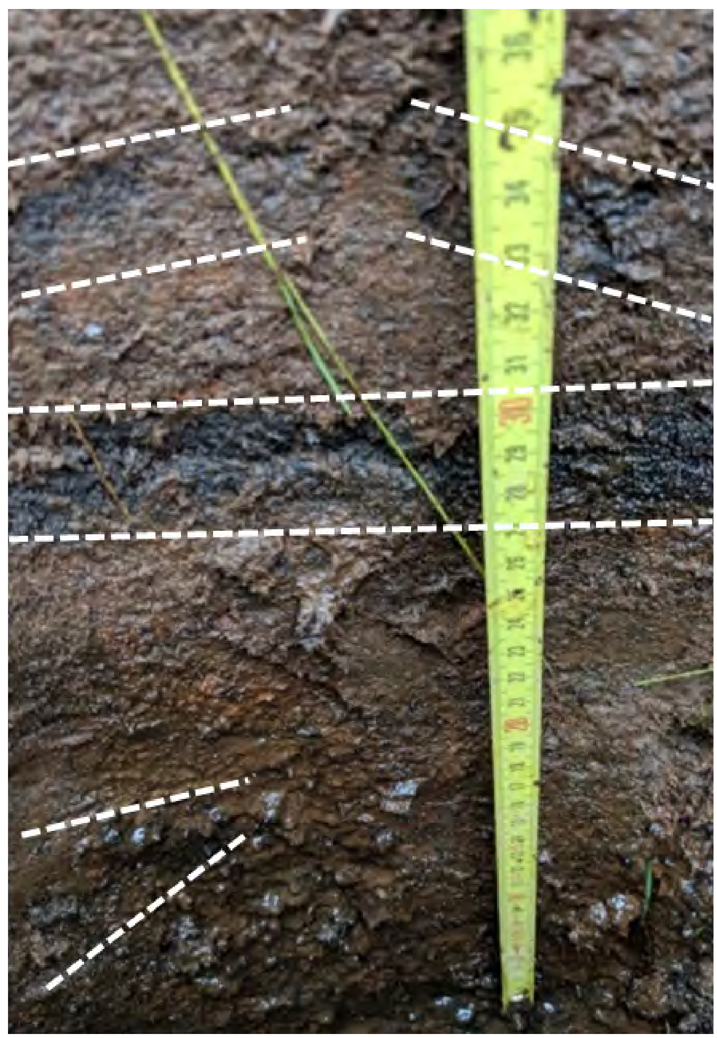


FIGURE 6. Frequency histograms show the number of times a volumetric soil moisture content sample within a given percentage range occurred at a) Hvanneyri, b) Þúfa, and c) Prestbakki drained patches (e.g., SMC (%) fell into the 90-100 percent range a total of 7 times at Þúfa). Greater variation in soil moisture is seen at Prestbakki in the southeast, an area located near volcanoes and highly influenced by tephra and aeolian deposition.

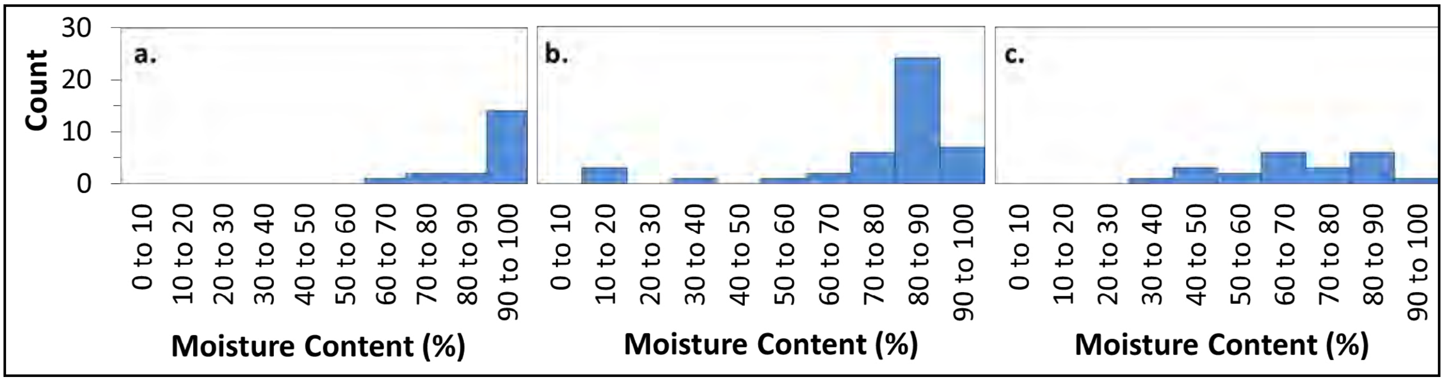


FIGURE 7. Ditch drawdown at study sites: a) Hvanneyri, b) Þúfa, and c) Prestbakki. A step function of near surface soil moisture (%) indicates that soil moisture levels off at 5 m to 10 m distance from drainage ditches. The ditch is indicated by an arrow at 0 meters. Darkened lines represent an average of the total soil moisture values from transects; the lighter lines indicate the original measured soil moisture transects.

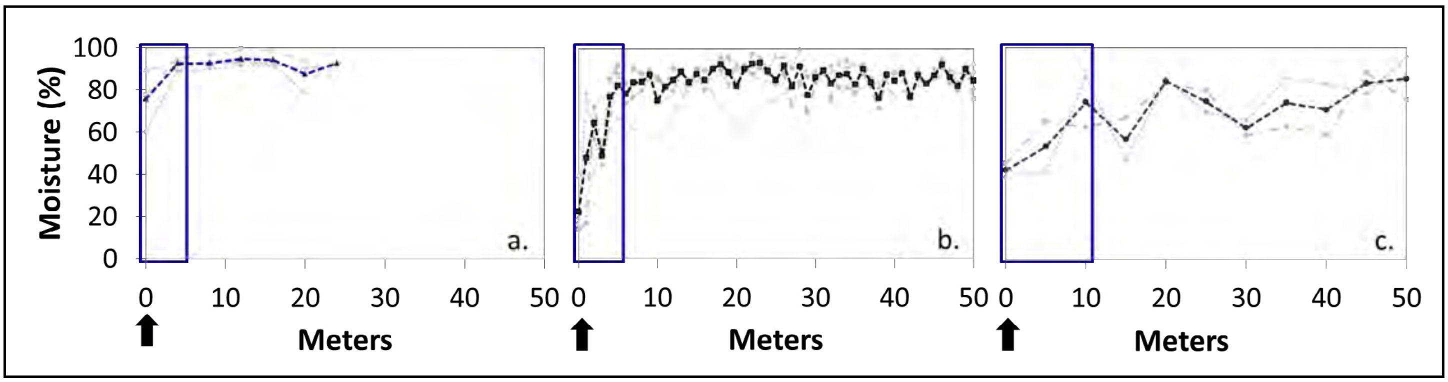
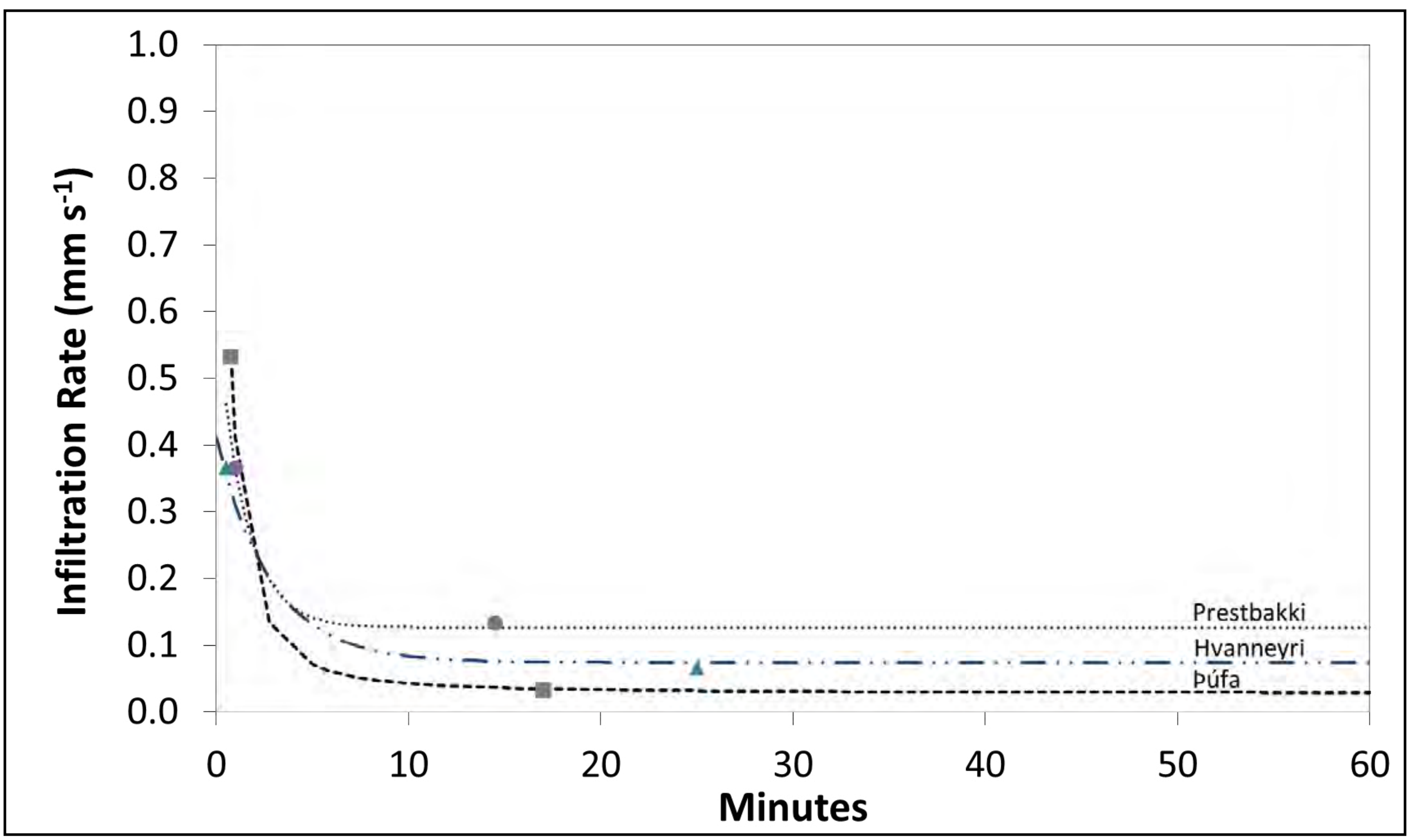


FIGURE 8. Infiltration curves for the three soil types in this study: histosols (Hvanneyri), gleyic andisols (Prestbakki), and histic andisols (Þúfa). Initial (f0) and equilibrium (fc) points are marked for each curve.



tically significant ($p < 0.001$) between the intact wetland (wetter) and the drained patch (drier) at Prestbakki, likely as a result of sharply inclined slopes at the intact wetland compared to the hilly but more level drained patch.

Soil moisture content at all three drained patches shows minimal drawdown from the drainage ditches compared to other peatland sites, except for decomposed fen peats at lower latitude in western England (Price et al. 2003). This drawdown is noticeable in Figure 7, where at Hvanneyri (a) in the west and Þúfa (b) in the south, respectively, ditch drawdown is 5 m, and ditch drawdown at Prestbakki (c) is up to 10 m. Although the study period here did not cover the entire summer growing season (May to September), this indicates the possibility that drainage ditches here lose their efficacy faster than peatland at other sites where drawdown is within 15-50 m of ditches (Price et al. 2003), at least resulting from the antecedent soil moisture conditions for this year. If this study had continued through September, the lateral drainage of the ditch could possibly remain the same in these areas due to the high water retention of gleyic andisols, with similar results in histosols because of poorly decomposed organic matter and limited shrinkage (Arnalds et al. 2016.)

Many of the infiltration curves (7) produced highly saturated results; however, one curve per drainage patch offers an idea of their differing infiltration variables (Figure 8). Results here are similar to previous High Arctic and Low Arctic wetland studies (Woo and Young 1997; Orradottir et al. 2008). Southern Icelandic lowland summer final rates ranged from 28 to 369 mm h^{-1}, while maximum capacity rates here are slightly higher than other arctic silts (except for those with large cracks), at 0.13 mm s^{-1} versus ~0.10 mm s^{-1} (Woo 2012; Orradottir et al. 2008). These soils are silty wetland soils with infiltration rates ranging between 2-22 mm min^{-1}. The data for total test runs with *in-situ* measured infiltration rates for Figure 8 show that Þúfa has a higher initial infiltration rate (f_0 = 0.53 mm s^{-1}) than Prestbakki and Hvanneyri (f_0 = 0.37 mm s^{-1}), while the latter two had higher final infiltration capacities ($f_{c(pr)}$ = 0.13 and $f_{c(hv)}$ = 0.07 mm s^{-1}) than Þúfa (f_c = 0.03 mm s^{-1}).

Cumulative infiltration displayed the most water infiltrated was first at Prestbakki, which infiltrated 789 mm of water, next at Hvanneyri, which infiltrated 744 mm of water, and lastly at Þúfa, where 172 mm of water entered the soil. Ground surface ponding was observed at 50 m at Prestbakki, and pooling was observed in soil pits at 10 m and 25 m from the drainage ditch at both Þúfa and Prestbakki.

SUMMARY

Excessive precipitation in May yielded high volumetric soil moisture contents in drained patches, with several low infiltration capacity rates due to saturation. Infiltration rates are comparable to prior studies of patchy wetlands and andisols in the Arctic (Woo and Young 1997; Orradottir et al. 2008). More variation is seen in the southeast at Prestbakki, possibly due to the influence of tephra in the soil. This variation in near surface moisture also led to pooling observed in soil pits at drained patches Þúfa and Prestbakki, and surface ponding seen at Prestbakki. In previous years, the varying infiltration and soil moisture contents would likely be lower from drier antecedent conditions.

Next steps for this study will begin with comparisons of soil properties to previous studies (Gudmundsson et al. 2004; Arnalds et al. 2016) as soil testing has been completed for soil texture, bulk density, soil organic carbon, and pH. Attempts will be made to analyze these data using Principal Components Analysis where factor 1 is based on soil textural properties and factor 2 is composed of properties relating to porosity (modifying the approach used by Neris et al. 2012). Albedo measurements and meteorological data will be compared between and within both intact wetland patches and drained patches to assess differences, if any. *In-situ* pH of ditch and pooled water, and electrical conductivity measurements of ditch water will be compared between intact wetlands to the drained patches. Vegetation and landscape characteristics such as slope and hummock filled ground will also be examined amongst drained patches for an understanding of how micro-topography affects infiltration and soil moisture content. Afterwards, these wetlands can be understood on a case-by-case basis for each site, to help better inform policy makers about the characteristics of these drained, patchy wetlands. ■

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Introduction to Articles on Floating Wetlands

Mason Bowles

Floating wetlands was the topic of one workshop at the 2018 annual meeting of the Society of Wetland Scientists titled "Wetland Science: Integrating Research, Practice, and Policy - An Exchange of Expertise" held in Denver, Colorado from May 29 to June 1. The meeting forum was designed to encourage collaboration and partnerships among wetland researchers, practitioners, managers, and policy-makers, with the overall goal of improving wetland science. Ralph Tiner attended a number of sessions at the meeting and thought that the topic of floating wetlands would be of interest to the wider SWS membership and others. Consequently, he approached me about having my presenters prepare short articles based on their presentations. After contacting them, I learned they were willing to contribute and as a result, this issue of WS&P is largely focused on the inventive design, application and research that is occurring to develop constructed floating wetlands (CFWs). Derived from naturally-occurring ecotypes that form in highly productive aquatic ecosystems, CFWs are being designed, engineered and deployed in coastal and aquatic environments across the globe. They can be used to retrofit and revive degraded urban shorelines and waterways to improve water quality and provide more opportunities for wildlife.

The first article - Reviving Urban Ecosystems with Constructed Floating Wetland - provides a broad overview of the structure, functions, processes and potential of CFWs to restore near shore wetlands to cities, including attempts to provide habitat for threatened salmon in the Pacific Northwest. The following two articles, Design Optimization in Floating Treatment Wetlands: An Examination of Key Challenges and Solutions and Adapting Floating Wetland Design to Advance Performance in Urban Waterfronts provide a deep dive into the challenges of designing CFWs that can withstand the physical challenges of long-term deployment in challenging urban environments. BioHaven Floating Islands: Modeling and Their Role in Water Resource Recovery and Potential and Problems of Floating Treatment Wetlands for Mitigating Agricultural Contaminants examine the water quality improvement aspects of CFWs. The last two articles provide the perspective and vision of two leading CFW industry leaders in Structural Floating Wetlands: Achieving Ecosystem Services in Heavily Modified Waterbodies and Fish Fry Lake: Perspectives from an Inventor on the Application of Created Floating Islands for Water Quality Renovations. After reading these articles, people should have a better understanding of constructed floating wetlands, their variability, their purposes, and the challenges for installation, operation, and maintenance. Please note that the October issue of *Wetland Science & Practice* will include another article from our workshop - Formation and Development of Floating Peat Mats in a European Eutrophic Lake: A Case Study. It will describe the conditions that support the formation and development of naturally-occurring floating wetlands. ■

Floating island wetlands comprise the De Groene Tunnel (the "Green Tunnel") in Amsterdam's IJburg neighborhood. IJburg is the biggest project of housing construction in Amsterdam and consists of seven artificial islands. For more information on this project: http://endretimar.com/wp-content/uploads/2015/05/ijbteaser.pdf. (Photo courtesy of Mason Bowles)

Reviving Urban Ecosystems with Constructed Floating Wetlands

Mason Bowles[1], Bioemergent Wetland Solutions, Seattle WA

INTRODUCTION

Constructed floating wetlands (CFWs) are a highly efficient ecosystem restoration technology that can be used to improve stormwater quality and reclaim degraded urban shorelines to provide a wide variety of wetland ecosystem services. The concept of CFWs has its origins from naturally-occurring floating wetlands found around the world. They consist of a buoyant substrate that supports wetland plants growing hydroponically, with roots suspended below the water surface. They have the capacity to tolerate fluctuating water levels and variable nutrient loading and can be designed for a number of purposes including to improve water quality, provide bird and wildlife habitat, protect and beautify shorelines, reduce flood risk, sequester carbon and conserve economically important fisheries.

In the Pacific Northwest, coastal urbanization and stormwater runoff have been directly linked to the high mortality of returning spawning salmon (Feist 2011). Cities including Amsterdam, Baltimore, Chicago, London, Seattle, Singapore, and Washington are implementing shoreline projects that integrate floating wetlands into river restoration projects designed to revitalize ecologically degraded urban waterfronts. These projects have multiple ecological, economic and social objectives to increase water quality, wildlife and open space services in formerly degraded waterfront neighborhoods. For densely urbanized cities floating wetlands provide a cost-effective advantage over soil-based wetlands for retrofitting urban shorelines without the cost of cleaning up contaminated sediments and relocating waterfront buildings and infrastructure.

Constructed floating wetlands may be variously referred to as floating treatment wetlands, artificial floating islands, and floating ecosystems (Fonder 2010). They are most widely recognized for their capacity to improve stormwater quality and their proven capacity for reducing nitrogen, phosphorous and metals found in stormwater (Palvineri 2017; Tanner 2011). They are recognized as a water quality best management practice for providing sustained water quality treatment (https://chesapeakestormwater.net/bmp-resources/floating-treatment-wetlands, accessed 3/15/2018) and as the only recognized biological method for controlling harmful algal blooms (www.epa.gov/nutrient-policy-data/control-and-treatment, accessed 3/15/2018).

FLOATING WETLAND ANALOGS

Natural floating wetlands form in quiescent lakes and rivers when mats of wetland vegetation break loose from shorelines or organic sediments to become floating islands. Floating wetlands are found in both temperate to tropical mesotrophic-eutrophic ecosystems worldwide (Van Duzer 2004). Floating wetlands in the Danube River Delta, known as "plaur," consist of mats of common reed (*Phragmites communis*), cattail (*Typha* spp.), sedges (*Carex* spp.) and bulrush (*Scirpus* spp.) (Coops 1999).The largest wetland ecosystem in the world, the Pantanal of central Brazil, contains a variety of floating wetlands called ""baceiro" formed by communities of grasses including burhead sedge (*Oxycaryum cubense*) and *Eleocharis plicarhachis* (Pott 2011). In Louisiana the coastal floating wetlands of the Mississippi River Delta are called "flotants" (Sasser 1996). In freshwater marshes flotants are dominated by maidencane (*Panicum hemitomon*), while in in brackish marshes they are colonized by saltmeadow cordgrass (*Spartina patens*) and bulrush (*Scirpus* spp.) New forms of floating wetlands are still being described, such as the submerged and floating plant communities in floodplain wetlands of the Upper Columbia River (Rooney 2013).

PROCESS

Floating wetlands intercept sunlight, reducing photosynthesis, primary productivity and algal blooms. Overwater coverage affects dissolved oxygen concentrations with aerobic bacteria found along the perimeter, and anaerobic bacteria colonizing the interior of the floating wetland. Aerobic and anaerobic biofilm-producing microbes perform the biochemical work of processing nutrients, metals and other chemical compounds in floating wetlands. Their buoyancy is caused by both oxygen trapped in the plant rhizomes (i.e., aerenchymatous tissue), and from microbial (i.e., 'swamp') gases being trapped underneath organic substrates (histosols). These substrates consist of living rhizomes and organic litter, as well as inorganic sediments

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such as fine silts and clays. The substrates are about 50 cm thick but can exceed 1 meter (Tanner 2006). Wetland plants transport atmospheric oxygen into the rhizosphere via aerenchyma to form roots, rhizomes and stolons that quickly multiply in nutrient rich water. Through photosynthesis plant roots secrete sugar and oxygen that feed microbes, including both bacteria and fungi, which consume nitrogen, phosphorus and ammonia to feed the plants. Plant roots suspended in the water column capture nutrients that are both in solution and adsorbed to suspended sediments. Anaerobic bacteria metabolize these nutrients and produce lighter than air gases, mainly methane (CH4) as well as carbon dioxide ($C0_2$) and nitrogen (N) (Sasser 1991).

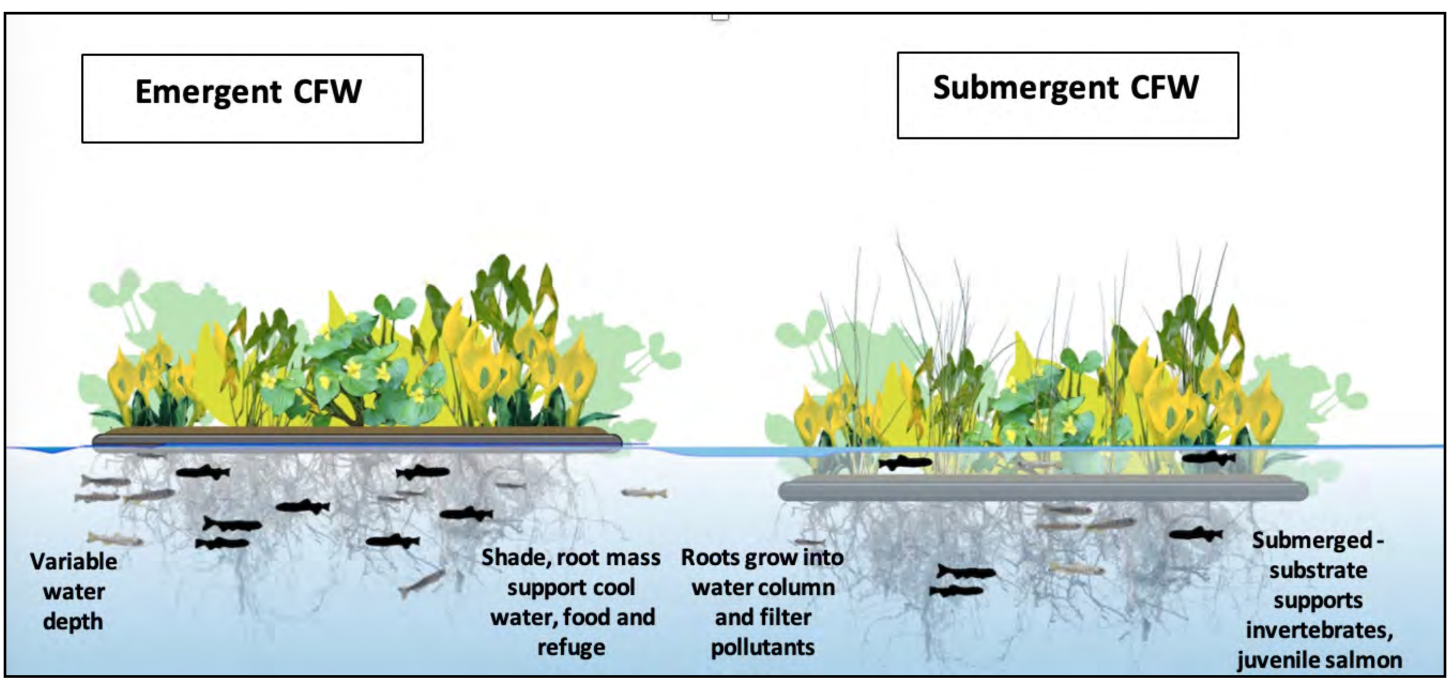
Constructed floating wetlands can be designed to perform both nitrification and denitrification (Rehman 2018). Bacteria can be inoculated into floating wetlands to remove organic and inorganic oil field wastewater and can provide a low cost, passive biological approach to effectively treating acid mine drainage (Kiskilia 2017). Increased removal of TN, TP and ammonium has been shown (Li 2009) to occur through the incorporation of biomedia such as clams and biofilm carriers along with wetland plants. White (2013) has demonstrated that floating wetlands can lead to increased reduction of nutrients from commercial greenhouse operations. Bourne (2013a, b, 2014, 2015) quantified water quality improvement induced by floating wetlands including the removal of metals (copper and zinc) and nutrients (nitrogen and phosphorous). Palvineri (2017) performed a meta-analysis of data from studies of floating wetlands and identified the pollutant removal processes as biosynthesis, settling and biofilm metabolism with pollutant accumulation in plant tissues, entrapment in roots, sedimentation, and physiochemical transformation.

DESIGN AND DEPLOYMENT

Floating wetland ecosystems are unique because they can function in waterbodies with fluctuating water levels and variable nutrient loads. They can be designed to float above or below the water surface to support a diverse assemblage of upland and wetland trees, shrubs, and herbs as well as submergent plant communities (Figure 1). They can be fabricated out of both bio-based materials, as well as inorganic plastic and metal materials. The water quality treatment performance of floating wetlands is affected by the size and depth of the parent water body, including depth and volume of water passing beneath the floating wetland. A review of stormwater CFWs experimental designs and installations by Lucke (2019) recommended the use of baseline monitoring, experimental controls, hydraulic conditions analysis and arranging CFWs to form baffles for optimal flow interception and performance.

Commercially-available floating wetlands are typically fabricated using plastic and metal components that are biologically inert, durable, and provide buoyancy. Two types of commercially-available floating wetlands are available. Mat-type designs consist of a non-woven polyester mat injected with urethane foam to provide buoyancy, e.g.: http://www.floatingislandinternational.com/. Wetland plants

FIGURE 1. Two conceptual designs for constructed floating wetlands (CFWs): one floating on the surface (emergent CFW) and the other slightly submerged.



grow in holes cut into the open cell foam mat, with roots colonizing the open cell foam and hanging below the mat substrate. A variant of this design consists of a buoyant polyvinyl chloride (PVC) mat with pre-cut holes that support cups in which plants grow: e.g.: http://www.beemats.com/home.html.

Pontoon frame floating wetlands, e.g.: http://www.biomatrixwater.com, http://terrapinwater.com, have high structural rigidity with a pontoon perimeter composed of high-density polyethylene (HDPE) pipe, inside of which plants are held in place in open cell foam mats or flexible plastic channels. Pontoon-style of floating wetlands is being used at the National Aquarium in Baltimore and includes complex microtopography to provide both emergent and submergent salt marsh habitats. These floating wetlands include air valves to regulate buoyancy (https://asg-architects.com/a-new-model-for-floating-wetlands/).

FIGURE 2. Floating wetland comprised of bio-based substrate with *Schoenoplectus acutus.*

Floating wetlands are also being developed using bio-based materials derived from biological products. Bio-based materials include natural organic matter, biocomposties and biopolymers. Gunther (2014) developed "reed-gabion" floating wetlands using natural organic matter consisting of dried common reed (*Phragmites communis*) encapsulated in untreated wire that achieved the "auto-buoyancy" of naturally-occurring floating wetlands after 1.5 years. The University of Washington is testing the use of the Mycoboard©, a biocomposite composed of wood chips fused with fungal mycelium, and Biofoam© a biopolymer similar in material properties to Airpop (expanded polystyrene). These materials are naturally hydrophobic and buoyant and are being using in floating wetlands designed to provide salmon feeding and refuge habitat in the Duwamish River in Seattle (Figures 2 and 3).

FIGURE 3. Floating wetland biofilter constructed of bio-based substrates protected by untreated gabion basket.

WATER QUALITY

Stormwater is a global ecological issue affecting water quality, water quantity, habitat and biological resources, public health, and the aesthetic appearance of urban waterways. Stormwater carries a soup of trash, bacteria, heavy metals, and other pollutants into local waterways. Floating wetlands have been most thoroughly researched for their ability to utilize the water quality improvement processes provided by wetlands to treat urban stormwater. A meta-analysis of research on floating wetlands by Palvineri (2017) provides removal rates, derived mainly from mesocosm design deployments (Table 1).

CFWs have demonstrated the capacity to control and prevent harmful algal blooms (HABS) or "red tides" which occur when toxin-producing algae grow excessively in a body of water. CFWs control algae blooms by shading water, preventing photosynthesis, reducing water temperatures and consuming nitrogen and phosphorous. HABS are a global phenomenon affecting virtually every country in the world, causing illness and death in humans, fish, seabirds, marine mammals, and other oceanic life, damaging ecosystems, fisheries resources, and recreational facilities, often due to the sheer biomass of the accumulated algae. HABS occur in response to a combination of increases in water temperatures, excessive nutrients, changes in salinity, increases in atmospheric carbon dioxide concentrations, and changes in rainfall patterns (https://oceanservice.noaa.gov/hazards/hab, accessed 3/15/2019). These algal blooms are predicted to occur more often, in more waterbodies, and to be more intense, threatening human health, the environment and economies across the world.

SEA LEVEL RISE

By 2100 coastal cities across the globe will be facing future sea-level rise of up to 2.0 meters/6.6 feet (Melillo 2014) resulting in widespread loss of coastal wetlands (IPCC 2013, Tiner 2013). Floating wetlands can be used to mitigate coastal wetland loss and help communities adapt to climate change. In Louisiana, for example, floating wetlands are being used as living breakwaters to reduce shoreline erosion, mitigate wetland loss, and sustain wetland fish and wildlife. In Seattle, Washington, floating wetlands are being developed as “salmon pocket parks” to provide food and refuge for threatened Chinook salmon (*Oncorhynchus tshawytscha*). These projects demonstrate some of the ecosystem services that floating wetlands may be capable of providing as a type of ecosystem-based adaptation that can help communities adjust and accommodate to climate change.

RIVER RESTORATION

Coastal and waterfront cities worldwide are undergoing shoreline revitalization with floating wetlands that can replace lost wetlands and shoreline habitats along rivers (Figure 4). Haynes (2014) developed a conceptual design for revitalizing the shorelines of San Francisco using a variety of floating wetland configurations. CFWs can be integrated into shoreline redevelopment projects to retrofit hardened riverbanks and restore wetland ecosystem services without the challenge and expense of buying and reconfiguring these lands and relocating transportation, industrial or commercial structures. Urban shorelines and estuaries often have legacies of industrial use, especially contaminated sediments and groundwater. In these landscapes floating wetlands may provide a cost-effective alternative to purchasing and remediating contaminated shoreline properties.

In Seattle, the University of Washington’s Green Futures Research and Design Lab is researching the use of floating wetlands to provide habitat for Chinook salmon. In the Duwamish River over 97% of the historic wetlands have been lost to urbanization. These riverine and estuarine wetlands provided margin-habitat with slow and shallow water where thousands of ocean-bound smolts could quickly grow by feeding on a rich diet of aquatic and terrestrial invertebrates. The loss of these habitats has contributed to the ongoing decline of Chinook salmon populations and the Southern Puget Sound Orcas (*Orcinus orca*) that depend on Chinook salmon as their primary food prey. Efforts to restore these habitats using land-based wetland creation are ongoing but are limited by the cost of land and cleaning up historic contaminants. The Duwamish River is a federal superfund site with a legacy of industrial waste containing polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) having spoiled the river sediments. Floating wetlands may provide a cost-effective temporary alternative to retrofit these hardened, contaminated shorelines and provide substitute rearing habitat as clean-up efforts advance.

Retrofitting urban rivers and estuaries with floating wetlands is occurring in many cities. Washington, DC

TABLE 1. Floating wetland performance (Palmineri 2017).

Parameter	Average
Total nitrogen (N)	58.0%
Total phosphorous (TP)	48.75%
Amonium nitrogen (NH4-N)	72.8%
Chemical oxygen demand (COD)	57.8%

FIGURE 4. Biobarge providing near-shore wetland habitat.

has integrated 153-square meters of floating wetlands into the District Wharf Park to provide a variety of water quality, habitat, and open space services. In the French city of Rennes, Biomatrix Water Solutions Ltd. installed 620-square meters of floating wetlands along the historic stone walls that form the banks of the river Vilaine. These “floating ecosystems” are capable of supporting trees, as well as emergent plants, and include deflectors to protect the floating wetlands from boats and water-carried debris. A movement to retrofit the Chicago River with floating wetlands came out of research by Yellin (2014) who observed a 100% increase in fish species adjacent to a vegetated floating wetland. This research helped launch a new community group - Urban Rivers - and a community Kickstarter campaign to install 160 feet of floating wetlands that eventually obtained grants from a variety of sources. These floating wetlands are restoring fish, bird and wildlife habitat, beautifying the shoreline, and providing urban gardens for raising food. The project has helped to revitalize a degraded neighborhood and led to plans for creating a mile-long floating eco-park.

In Baltimore Harbor three floating wetland projects have been developed. In 2009 a pilot project was launched to study whether floating wetlands could contribute to the goal of restoring water quality and wildlife to Baltimore’s Inner Harbor (Streb 2013). Biohabitats Inc. designed a series of floating wetlands that were fabricated using a mix of polymer, bio-based and recycled materials, with the participation of local schools. The project proved to be popular with the local community and ecologically successful, bringing back wildlife including mollusks, fish, crabs, otters and birds. In 2013 the Maryland Port Administration deployed 278-square meters of floating wetlands specifically targeted to improving water quality adjacent to commercial container port facilities. In 2017 a new generation of floating wetlands was designed and deployed to provide intertidal wetland habitats for the National Aquarium. These floating wetlands won the 2018 American Society of Landscape Architects research award for a design that allows the elevation and buoyancy of the floating wetlands to be adjustable.

REGULATION

In the U.S., structures planned for construction in waterways are subject to provisions of Section 404 of the Clean Water Act that require federal permits administered by district offices of the US Army Corps of Engineers in addition to state and local requirements. The regulatory view of floating wetlands may vary regionally, in large part due to the emerging technology and the lack of data on long-term performance, including operation and maintenance requirements. Floating wetlands are a non-traditional form of constructed wetland that are most often deployed to help stormwater facilities achieve compliance with National Pollutant Discharge Elimination System (NPDES) permits or other discharge targets. Outside of their use in stormwater facilities, most federal, state and local agencies are unfamiliar with the use of floating wetlands to enhance wetland ecosystem services or provide compensatory mitigation for wetland impacts. Typical regulatory concerns are expressed regarding floating wetlands durability, overwater coverage, and predator-prey interactions, among others. Permits for the Chicago River floating wetlands project took over three years to acquire and regulators required extensive monitoring to evaluate project performance. The National Aquarium floating wetland project was initially permitted as a research project, an interim approach favored by some regulators to corroborate claims that floating wetlands are capable of providing functions similar to soil-based wetlands.

THE FUTURE OF CONSTRUCTED FLOATING WETLANDS

Floating wetlands are a highly efficient ecosystem restoration technology that can provide wetland ecosystem services as a form of green infrastructure. They can be used to improve stormwater quality, provide fish, bird and wildlife habitat, and mitigate climate change impacts. They are cost-effective approach to retrofitting built-out urban shorelines and increasing ecosystem services along rivers and harbor waterfronts where land costs and contaminantion make land-based restoration extraordinarily expensive. Improved engineering has resulted in designs that can be configured to support a broad range of upland and wetland habitats with trees, shrubs, herbaceous and submergent plant communities.

A substantial body of research exists on the capacity of floating wetlands for improving water quality in mesocosm settings; however, additional research is needed to study the performance of field deployments. While the habitat benefits of floating wetlands have been widely promoted, very little research has specifically examined field-based deployments of floating wetlands and their impact on fish and wildlife populations. In order to advance the habitat benefits of floating wetlands design guidelines are needed to create habitat structures that can support invertebrates, amphibians, fish, birds and mammals.

Improved understanding is needed about the fate and transport of nutrients, metals, and contaminants of concern (COCs). If plant and root tissue uptake is a principal pathway for removing nutrients and COCs from these aquatic ecosystems, floating wetlands will need to incorporate design features that support periodic harvest and disposal of accumulated plant leaves, stems, rhizomes and root networks. This may lead to the development of buoyant, bio-based compostable substrates that can be rapidly colonized by wetland plants installed as plugs or sod. Such a biodegradable floating wetland system could theoretically be seasonally deployed and decommissioned to achieve specific water quality ecosystem services to reduce the impacts of stormwater and prevent HABS.

More information is needed on how to locate, size, arrnge, operate and manage floating wetlands to optimize water quality processes to reduce turbidity, reduce nutrients, remove metals, and degrade contaminants. The structure and material of floating mat, plant density, plants harvesting and disposal procedures. Further investigation is needed to identify the type of micro-organisms specific for various kinds of pollutants, their organic pollutants degradation capacity, plant growth-promoting activities, performance, and synergistic relations with plants. Integrating floating wetlands into stormwater infrastructure will require the development of specific water quality performance data for each proprietary product. ■

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Design Optimization in Floating Treatment Wetlands: An Examination of Key Challenges and Solutions

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INTRODUCTION

The use of Floating Treatment Wetlands (FTWs) for a number of important environmental remediation applications is rapidly gaining traction both in North America and elsewhere. As more diverse applications for FTWs emerge there is a natural and necessary process of refinement and optimization of design that must occur. This process is all the more challenging in the context of climate change as we face increasingly severe storm events on a more frequent basis. The following article is intended to provide a brief overview of some of the key challenges and failures in full scale deployment of FTWs as well as the design optimization process that Terrapin Water used to develop a modular components-based FTW system called "PhytoLinks." Two key PhytoLinks installations in particular were at the center of a 100-year storm event in Toronto, Ontario Canada on July 8, 2013 and have provided invaluable insight into how FTW systems respond to the unforgiving forces of nature. It is hoped that by providing this type of information we can help both fellow FTW practitioners and end-users in the refinement and ongoing management of their own technologies and/or installations.

Terrapin Water has over ten years of professional and research and development experience with FTWs in a variety of different settings. We worked extensively with three commercially available FTW systems from 2008-2011 and immediately began to compile a list of key challenges that none of those systems was fully able to address including:

- Cost (both upfront and replacement)
- Ease of plant establishment
- Anchoring
- Maintenance
- Flexibility
- Durability.

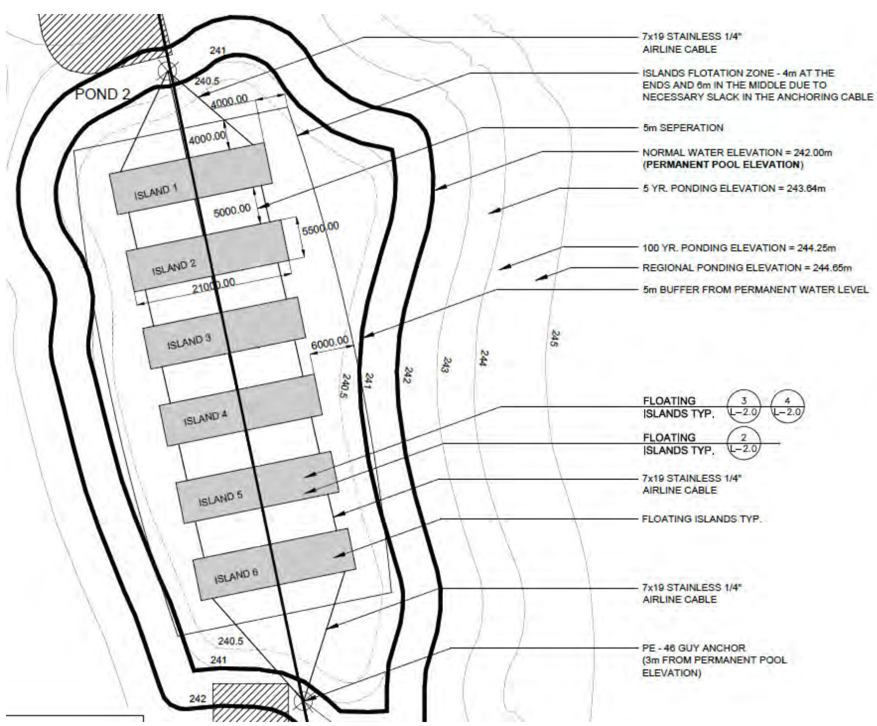
Based on this experience, we initiated a program to develop our own modular, components-based FTW technology that would be capable of meeting as many of the identified challenges as possible. We selected urban stormwater management ponds as the key application to build our design around since we felt it placed the most demanding set of constraints on FTW design. More specifically, stormwater ponds provide a unique combination of rapidly changing water levels, periods of relatively high water velocity, ice-locked winter conditions (in northern locations), periods of intense strong winds and presence of large numbers of herbivorous animals such as Canada geese and muskrats.

Three installations have provided the necessary full-scale performance data for our design optimization process, the details of which are briefly summarized below.

POND 10 FTW THERMAL MITIGATION

The Pond 10 FTW installation was a collaborative pilot project with the Credit Valley Conservation Authority for which Terrapin Water installed approximately 7,452-square

FIGURE 1. Anchoring layout for Pond 10 Thermal Mitigation Project, Brampton, Ontario (Single helical piles were installed at the north and south ends of the FTWs).



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feet of FTW constructed primarily of a 2-inch thick recycled foam board. The FTW was installed in August 2010 into a municipal stormwater management pond in Brampton, Ontario Canada. The main purpose of the installation was to reduce the temperature of water being discharged from the pond. A total of six rectangular modules where installed in a suspension bridge pattern using 7x19 ¼-inch stainless aircraft cable and a helical earth anchor at either end (Figures 1 and 2). Key failures at this installation included:

- Failure of helical earth anchor and partial foam board collapse after a severe wind storm in Year 2 (winds gusting in excess of 63 mph or 100 km/hour);
- Failure of hardware attaching modules to main anchor line in Year 5;
- Localized damage (holes) in foam board matting due to muskrat digging starting in Year 5;
- Failure of the main anchor lines in Year 6 and again in Year 8;
- Failure of foam board module in Year 8 (Figure 3).

The key lessons learned from this installation included:

- Wind-induced shock loading can pose a significant problem for FTWs using non- stretching anchoring/support lines such as stainless steel cables or chain;
- Suspending multiple large FTW modules from a single anchor/support line is not an optimal anchoring strategy;
- Recycled foam board lacks sufficient integrity to stand up to the long-term rigors of FTW deployment in an urban stormwater pond;
- Large-scale modules are cumbersome and difficult to adjust in full-scale FTW installations when troubleshooting;
- Goose and muskrat deterrent fencing must be maintained permanently on FTW installations in areas where these animals are common to prevent excessive damage.

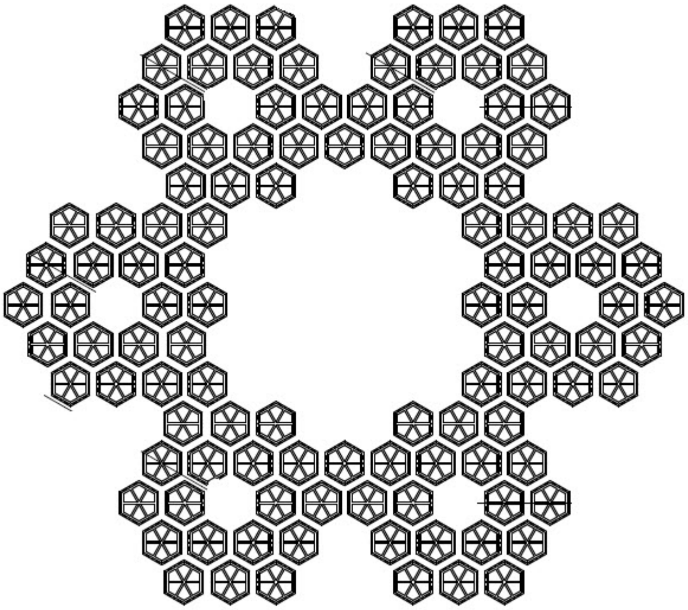
LAKE WABUKAYNE FTW PILOT PROJECT

This municipal storm water installation located in Mississauga, Ontario Canada was a collaborative pilot project with the Credit Valley Conservation Authority and the City of Mississauga. In May 2013 Terrapin Water installed approximately 912-square feet of FTW comprised of 114 individual hexagon-shaped PhytoLinks modules that were anchored using a total of six 100lb concrete anchors fastened to the modules by means of a vinyl buoy and 5/16 inch chain (Figures 4 and 5). On July 8th, 2013 (2 months post installation) the Greater Toronto Area experienced a severe storm event that dumped approximately 5 inches (126 mm) of rain in the span of a few hours and caused hundreds of millions of dollars in infrastructure damage. Both the Lake Wabukayne and Jannock Pond (see below) FTW installations were near the center of this event which would have been expected to produce a rapid increase in water level of approximately 7-10 feet (2-3 meters) and water velocities approaching 17 feet per second (5.4 m/second). This provided us with an invaluable test of our design. The module layout and location of this installation was eventually changed to create a more stable configuration and eliminate flipping (Figure 6).

FIGURE 2. Pond 10 Thermal Mitigation FTW, Brampton, Ontario (Fall 2011, 1 year post installation).

FIGURE 3. Pond 10 Thermal Mitigation FTW, Brampton, Ontario (Spring 2018, broken module)

FIGURE 4. Lake Wabukayne FTW pilot project design layout (Anchor buoys located at the center of each cluster of modules).



Key failures at this installation included:

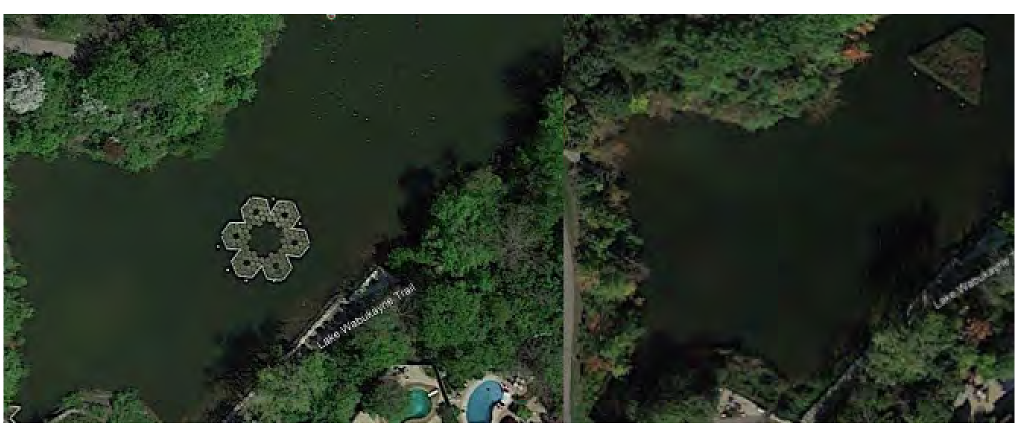
- Destruction of greater than 75% of plants following 100-year storm event in Year 1;
- Flipping of approximately 20 modules during the same storm event (Figure 7);
- Failure of approximately 10% of polyethylene (PE) foam rod flotation due to ice damage during the first winter.

The key lessons learned from this installation included:

- Use of stretchable nylon rope instead of cable for module-module connections was able to reduce wind induced shock-loading and withstand the severe forces of a 100-year storm event with no failures;
- Anchoring systems must provide support to each and every module on the leading edge that is exposed to rapidly flowing water to avoid flipping (Figure 8);
- FTW floatation requires rigid structural support to resist the crushing force associated with ice;
- Removable components-based construction of modules allowed for complete onsite replacement of PE floats with more robust high-density polyethylene (HDPE) encased floats in 1 day;
- Small-scale modules are much easier to work with and provide greater flexibility for troubleshooting including complete layout change (Figure 6);
- Goose and muskrat deterrent fencing should be checked after all moderate to severe storm events as most FTW modules will tend to partially submerge under high flow conditions.

FIGURE 5. Lake Wabukayne FTW pilot project, Mississauga, Ontario Canada (Summer 2015).

FIGURE 6. Lake Wabukayne FTW pilot project, Mississauga, Ontario Canada. Left view is initial configuration summer 2015. Right view shows the same modules reconfigured and relocated in Summer 2016.



JANNOCK POND FTW PILOT PROJECT

This municipal storm water installation located in Mississauga, Ontario Canada was a collaborative pilot project with the Credit Valley Conservation Authority and the City of Mississauga. In May 2013 Terrapin Water installed approximately 1,112-square feet of FTW comprised of 264 individual hexagon-shaped PhytoLinks modules that were anchored using ground screw-type anchors fastened to the modules by means of a vinyl buoy and 5/16 inch chain (Figure 9). Similar to Lake Wabukayne, this location was exposed to the 100-year storm event approximately 2 months post installation. Another significant challenge with this location was the resident year-round population of more than 50 Canada geese. Fence failures in early 2015 allowed access by geese which rapidly eliminated the majority of the vegetation. Subsequently, all modules were removed from the pond in late summer 2015 and transferred to a nursery pond (Figure 10). All modules were successfully reinstalled, fully vegetated in a new more stable configuration in late 2016 (Figure 11).

Key failures at this installation included:

- Destruction of greater than 90% of plants following 100-year storm event in year 1;
- Flipping of approximately 60 modules during the same storm event (Figure 12); and,
- Elimination of approximately 85% of viable plants by Canada geese following a fence failure (Figure 11).

The key lessons learned from this installation included:

- Transplanting of fully vegetated FTW modules from a nursery pond is a viable approach to mitigate risks associated with onsite plant establishment;
- In areas with abnormally high populations of geese fencing must be checked on a regular basis;
- Canada geese can quickly eliminate all viable vegetation from fully mature FTW modules in a matter of months if fences are not maintained (Figure 11).

PROJECT DESIGN CONSIDERATIONS

The importance of having pilot projects like these to expose FTWs to full-scale forces cannot be overstated. It is virtually impossible to artificially recreate the conditions and forces that a 100-year storm event creates. The patience and support that was provided by both the Credit Valley Conservation Authority and the City of Mississauga were essential to the success of this program and have allowed Terrapin Water to make significant improvements in our overall understanding of the practical side of FTWs.

FIGURE 7. Lake Wabukayne FTW pilot project, Mississauga, Ontario Canada after 100-year storm event. Modules were flipped but module-module tethering system and anchor lines were all intact.

FIGURE 8. Revised PhytoLinks anchoring system for urban stormwater ponds (each module on the leading edge has a support line that connects it to the anchor line to eliminate flipping).

FIGURE 9. Initial configuration of Jannock Pond FTW pilot project, Mississauga, Ontario (September 2013).

FIGURE 10. PhytoLinks FTW modules being grown in a nursery pond prior to reinstallation in Jannock Pond.

The key aspects of FTW design optimization based on our experience to date are summarized below.

Cost (Initial & Replacement)
The most likely end-users of FTW technology (municipalities) are already tasked with managing increasingly complex infrastructure with finite financial resources. Any investment in new technology such as FTWs, regardless of the potential benefits, will therefore require a careful analysis of all the associated short-term and long-term costs. A second key consideration with regards to cost is that size in FTWs is generally very important. The realization of significant treatment effects (in most cases) will require large-scale FTW installations. These are the main reasons that our design process used both initial and replacement costs as a key constraint. The way in which we addressed this constraint was very straight forward, we used the bare minimum of materials in our module construction in order to reduce the overall cost. Buoyancy in particular was noted as a relatively expensive component of the FTW system. Therefore we conducted a number of tests to determine the exact amount of buoyancy we needed to float fully mature vegetated modules. Our relatively small module size (approximately $8ft^2$) and quick attach module-module connection system meant that we did not need to provide enough buoyancy for people to walk on the modules in order to perform routine maintenance activities (Figure 13) .

We also factored in that FTWs deployed in outdoor environments will have a finite lifespan of approximately 10-15 years for locations where winter is a reality. With many of the commercially available systems we studied and installed, the entire FTW system including plants would need to be replaced at the end of that lifespan which would introduce a significant financial challenge for end-users. We addressed this challenge by making the compo-

FIGURE 11. Reconfigured module layout, Jannock Pond FTW pilot project, Mississauga, before (right) and after (left) goose damage due to fence failures.

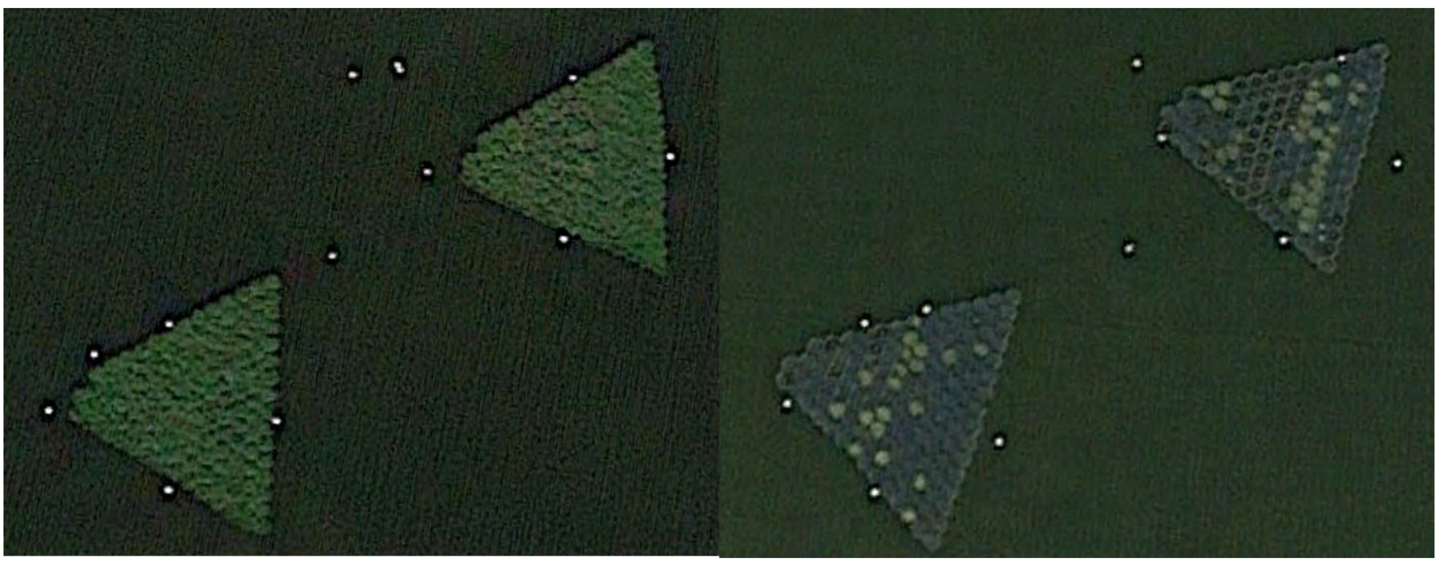


FIGURE 12. Jannock Pond FTW pilot project, Mississauga, Ontario after 100-year storm event. Multiple modules were flipped but module-module tethering system and anchor lines were all intact.

nents that wear out, namely buoyancy and module-module connection systems fully replaceable; in effect reducing the cost of system replacement at the end of the expected lifespan by greater than 65%. Based on our experience to date we also know that we can conduct this manual components replacement onsite without sacrificing the vegetation resulting no significant lapse in treatment effect.

Ease of Plant Establishment

Our experience with FTWs has shown that getting plants established is one of the most significant challenges to overcome. Even locations with obvious symptoms of eutrophication such as excessive algae blooms and odors may lack sufficient sustained quantities of dissolved nutrients to allow for optimal hydroponic growth and establishment of plants in the first year of deployment. In northern locations plants must attain a certain minimum amount of root growth in Year 1 to avoid excessive winter mortality. Some FTW systems address this by adding growth media to the surface of their modules to provide additional nutrients to establish plants. However, we decided against this approach since it requires additional buoyancy and hence adds cost to the FTW design. Instead we opted for a module size (approximately 8-square feet or 1-square meter) that was small enough that even a fully vegetated and mature module could be moved by hand. This has allowed us to rear our FTW modules offsite in a nursery pond environment where we can control nutrient levels and predation pressures much more effectively (Figure 10). In most cases we now deliver fully established vegetated FTW modules to the job site at the end of their first year of growth. This design feature has provided several key benefits including:

- Reduced plant mortality in first winter;
- Reduced predation pressure by geese (mature vegetation is much less attractive than immature vegetation);
- Reduced opportunity for colonization by invasive species (fully established modules have virtually no space for invasive plants); Greater success with plant establishment in low nutrient conditions such as newly built ponds.

Anchoring

For the purposes of FTWs we define anchoring as both the means of tethering individual modules together as well as the system used to attach groups of tethered modules to the bottom of a waterbody. Anchoring is a key constraint for design since keeping the modules in their desired location is necessary both from a functional and a liability perspective. The anchoring system must not only keep the modules connected to each other and the bottom but also help to absorb and dissipate the significant forces associated with gusting winds (termed “shock loading”).

Based on our experiences with several anchor failures at our Pond 10 installation we elected to incorporate the module-module tethering system into the underside of the plastic frame that forms each individual module. We selected stretchable rope as opposed to cabling to effectively mitigate shock loading from gusting winds. Our tethering system and quick-attach connectors also allow for spacing and subtle movements between adjacent modules which in turn contributes to the active dissipation of force (Figure 13).

During the design process we also embraced the reality that tethering and anchoring systems can and will fail periodically regardless of how robust the design may be. Accordingly, we incorporated redundancy into our connection system such that each module in a typical PhytoLinks layout is connected to six adjacent modules (Figure 13). This

FIGURE 13. Mature PhytoLinks modules showing module-module tethering and quick attach connections.

FIGURE 14. PhytoLinks FTW installation Brampton, Ontario Canada (2017) showing 6 anchor lines (white buoys) per grouping of modules.

effectively means we can experience a failure in multiple module-module connections without having a catastrophic system failure where all tethered modules come loose from their anchor point. We also employ multiple anchors for any one group of tethered modules to provide a similar system of redundancy (Figure 14). Our experience has shown that both concrete deadman-style anchors as well as helical ground piles are effective for use with FTWs.

The last consideration for anchoring of FTWs in stormwater ponds is the ability of the system to withstand rapidly moving water during severe storm events. Because our modules make use of the bare minimum of buoyancy, they tend to ride relatively low on the water surface which initially made them susceptible to flipping during severe storm events (Figures 7 and 12). We were able to overcome this challenge by tethering each individual module that is exposed to the rapidly moving stormwater flow back to an anchor (Figure 8). This relatively simple adjustment has eliminated the issue of flipping during severe storm events.

The combination of forces acting on FTWs in stormwater ponds in northern locations is arguably one of the most challenging situations imaginable. However, the end result of designing and testing our system in this environment is an anchoring system that is both reliable and cost-effective and can be changed and adapted to meet other less demanding applications with relative ease.

FIGURE 15. PhytoLinks FTW installation Brampton, Ontario Canada (2017) modules frozen in place.

FIGURE 16. PhytoLinks module showing HDPE-encased flotation system.

Maintenance

Maintenance is crucial to the long-term success of FTW installations but rarely gets an appropriate amount of consideration. For the purposes of this article we define maintenance as all activities that occur post installation once plants have reached maturity. In stormwater pond installations the primary maintenance activities are visual inspections of anchoring and tethering systems and minor fencing repairs. Visual inspections need to be conducted in spring immediately following ice-out, during fall just prior to ice-up as well as following severe storm events to assess both the anchoring and fencing systems for problems. In locations with resident populations of geese, inspections may have to be conducted on a more regular basis during the growing season to ensure that the fencing is not breached.

Our design strategy with regards to maintenance was to make our FTW system as simple to work with as possible. As a result both our module-to-module quick attach tethering and anchoring systems require no special tools or technical skills to assess and/or maintain. In the majority of cases a simple visual inspection is sufficient to be able to quickly and accurately assess overall system integrity. This means that municipal staff or other end-users can quickly and easily be trained to conduct visual inspections and even carry out minor repairs or adjustments themselves. In rare instances requiring replanting or other adjustments to individual modules, the quick-attach connections can be easily removed to allow for easy access to the problem modules.

FTWs like any other type of infrastructure are certainly not maintenance-free, and, as such, they need to be designed with the end-user in mind. Making tethering and anchoring systems simple and straight forward makes it less intimidating for the end-user to effectively maintain their FTW system and may ultimately lead to wider spread investment in the technology.

Flexibility

FTWs like any other infrastructure can and will experience problems and failures whether it be due to severe weather, wildlife, or even vandalism. The ease with which one can trouble shoot a particular FTW system and solve the kinds of unforeseen challenges encountered in aquatic systems is a characteristic we define as system flexibility. Not surprisingly, the simpler the system, the easier and more flexible it is to work with. This is precisely why we opted for tethering and anchoring systems that can be manipulated by hand without the need for specialized tools. We also selected a relatively small and simple hexagon module shape and quick-attach module-to-module tethering system to give ourselves the ability to completely change both the shape and location of the groupings of tethered modules with minimal effort (Figure 6). In practice this has generally been applied in response to system failures or in an effort to improve treatment effects. We have found this attribute to be particularly important in new FTW applications where the optimal layout to achieve a certain treatment goal may not yet be known. The ability to adapt and change a particular FTW installation in response to challenges or data analysis is a critical component of long-term success.

Durability

The challenge of designing a sustainable FTW system capable of withstanding the punishing forces of nature is all the more daunting in the context of climate change. More frequent storms of increasing severity mean that the 100-year event is no longer just an abstract design concept but rather a reality that will likely be experienced in the short-term. Our strategy to mitigate this challenge was two-fold. First we accepted the humbling reality that severe weather events can and will cause all FTW systems to fail at some point. As a result we abandoned the concept of trying to make our system absolutely indestructible and instead made the components that bear the brunt of storm forces quickly and easily replaceable. This approach allowed us to recover rapidly from the severe weather event in 2013 without the need for total system replacement. The second element of our strategy was to eliminate cable and/or chain from our module-to-module tethering system in favor of rope. The subtle stretching ability of rope provides much needed protection against the types of severe shock loading from wind gusts that are so often associated with severe weather events.

Winter conditions create a unique set of challenges for FTWs with modules and flotation often becoming completely frozen in place (Figure 15). Repeated freeze-thaw cycles can lead to crushing type deformation of buoyancy and loss of flotation in some installations. As a result, we switched our buoyancy from PE foam rods to more robust HDPE-encased flotation (Figure 16). This change has significantly improved the durability of the PhytoLinks flotation system.

Ultimately, durability in FTW design is only attainable through subtle changes and adjustments in response to repeated exposure to the most challenging conditions available. In that sense we were extremely fortunate to have had multiple full-scale systems exposed to such conditions in 2013. However, we are certainly not of the opinion that our system or any other system is infallible, and we will undoubtedly adapt and change our system in response to future challenges in order to continuously improve the durability.

CONCLUSION

The use of FTWs to solve any number water-related environmental challenges shows outstanding promise. However, we are clearly still in the early stages of acceptance and widespread application. To overcome this hurtle key end-users such as municipalities will need to be convinced that FTW system designs embrace and address the various elements discussed in this article in a way that ensures a sustainable long-term solution.

At a glance, the open discussion of failures of FTW technologies by a FTW practitioner may seem counter-intuitive. However, we have come to understand through our various experiences that the success of environmental technologies such as FTWs is much more about embracing failure than it is about touting success. The design optimization program utilized to develop PhytoLinks has allowed us to achieve a simple, cost-effective, durable, flexible and portable FTW system that we have successfully used to solve a number of environmental challenges. That being said, we are by no means convinced that we know everything there is to know about FTW systems. Instead we are committed to a continuous process of learning, refinement and improvement that has allowed us to stay at the forefront of the FTW industry in Canada.

It is hoped that by providing this type of information we can help both FTW practitioners and end-users in the refinement and ongoing management of their own technologies and/or installations. ■

Adapting floating wetland design to advance performance in urban waterfronts

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The great cities of the Mid-Atlantic, from Washington, DC to New York City, were strategically placed along the fall line where the Piedmont physiographic province transitions to the Coastal Plain. Situated at the head of the tide, this landscape position held important attributes for city building, including safe harbor for ships, local stone for construction, and proximity to steep streams suitable to run mills (Walter and Merrit 2008). But the head of tide is also an important ecological landscape threshold, where carbon, sediment and nutrients are delivered from the uplands by streams and rivers and deposited in tidal freshwater and brackish marsh systems. In undisturbed landscapes, those marshes uptake and transform pollutants in the water while providing refugia for aquatic fauna, spawning habitat for fish, and feeding grounds for migrating waterfowl. As human development has displaced these ecosystems, the connection facilitated by the beneficial ecosystem services of the tidal marsh systems has been severed (Reusser et al. 2015).

As a result, urban waters are less likely to support a healthy aquatic community. In Baltimore Harbor, fish kills due to anoxia and harmful algal blooms are common. Warning signs discouraging subsistence fishing are necessary due to toxicity, poor water quality and potential for disease. Even recreational contact is considered a risk in highly impaired urban waters. But with increasing public awareness and access to waterfronts, there is a growing demand to address pollution, improve habitat, and make open water bodies a community amenity.

One strategy to restore habitat and ecological services in urban waterways is to deploy floating wetlands (FWLs), which are constructed systems that support plants on a buoyant mat floating at the top of the water column. Constructed FWLs are an ecotechnology deployed primarily to treat polluted natural waters and wastewater, while providing critical habitat (Panlineri 2018). FWLs can also be an aesthetic amenity that can include opportunities for education and research.

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Water Quality Improvement

As FWLs have moved from novel technology to increasingly refined products, the research quantifying their water quality effects continues to be primarily derived from work in the laboratory or controlled settings, if benefits are quantified at all. A recent literature review found that fewer than 40% of scholarly papers on urban treatments to enhance ecosystem services quantify their ecological effects (Prudencio and Null 2018). Nevertheless, the available information suggests that FWLs can have important impacts on nutrient removal in urban environments. Several variations of FWL designs in urban retention ponds have been tested and found to remove significant quantities of phosphorus and nitrogen, largely through organic matter decomposition (Fang and Sample 2014). The primary productivity (McAndrew and Ahn 2017) and plant uptake rates (Keizer-Vlek et al. 2014) of the FWL system are also strong drivers of nutrient removal. Published reports also include effects in the water column below FWLs, such as lower dissolved oxygen, sulfate, nitrate, and pH, dampened diurnal temperature fluctuations, and greater alkalinity (Strosnider et al. 2017). The effects can vary over time, but long-term assessments can show peaks of almost 70% increase in dissolved oxygen, almost 90% removal of fecal coliforms, and 75% removal of nitrate in eutrophic urban ponds (Olguin et al. 2017).

Habitat Provision

Although FWLs are often touted as habitat enhancements, their primary function is usually defined in relation to water quality, which is where the bulk of the research to quantify beneficial effects has taken place. In the earliest pilot projects near the Baltimore Aquarium, FWLs were quickly colonized by algae, mussels, and other organisms. After five months in the harbor, the microcosms had gained about three times their dry weight and supported a very high density of bryozoans, hydras and various protists (Nemerson 2011). How birds and juvenile fish use FWLs designed for water quality is little known, though anecdotal evidence is abundant. At a pilot study at William and Mary University, the floating surface was regularly used by birds including herons and kingfishers. Ducks often attempt to nest on FWLs. The subsurface habitat may be more important in urban waterfronts. Where harbors and rivers are heavily armored, escape and foraging habitat is often severely restricted for juvenile fish, and the below surface substrate and ecological community likely provide important refugia for young fish. A series of case studies and examples compiled in a FWL technical workshop included several examples of fish populations supported by FWL (Andrews and Rottle 2013).

Aesthetic and Educational Benefits

Wetlands are known to contribute to quality of life, offering nature encounters and an experience of beauty (Pederson 2018). Their aesthetic value and provision of cultural ecosystem services are the subject of emerging research, especially in Europe. Visitor's perceptions of ecological and aesthetic values are strongly influenced by aquatic vegetation (Cottet et al. 2013). Managers also recognize the educational value of FTWs, both in raising visitor awareness of ecological topics such as nutrient loads and habitat loss, and for focused research and study in settings such as University campuses (McAndrew and Ahn 2017).

CASE STUDIES

In recent years, three FWL projects in the Baltimore and Washington, DC area have attempted to maximize these benefits in field situations. This paper shares the primary design lessons and modifications developed over the course of those three projects. Although many of the project objectives were met in each case, the process revealed a series of lessons in FWL design and maintenance. If floating wetlands are to become a viable means of contributing benefits along urban waterfronts, it is imperative for the design community to share these challenges alongside the resulting modifications and insights. The following case studies chronicle a recent journey of refining FWL design for resource managers, design consultants and producers of commercial units.

Bio-Flotsam at Baltimore's World Trade Center

In 2010, two small pilot installations of FWLs were deployed in Baltimore Harbor for the Healthy Harbor Initiative - an effort to catalyze improving the Inner Harbor to swimmable and fishable conditions. Both projects were permitted for 200-square foot installations in two locations. The National Aquarium of Baltimore purchased and installed a Biohaven™ Floating Island, which is constructed of recycled plastic mesh (made from polyethylene terephthalate or PET) and buoyant marine foam. The Bio-Flotsam FLWs were constructed using buoyant plastic bottles, collected from the Harbor itself, sandwiched between PET media. The PET media was then retained within two frames of wood and plastic mesh. Both pilot systems survived for at least two growing seasons. Efforts were made to evaluate whether the FWLs were generating ecosystem services such as nutrient transformation and removal, improved water clarity, and refugia for insects, birds, fish and nekton. Scientists at the National Aquarium in Baltimore documented the colonization of the media by bryzoans, hydras, false dark mussels and polychaetes (Nemerson 2011).

In 2012, the Bio-Flotsam installation was expanded from 200-square feet to 2000-square feet (Streb 2013). (Figure 1) The same pilot design with small modifications to strengthen the connections was implemented. No exclosure fencing was used. During the first two years, the FWLs supported vigorous growth. Smooth cordgrass (*Spartina alterniflora*) grew more than 6 feet in its second year and largely crowded out other species, such as rose mallow (*Hibiscus moscheutos*). The project was celebrated as an example of community building and public engagement (Streb 2013).

In 2015, several FWL units were replaced as the biomass accumulation began to exceed the available buoyancy provided by the plastic bottles. Much of the biomass accumulation (bio-fouling) was due to barnacles, mussels, and other benthic marine organisms. As the units sat lower in the water, vegetative growth was stymied. Moreover, the successful growth of the FWLs attracted waterfowl

FIGURE 1. Bio-flotsam - portion of the full build-out (Summer 2012).

as feeding or nesting sites. This placed added pressure on the plants. In time, these units became bare of vegetation. Floatable waste collected on the units and was more visible. Nylon connections began to abrade and break, periodically forcing the system to fall out of alignment. Since the grasses were not subject to diurnal tidal flooding due to the platform design, the grasses did not become saturated detritus and naturally fall away. This required the harvesting of above-water biomass each spring to lighten the units and introduce sunlight to the base of PET media for new shoots to grow, which also extended the life of each unit.

Replacement units were built by volunteers and installed in each year from 2016-2018. Due to the waterfowl population, each new unit required fencing to enable vegetation establishment. However, the fences were often breached. Shortly thereafter, plants were either eaten, trampled, or used for nesting.

FIGURE 2. Bio-flotsam – volunteer planting event (Spring 2012).

FIGURE 3. Bond Street Canal project (Summer 2017).

Each FWL unit was 4 feet by 8 feet rectangles. (Figure 2) This size was ideal for volunteers to carry the units and plant, but too small to support a person. Moreover, a structure of these dimensions was subject to flipping; when a listing unit was flipped over due to wave action. All maintenance had to be performed by boat. Over time, the need for maintenance exceeded available budgets. As the FWL array looked progressively disorderly, the site owner asked that they be removed in the summer of 2018. The units were relocated to a marina where there was less exposure to the public. Disposal of several units was challenging, as the weight with biomass and water saturation required a motorized winch to lift out of the water.

Lessons Learned

- Biomass accumulation due to marine animal fouling exceeded buoyant force over time.
- Buoyancy elements integrated into planting media confined the unit to a short lifespan. Without ease of separating the media from the buoyancy, once the media was fully colonized by marine animals and the buoyancy was compromised, the whole unit was unsalvageable. Inability to physically occupy the wetland surface made maintenance difficult, required multiple vessels in most cases and was extremely time consuming and expensive.
- Small unit size was helpful for installation, but layout required complicated tethering plan which provided multiple points of failure, was extremely time consuming to repair/replace/navigate, and exceptionally difficult to remove any one unit from the mass.
- Accumulation of trash was an ongoing problem that also detracted from the structure's aesthetic quality. Flotsam included invasive and volunteer plants, which resulted in several wetlands to host common reed (*Phragmites australis*) and/or arrow-leaved tearthumb (*Polygonum arifolium*).
- Goose exclosures were difficult to work around during replanting, trash removal, and tethering replacement and were largely ineffective in prohibiting goose use, although far more effective than doing nothing.

- Accommodating nesting Canada geese made any maintenance effort potentially hazardous.
- Maintenance effort was costly, time-consuming and constant (broken tethering, dead plantings from herbivory, severe trash accumulation).
- Volunteer planting events occasionally yielded inconsistent planting depths which led to large die-offs.
- Planting of *Spartina alternifolia* outperformed/overtook other plantings over time.
- Any fabric hanging in the water was colonized by false dark mussels, which provided additional habitat and water quality benefits beyond the wetlands themselves.

Bond Street Living Canal in Baltimore

The Bond Street Canal Living Canal FWLs (Figure 3) were installed in May 2017 with the goal of providing water quality benefits and improving aesthetics to the canal adjacent to the owner's waterfront office building. The project presented an opportunity to distill the lessons learned from the Bio-Flotsam project into a next generation design. The Bond Street FWLs were designed to:

- Be constructed of durable materials,
- Separate buoyancy platform from planters,
- Include modular planters that enable removal for cleaning, research, or relocation, and
- Possess adequate reserve buoyancy to support standing access for maintenance.

A fundamental design change was to separate the buoyancy element from the planting media, which allowed for an exchange of planting media without the complete disassembly/disposal of the entire FWL. The buoyancy structure was fabricated using three parallel square aluminum tubes, capped at both ends, set about 5 feet apart and framed together. The media was also reimagined as being set in modular frames attached to the structure and could be removed or replaced, if desired. The modular frames were redesigned oyster cages - wire cages used in oyster aquaculture. To secure the cages to the structure, pontoons were oriented at a 45-degree angle (diamond shape in section) and fitted the cages with "wings" where by using its own weight to taper lock it into place (Figure 4). A similar media (unwoven PET panels) was used as the Bio-Flotsam design but was made thicker and specified with planting holes to be completed during fabrication. Planting was installed by student volunteers from local nonprofit foundation.

The first arrangement of the 1000-square foot installation was staggered to maximize edge and visual impact (Figure 5). Within the first two weeks, this arrangement was noted to be especially proficient at trapping floatable trash. The client asked that the system to be rearranged to create a continuous line of FWL. This new arrangement facilitated less trapping and easier access (Figure 3).

Plant establishment was hampered primarily by goose pressure and, to a lesser extent, by planting installation. To address the planting installation concern first, the adaptation of the installation process to the media hole size, site influences and plant material resolved the issue. The pre-drilled planting holes afforded the plug the benefits of wet-feet, wide spacing and deep media penetration. However, some plugs weren't snug in the media and caused many plantings to fail. Sited in an active harbor, wave energy from boat traffic contributed to a washing out of plug soil when not tightly contained. Additionally, *Hibiscus* specifically appeared not to have a highly fibrous root system and didn't hold the soil especially well. To resolve the issue, replacement soil plugs were wrapped with a woven coir/burlap fabric (both were used independently) prior to installation.

FIGURE 4. Bond Street buoyancy separation.

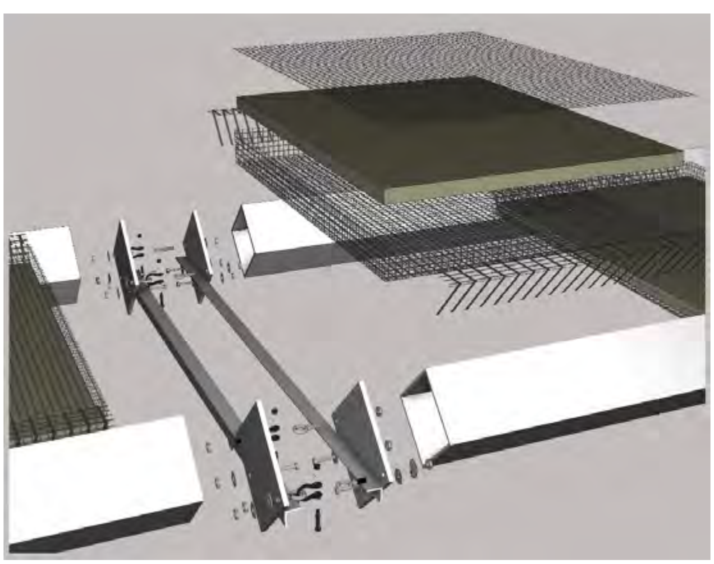
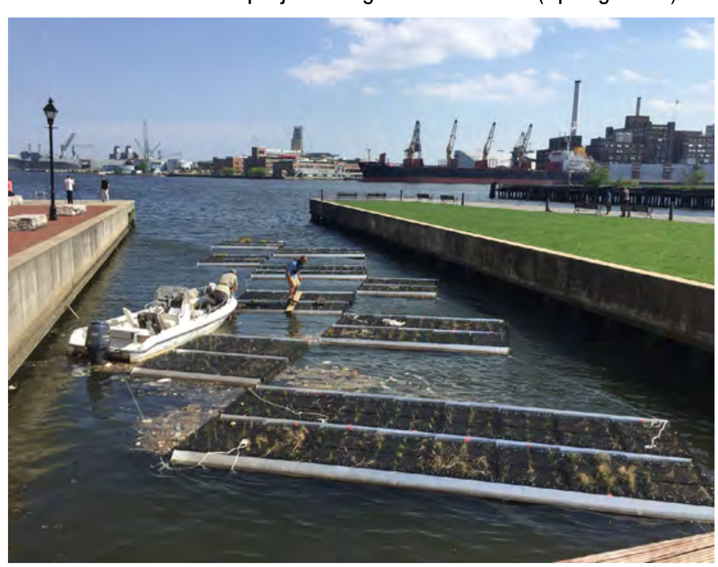


FIGURE 5. Bond Street project- original orientation (Spring 2017).



The added width better accommodated the hole diameter and protected the soil from being washed out.

Resident geese herbivory and impacts from their waste products was the single largest contributor of planting growth suppression and failure. Metal wire arches were placed over the media to inhibit access. However, the wire arches were both strong enough and the openings small enough (approximately 1 inch) that the material could support multiple geese who continued to feed on the grasses, creating a topiary effect. Those arches were later replaced with new wire fenced arches. The gaps in the wire were 4 inches which prevented the geese from walking on the arches and allowed the plants to get established. Aside from managing invasive *Polygonum* and thinning of senesced leaf material, the plants have continued to prosper through their second year.

The FWL array was tethered at multiple points. Wave energy generated from wind and boat traffic keeps the system continuously engaged. Nylon lines were attached to steel shackles. After the first year, connections were found to abrade and break. The lines have been replaced with chain. Stainless steel hardware fastening the pontoons also periodically failed. This was only resolve when diagonal cross braces were installed to stiffen the pontoon frames.

Lessons Learned

- Upgrades to buoyancy enabled standing access, greatly facilitating management.
- Wire frames holding plant media are more easily moved.
- Media colonized with plants and community of filter feeders creates the possibility of researching water quality benefits in a controlled mesocosm study versus an open water installation.
- Appropriate exclusion fencing was necessary for establishing plants.
- Steel chain connections were necessary in this high energy environment.
- Stiffening the buoyant framework has reduced mechanical failure rates of connecting hardware.
- Flotsam was reduced by arranging FLWs so that gaps and corners were minimized.
- Flotsam accumulation on wetland continued to be a problem, as the units sit nearly level with the water surface.
- *Polygonum arifolium* is observed throughout the wetlands and must be manually weeded to suppress its growth.

District Wharf in Washington, DC

The District Wharf is an urban waterfront revitalization effort along the Washington Channel, a freshwater tidal system connected to the Potomac River in Southwest DC. A cluster of FWLs, elliptical in shape (Figure 6), were envisioned, designed and installed adjacent to a new public pier as an aesthetic amenity, for habitat and to provide incidental water quality improvement.Though the project presented similar challenges and standards of success, the District Wharf is anticipated to be utilized throughout the year by tourists and residents. Therefore, the FWLs required a more refined and aesthetically rich approach.

With the Bond Street wetlands completed, the District Wharf FWLs again presented an opportunity to extract lessons from the previous design and make a better product. The new design conceptualized an aluminum band around the perimeter, resembling a weightless, floating aluminum ring occupied by plants (Figure 6). This design element is owed much to the eventual success of the project because it resolved several problems that would have otherwise been present. Not only does it hide the structure and provide a clean, consistent edge, it also acts as a structural frame to further secure the buoyant elements together. Additionally, the band prevents the accumulation of flotsam on the wetland, which detracts from the aesthetic value and is a key importer of invasive plant material to the system, otherwise requiring increased maintenance costs. The ellipses consist of two layers of buoyancy in the form of aluminum pontoons. Pontoons placed on the bottom of the structure are flooded to regulate the elevation of the units. Having the ability to adjust where the units sit in the water column is expected to extend the life of the system as well as facilitating management.

Another significant redesign was the elimination of the cages and replacing them with an underlying fiberglass support deck upon which the media would sit. The support deck provides uniform support and can be occupied by several people at once, whereas the cages at Bond Street provided enough support for just one person. The media was cut with 45-degree angles on the edges to help secure the media panels in place as with Bond Street.

A third major difference worth noting is the process behind the planting establishment to the media. Unlike Bond Street FWLs, the PET media panels were shipped directly to the nursery to pre-grow the plants in the media prior to installing onsite (Figure 7). The primary goal for pre-growing plants into the media was to ensure substantial establishment for a scheduled September install date. It was also hoped that the plants would be more resistant to site stresses, including herbivory and sun intensity. Since the Washington Channel is freshwater, salinity acclimation was not necessary. The pre-grown panels were shipped to the site for installation with large root mats spread under and throughout the media. Posts and wire line were strung across the units to reduce herbivory pressure. In Spring of 2018, an area of the line was compromised, and a Canada goose female nested on the unit. Upon her eggs hatching, she left the unit and the exclosure was repaired.

Lessons Learned

- Pre-growing the plants in the media can yield a more immediately aesthetic product, but care should be taken to acclimate plants from nursery to open water.
- Perimeter and interior cabling is an important, if imperfect, defense against herbivory.
- Planting palette was designed with herbivory-prone species in the center and less desirable plants along the perimeter.

DISCUSSION

FWLs are an ecological prosthetic along urban waterfronts aimed at restoring a semblance of the ecological functions severed due to urbanization. FWLs cannot compensate for the comprehensive elimination of natural marshes along urban waterfronts, but they can be employed to provide meaningful benefits. In the U.S. mid-Atlantic region, a few generations of FWLs have been deployed in tidal waters, each with new adaptations to better educate, beautify, provide habitat, improve water quality, or enable research. The following lessons learned from case studies in the Baltimore-Washington DC area are presented as considerations for resource managers, design consultants and producers of commercial units.

FIGURE 6. District Wharf (Summer 2018).

FIGURE 7. District Wharf - planting media grow-out at Wicklein's Nursery (Summer 2017).

	Bio-Flotsam	Bond Street	District Wharf	Recommended Practice
Herbivory Protection	Mesh perimeter – limited protection	Wire arches – inhibits nesting, good protection	Cable wiring – good protection, needs monitoring	Wire arches work, cable wiring shows positive results
Planting Survival	Medium - Consistent herbivory pressure	Medium – Rough start but resolved	High – Well established	Establish plants offsite prior to project install
Aggressive or undesirable volunteer plants	Slow invasion	Established early; highly competitive with plantings	Added metal barrier to prevent intrusion, especially via floating mats	Incorporate perimeter barrier
Trash Accumulation	High accumulation	Medium/High accumulation	Minimal accumulation	Incorporate perimeter barrier
Maintenance Access	Challenging: structure cannot support a person	Medium – can support a person	Superior - structure supported multiple people	Supporting multiple people should be design parameter
Aesthetic Value	Compromised by uneven surface, trash accumulation, and herbivory	Medium – Trash, moderate herbivory pressure, one flowering plant	High – Metal bar gave clean aesthetic and prevented trash, herbivory was better controlled, and plant survival and flowering was high	Preventing trash, consistent buoyancy and plant palette are critical to high aesthetic value

Aesthetics

Reintroducing vegetation to conceal and beautify urban bulkheads and marine infrastructure is the first perceived benefit associated with FWLs. Regardless of whether the true purpose of the FWLs was to provide habitat or improve water quality, the visual appearance of the system will be the primary criteria through which the public and the client determine performance. Nassauer (1995) postulated that ecological quality may not be appreciated without cues indicating human intention. In support of this contention, the Bio-Flotsam FWLs were embraced when they were lush with vegetation and the array was orderly and symmetric. However, as time and weather strained and broke connections, exclusion fencing was breached, vegetation browsed and trash made visible, the FWLs became unsightly and the property owner asked that they be removed.

Truly understanding the site context may help inform the degree to which attention is given to the aesthetics of the FWLs. In general, the more populated and closer the system is placed before viewers, the more important high aesthetic design standards are for the FWLs.

At the District Wharf FWLs, the four installed units are characterized by their elliptical shape defined by a 10-inch aluminum curb around the perimeter. The freshwater marsh community may be considered wild and unmanaged but given that they are contained and framed by the urbane edge, the public and client reception has been positive. These particular FWLs seem to delight by fusing the intention of providing ecological habitat into objects of landscape art.

Durability

FWLs were placed in open tidal water systems. The continuous exposure to sun, wind, and wave action over time weathered and degraded the structural integrity of the tethering and platforms supporting the plants. Failures to the tethering were observed within the first two years of the installation of the Bio-flotsam array in Baltimore and occurred with more frequency over time. One factor observed was corrosion. Nylon lines were tied to galvanized or stainless-steel shackles. In salt water, the surface of the shackles developed pits and abrasive mounds that cut through the nylon tethering lines, particularly with wind and wave action keeping the units rocking. Platforms also were observed to be impacted by weather.

The first pilot of the Bio-flotsam systems wood frames were broken open during a tropical storm. The first installation of the National Aquarium FWLs were built without any rigid materials. The PET media began to weaken with photodegradation and delaminate as the system experienced tensile stress from anchored steel cables countering the upward force as the unit floated. At the Bond Street Living Canal project, high wave energy from boat traffic keeps the FWLs in continuous motion causing nylon tethers to wear and break.

At the District Wharf FWLs, the aluminum band around the perimeter of the units stiffens the structure. The tethering is steel cable anchored to concrete blocks. No failures have occurred to date, nor is there any indication of any risk after one year. At the Bond Street Living Canal, all connections have been upgraded to galvanized chain to reduce the risk of abrasion observed with nylon lines. In both systems, the PET media is used only to support the plants and benthic organisms. The top of the media is treated to defend against ultraviolet degradation. As the media is under no tensile stress and protected from sun, there has been no indication of degradation.

Buoyancy

A factor contributing to the life of FWLs in brackish water is the reserve buoyancy. In Baltimore, all FWLs installed to date have provided colonization sites for a variety of benthic organisms. These organisms represent the base of the estuarine food web. With filter feeders, including hydroids, barnacles, mussels and anemones, these organisms may help clarify urban waters. However, as populations grow on FWLs, the buoyancy of the units has been compromised overtime. At the Bio-Flotsam FWLs, biofouling rates of 1.5 pounds per square foot were observed. Units with designed buoyancy of roughly 6 pounds per square foot sat below water after four years. As the units sunk lower in the water column, the plant community shifted toward *Spartina alterniflora* before becoming unvegetated.

Units designed for the Bond Street Living Canal, the District Wharf and National Aquarium addressed this concern by separating the growing media (PET) from the floating structure. Each of these newer systems include reserve buoyancy with the ability to optimize the elevation of the growing media by including water ballast. As organisms foul the structures, water can be pumped from the ballast so that plants are not drowned. After one year of installation, the District Wharf FLWs have shown no evidence of biofouling as it is the only FWL reviewed in tidal freshwater. The National Aquarium FLW has been actively managed by the owner to optimize elevation for supporting the desired plant community.

Understanding the potential for biofouling is an important factor for determining the long-term buoyancy and function of a proposed FWL. Biofouling can be managed by designing adequate reserve with a means to adjust the plant media elevation. Over the long term, designing a structure that can be cleaned and planting media can be replaced will extend the life of the FWLs and increase the sustainability of the project.

Herbivory

Urban waterfronts in the mid-Atlantic region have limited habitat for waterfowl. The introduction of FWLs along waterfronts can provide additional feeding and nesting locations. In Baltimore, early pilot projects were vegetated after the first year of installation without fencing. However, mallard duck and geese soon discovered the habitat, causing new units installed over the ensuing years to require fencing and exclosures to protect marsh plants from waterfowl.

At the Bio-Flotsam FWLs, vertical posts with plastic netting were installed around the perimeter of each unit. The fences were prone to being overcome by waterfowl. In these cases, the breached FWLs were never able to support plants due to herbivory, trampling, or being pulled for nest materials.

At the Bond Street Living Canal, several steel wire arches were installed over the planting beds. The first system used rigid wire with 1-inch openings. Geese were observed standing on the units and cutting stems protruding through the wire. A second installation using wire fencing with 4-inch openings was found to inhibit geese from accessing the plants from above. After the first year, the arched wire exclosures were concealed by vegetation.

The District Wharf FLWs waterfowl exclosure was constructed with wire lines strung on aluminum posts around the perimeter and through the middle of each unit. Some herbivory has been observed but was limited to a few locations. One female goose nested and brooded her clutch of eggs in Spring of 2018 where a few lines were compromised. The lines were repaired, and no additional pressure has been observed in that location.

CONCLUSION

As urban waterfronts increasingly transform into publicly accessible civic spaces, people are connecting to the natural water bodies that made their city a desirable place for human society. With access comes awareness and a demand for improved water quality and habitat along these waterfronts. FWLs are akin to ecosystem prosthetics, restoring some of the ecological services lost with the conversion of tidal marshes into urban centers. The benefits of FWLs are that they can be deployed to provide habitat in waterways that have been dredged or channelized and now consist of deep water. The flexibility of application can be used to enhance the aesthetics of urban waterfronts, creating gardens on the water that may conceal infrastructure. Water quality benefits of the FWLs continue to be studied. Perhaps the greatest benefit of FWLs installed along urban waterfronts are that they serve to reflect the ecosystem that was once a part of that place. This type of engagement with the public can communicate and educate the need for improving urban waters as a valuable habitat for wildlife.

Advances in FWL design and management require resource managers, design consultants and manufactures to share successes and failings. Three case studies were reviewed to show how unexpected challenges were employed to improve structure design for durability and to reduce maintenance efforts. ■

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BioHaven Floating Islands: Modeling and Their Role in Water Resource Recovery

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BioHaven® floating islands remove excess nutrients and other contaminants from lakes, streams and wastewater lagoons, and are the flagship product of Floating Island International (FII). A BioHaven floating island or floating treatment wetland (FTW) is an example of biomimicry – the science of adapting designs from nature to solve modern problems. BioHavens leverage natural microbial processes to clean water, using a combination of microbial (bacteria and algae) and plant growth to effectively take up, precipitate and/or filter contaminants from water. The matrix and plant roots that grow through it provide an activated surface area for microbes. Producing a sticky biofilm, these microbes are responsible for breaking down nutrients and other contaminants.

BioHavens comprise layers of a non-woven, non-toxic durable matrix of fibers made from polyethylene terephthalate (PET). Dense and porous, the matrix is inert and coated with a UV-resistant resin that is compliant with U.S. EPA standards. An additional armor coating of polyurea is added to provide extra protection against environmental degradation and waterfowl damage.

BioHaven Floating Islands are currently improving water quality at sites around the world (Figure 1). Over 8,000 islands have been launched, and approximately 30 different applications/uses have been identified and evaluated. The purpose of this article is to: 1) describe a BioHaven treatment model that has been developed and used to date by FII, and 2) project how BioHavens can be used in the growing realm of Water Resource Recovery (WRR), where the treatment model is replaced or supplemented by a Return on Investment (ROI) model.

MODELING

The purpose of modeling BioHaven performance is to predict efficacy for various contaminants in new settings. When FII receives an inquiry from a potential client, inevitably one of the first questions is—how many floating islands will I need to budget for? An essential step to establish a budgetary estimate is to calculate the system size needed.

All of the modeling and results discussed are for BioHavens, the standard FTW embodiment for FII. Results cannot be extrapolated to FTWs produced by other manufacturers.

To develop its proprietary model, FII used contaminant removal data from numerous independently-monitored BioHaven studies since 2006. Removal rates are expressed in terms of pounds of contaminant removed per year per cubic foot of BioHaven (lbs/yr/ft^3). Cubic feet are used rather than square feet to account for possible different BioHaven thicknesses, although eight inches is typical.

An Excel spreadsheet model was developed to estimate BioHaven quantities, and subsequently costs, for new projects. The model addresses waterways with either continuous flow or no flow. A factor of $1.05^{(\text{new T} - \text{reference T})}$ is used to correct for temperature. This "theta" value of 1.05 is typically used for temperature correction. Since 2018, a

FIGURE 1. BioHavens are part of an industrial waterfront beautification project at the Urban Institute in Washington, DC. (Note: All photos for this article provided courtesy of Floating Island International, Inc. – permission granted March 22, 2019.)

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different theta value for cold-weather performance derived from Canadian studies has been used when appropriate.

Model Input

Standard model input for design of a continuous-flow system includes:

- Flow rate (gallons per minute),
- Current and desired effluent concentrations (mg/L) for each contaminant of concern, and
- Water temperature (°C).

The same input is used for a no-flow ("batch") system, except that the flow rate variable is replaced by:

- Water volume (gallons),
- Startup time (months) - the time for BioHaven biofilm and plants to grow and become effective (e.g., typically estimated at three months), and
- Total time for restoration (months) - the time requested by the client for desired effluent concentrations to be achieved (note: a typical time might be 24 months; a shorter time requires more BioHavens and a higher capital cost).

The difference between startup and total times is the time the BioHavens are effectively treating water, or the remediation time.

Typical contaminants of concern include biochemical oxygen demand (BOD), total suspended solids (TSS), ammonia, nitrate, total nitrogen (TN), total phosphorus (TP) and total metals. FII has developed typical BioHaven removal rates for each of these contaminants, including both total and dissolved copper and zinc for metals.

Model Output

For each contaminant of concern, the model provides the minimum BioHaven volume required (ft^3). One of the contaminants will be the limiting variable, in that it requires the largest volume and determines the design volume. For example, where model results for a new application predict required volumes of 800, 300 and 600 ft^3 for TN, TP and BOD, respectively, the recommended design volume would be 800 ft^3. That volume should remove all of the TN required (the limiting variable), so the system would then be "over-designed" for removal of TP and BOD.

The volume required is then converted to the BioHaven area required (ft^2), using the typical thickness of eight inches. The area is converted to a number of islands required and a cost. Several BioHaven sizes are available, including standard, high-energy and wastewater-specific models.

FIGURE 2. Total Nitrogen (TN) removal rates for various BioHaven case studies in the United States and New Zealand. Total removal rates are much higher than net rates in most cases.

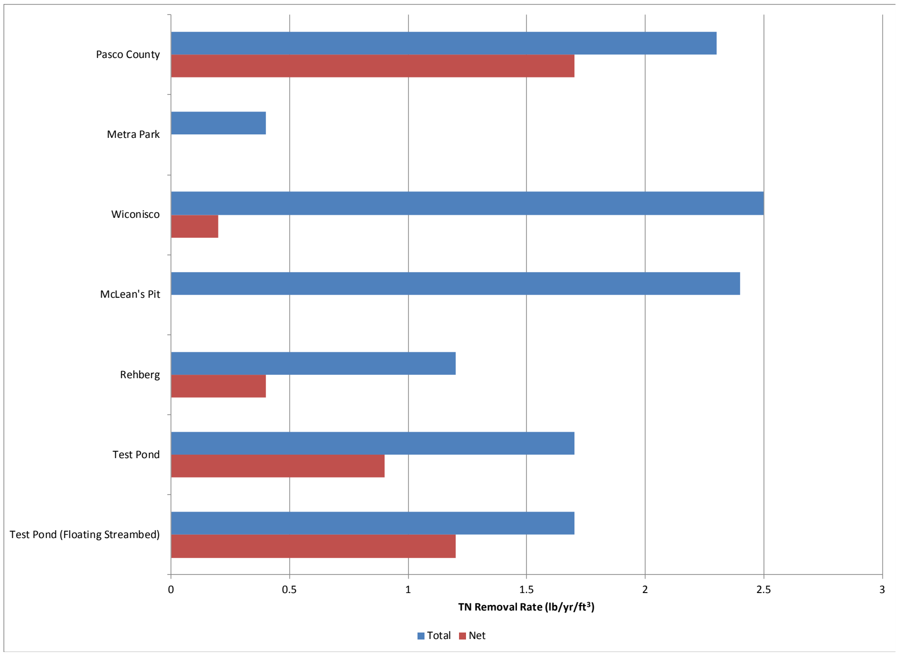
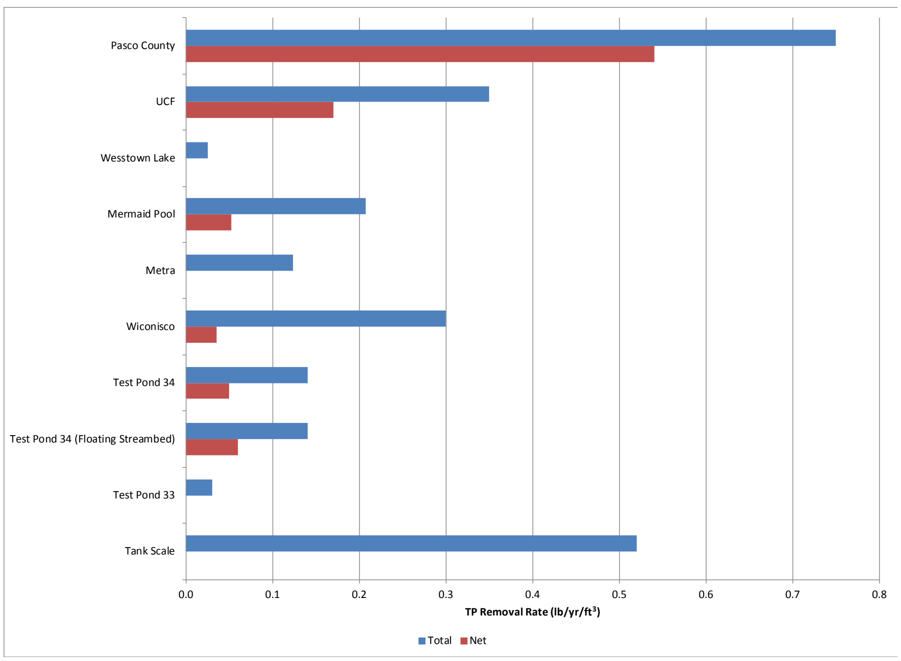


FIGURE 3. Total Phosphorus (TP) removal rates for various BioHaven case studies. TP removal rates are much lower than those for TN.



Total vs. Net Rates

It is necessary to explain the difference between what FII calls the "total rate" vs. the "net rate." The total rate includes effects of both the waterway and the BioHavens. The waterway will typically provide some removal by itself, called the "control rate." Net rate is the effect of the BioHaven only, which equals the total rate minus the control rate.

An example is the FII case study at the Rehberg Ranch subdivision wastewater ponds in Montana. Two parallel ponds were used for the study. The first pond contained BioHavens (the "island pond"), while the second contained no BioHavens (the "control pond"). The island pond removed 1.3 lbs/yr/ft^3 of ammonia (the total rate), while the control pond removed 0.9 lbs/yr/ft^3 (the control rate). Therefore, the net BioHaven rate for Rehberg Ranch was 1.3 – 0.9 = 0.4 lbs/yr/ft^3, which would be the removal rate attributed to BioHavens and the rate used for system design.

Total and net removal rates for total nitrogen (TN) are shown in Figure 2 for several FII case studies. Applications include wastewater treatment, wastewater polishing, stormwater and landfill leachate. Rates for total phosphorus (TP) are shown in Figure 3.

Typical BioHaven rates ("net removal") are shown in Table 1. Removal rates are higher for higher concentrations, as would be expected. A linear increase in rate with concentration would mean first-order kinetics. No change in rate with a change in concentration would mean zero-order kinetics. Since bacteria have been shown to provide at least 80 percent of contaminant removal in BioHavens (Gersberg et al. 1986), and bacterial activity typically follows Monod[2] kinetics (Characklis and Marshall 1990), BioHaven removal rates would be expected to also follow Monod kinetics. Monod kinetics fall between first-order kinetics (where the rate varies linearly with concentration) and zero-order (where the rate is independent of concentration).

TABLE 1. Typical removal rates for BioHavens per cubic foot of island matrix. "High concentration" cases are for wastewater, with "low concentration" cases for lake water or stormwater.

Typical Removal Rates		
	Net Removal Rate (lb/yr/ft3)	
Parameter	**High Conc.**	**Low Conc.**
TN	1.7	0.40
TP	0.54	0.052
TSS	26	1.5
BOD	15	0.8
NH3-N	2.8	0.1
NO3-N	0.9	0.02
Total Cu	NA	0.01
Total Zn	NA	0.06

Verification of Model Results

Since the model has been used in numerous applications, it is appropriate to review how model results compare to actual performance. FII continues to collect data to obtain as complete a picture as possible. The data to-date are quite promising.

At Moonlight Basin near Big Sky, MT (Figure 4), a BioHaven system was installed in 2016 using the best available rate at the time of 0.3 lbs/yr/ft^3 for TN. TN removal measured in 2018

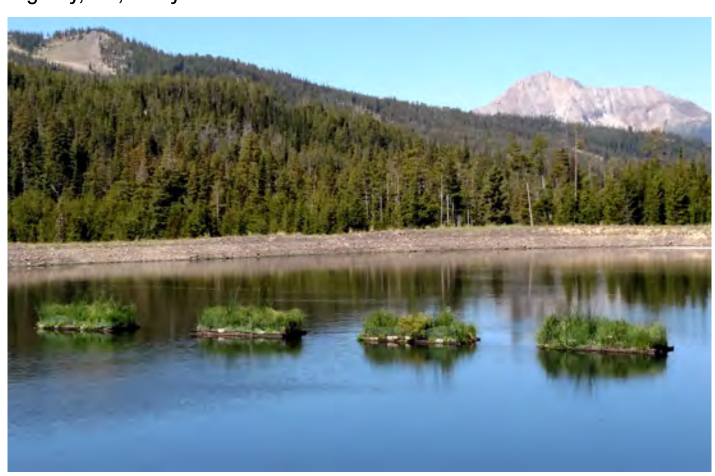
was 1.2 lbs/yr/ft^3, so the actual rate exceeded the design rate by a factor of four. This greatly pleased the client, with the only possible downside being that the system could have been smaller (less expensive) to meet the client's requirements. If FII were to design this system today, it would use the TN net removal rate for wastewater of 1.7 lbs/yr/ft^3 from Pasco County (Figure 2). Using the selected temperature correction factor discussed earlier, for the average water temperature of 10°C at Moonlight Basin, provides a rate of 0.9 lbs/yr/ft^3. This is slightly below the measured rate of 1.2 lbs/yr/ft^3, and appears to be an ideal solution in that the system exceeds design performance at little extra cost.

Comparison data for various parameters are being collected at several other sites where BioHavens were installed in 2017-18: 1) a wastewater lagoon (Joliet, MT), 2) an estuary impacted by wastewater (Guayaquil, Ecuador), and 3) Levings Lake (Rockford, IL).

Other Modeling Tools

Alternative BioHaven modeling is being developed for other cases. An alternative modeling tool for urban stormwater was published in Australia in 2016 after extensive

FIGURE 4. BioHavens located in a high-elevation wastewater pond near Big Sky, MT, one year after installation.



2 $\mu = (\mu_{max} * S)/(K_s + S)$, where μ_{max} = maximum specific growth rate
K_s = rate (saturation coefficient)
S = substrate concentration

testing on a BioHaven FTW system. That model uses the catchment area of the stormwater pond as a key sizing variable. When compared with the FII sizing model, a promising correlation was noted. FII is also developing a model for the BioHaven Streambed (the forced-flow embodiment), which is currently in use in a wastewater trial.

FII continues to refine the Excel spreadsheet model as more case study data become available. A Water Resource Recovery (WRR) modeling tool that focuses on return on investment (ROI) rather than performance is in its early stages of development by FII.

WATER RESOURCE RECOVERY

This initiative launched nationally over the last decade and has been applied primarily to large wastewater facilities. The basic concept is to turn waste into revenue. In principle, it targets value recovery from wastewater that typically occurs in two forms, energy conservation and product generation.

FII is bringing WRR to small lagoon-based wastewater facilities, which comprise 93% of all U.S. wastewater treatment facilities and serve about 27% of the U.S. population (National Science Foundation et al. 1995). Both of the value recovery forms can be used by the BioHaven WRR system.

Modeling for minimal volume of island required to provide a solution has been the standard until now. Today, however, the best "solution" may also incorporate a commercial endeavor. Instead of modeling to limit the costs of a project, WRR suggests that spreadsheet calculations tracking ROI can become the basis for project scale. Other considerations such as regional market may become the standard (the limiting variable) for wastewater projects. This premise assumes that wastewater and its nutrient load are indeed valuable.

Solar Energy Harvest System

Simply placing a BioHaven system in a lagoon can take the pressure off aeration systems to keep the lagoon in compliance. However, FII's WRR-specific energy conservation design represents an innovative way of using solar panels and BioHavens to retain heat and enhance system performance in cold temperatures.

The WRR energy conservation design places solar panel arrays between rows of high-energy BioHavens, set end-to-end, with a four-feet-wide channel between the rows. The solar panel housing is mounted over the channel, within which a proprietary air-blower system provides circulation within and around the BioHaven module perimeters, and the perennial plant roots in place under the modules. Air flow can be adjusted depending on the output desired.

Waste heat from the solar panels plus compression heat from the air blower combine to boost air temperature inside the solar frame structure by about 55-60°F over ambient temperature. The solar panels are fixed at a 62° angle to optimize for solar energy harvest during winter around the 45th parallel. This solar energy harvest system is designed to operate only during daytime hours, to minimize battery expense. However, a battery is needed to facilitate daily startup, which otherwise requires a large power draw by the solar power-driven air blowers that could restrict operation hours.

This solar design is not intended to heat an entire wastewater lagoon, but to provide a small amount of additional heat around the BioHaven matrix and plant roots, boosting biofilm performance. Air blowers used in this design can draw water from any depth; they would target the stratified zone where water temperature is typically near 39°F. Per FII modeling projections, adding a few degrees of heat to 39°F water within the channel defined by the solar panel mounting structure is projected to measurably reduce the island size required to remove ammonia in cold weather.

This energy conservation system is designed to be used on the final pond of an in-series lagoon layout, but could also be used earlier in a system. To optimize for the 39°F temperature, lagoon systems must be at least eight feet deep. Aeration/circulation systems currently in operation could be shut down and replaced with the FII solar-powered air blower system.

Cost savings associated with shutdown of existing aeration/circulation systems (typically up to one-third or half) are projected to save clients substantial O&M expense, which can be projected in typical spreadsheet calculations, and which represent an important component of FII's WRR initiative.

Generation of Saleable Products

The second FII WRR component is product generation. Over the course of thousands of island launches around the world, a broad variety of plants and trees have been successfully grown on BioHavens. While most of these macrophytes can be described as plants that enjoy "wet feet" (obligate hydrophytes), many facultative plants that grow both in wetlands and terrestrial habitats also succeed on BioHavens. Examples of trees that will be targeted as commercial prospects in FII's WRR system include willow, poplar, cottonwood, specific forms of oak, elm, birch and alder, and melaleuca/tea trees.

FII has developed a system for steering plant roots towards vertical growth down into water, rather than laterally (Figure 5). This prevents them from integrating into

BioHaven matrix and allows for straightforward plant harvest. Projections indicate that valuable landscape trees and plants can be grown on BioHaven WRR modules designed for human access.

BioHaven buoyancy can be customized to support various levels of human activity. For example, a 40,000-square-foot BioHaven in California supports 9,000 tons of gravel. Other BioHavens support rigidified walkways and buildings (Figure 6). Integration of optimal walkways to enhance for plant nursery activities on FII modules is a key design feature in this WRR system.

Growth of macrophytes and other biota on and in wastewater has several important advantages, including relatively high nutrient density associated with inflow water, an ample water supply, and favorable water temperatures. Disadvantages include potential hygiene issues associated with wastewater, and public perception of products derived from wastewater.

Forage Fish Growth and Harvest

Another prospective product that could be aligned with lagoon-based wastewater facilities is forage fish, such as fathead minnows (*Pimpephales promelas*). The fathead is noted for resilience, and an ability to sustain and flourish in poor-quality water including wastewater (B. Kania, Michigan DNR, pers. comm. 2018). It has also been used for biological mosquito larvae control (Irwin and Paskewitz 2009). FII has operated a fathead production pond at its headquarters; the pond's nutrient inflow contains nonpoint agricultural fertilizer.

SUMMARY

FII has created an Excel spreadsheet model incorporating contaminant concentrations and goals, flow rates and remediation times for its BioHaven floating islands. Model predictions are then translated to a number of islands and budgetary cost for a given application. The model accurately predicts total nitrogen performance at a cold-weather application in Montana, while other verification testing is underway.

Water Resource Recovery is an emerging field and FII is seeking to apply it to small lagoon-based wastewater facilities. The FII WRR initiative is in its initial stage, with efforts focusing on solar energy generation, tree harvest and fathead minnow production. ■

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FIGURE 5. Vertical root growth seen on plants installed into BioHavens.

FIGURE 6. BioHavens along walkway on Fish Fry Lake near Shepherd, MT.

Potential and Problems of Floating Treatment Wetlands for Mitigating Agricultural Contaminants

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Floating treatments wetlands (FTWs) are a relatively new water treatment technology and are designed to float on top of ponds or other existing water bodies, whereby the submerged root systems of plants aid in removal of nutrients and metals carried in runoff from wastewater, urban, or agricultural sources (Majsztrik et al. 2017; Stewart et al. 2008; Winston et al. 2013). Research documents the efficacy of FTWs to mitigate both metal and nutrient contaminants from runoff (Borne et al. 2014; Lynch et al. 2015; Olguín et al. 2017; Pavlineri et al. 2017). The most recent meta-analysis of published FTW research concluded that biosynthesis, settling and biofilm metabolism are the primary processes driving contaminant removal (Pavlineri et al. 2017). Most FTW studies have focused on quantifying changes to contaminant concentration in water, the mass of contaminant fixed in plant tissues, or plant growth rates as proxies for FTW performance (Olguín et al. 2017; White and Cousins 2013). A few studies have preliminary descriptions of the microbial communities that colonize the roots of plants installed within FTWs (Chang et al. 2012; Zhang et al. 2014). Floating treatment wetlands are being used to mitigate nutrient and metal contaminants in urban stormwater and agricultural runoff, and their rate of adoption will likely continue to increase due to their versatility and function.

The factors most likely to influence FTW performance in agricultural applications include sizing, contaminant loading rate, the consistency or periodicity of hydraulic loading, plant selection, management strategy, wildlife pressure, climate, and geographic region. Adoption of FTWs by agricultural producers to mitigate contaminants is primarily determined by the cost of installation, as well as by the capacity of the technology to integrate within their production system (Lamm et al. 2017b).

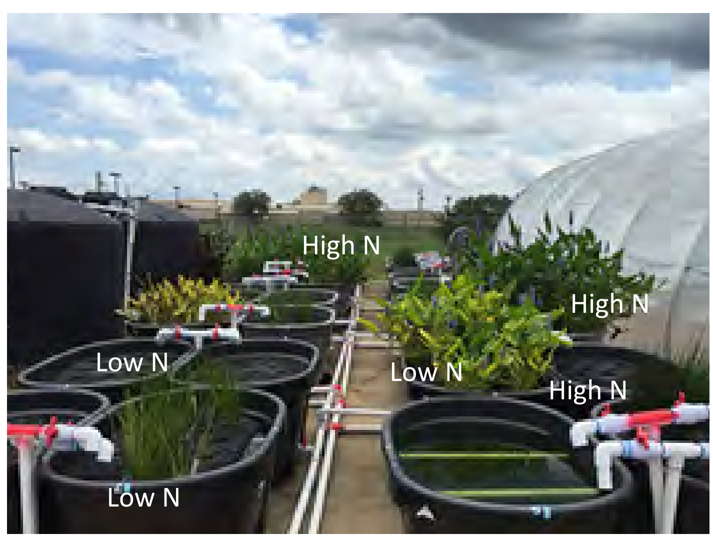
WATER QUALITY, NUTRIENT LOAD, PLANT SELECTION, AND SIZING

Research on pilot-scale FTWs has been conducted at the Water Treatment Technology Laboratory at the Clemson Water Resources Center since 2008 (Figure 1). Over the last decade, FTW performance as influenced by plant species, nutrient loading rate, percent surface area covered, planting density, aeration, and hydraulic retention time have been evaluated.

Plant selection plays an important role in the performance of floating treatment wetlands (Pavlineri et al. 2017), just as it does within constructed wetlands (Brisson and Chazarenc 2009). Results of the plant screenings indicate that both traditional wetland species (*Agrostis alba*, *Andropogon glomeratus*, *Canna* 'Firebird', *Canna flaccida*, *Carex stricta*, *Iris ensata*, *Juncus effusus*, and *Panicum virgatum*; Garcia Chance and White 2017; Garcia et al. 2016; Glenn et al. 2011; White and Cousins 2013; White et al. 2011) and alternative species with enhanced economic value like specialty basil (*Ocimum basilicum*; Van Kampen et al. 2013) and swiss chard (*Beta vulgaris*; Tyrpak et al. 2013) absorb substantial nutrients from the water column, fixing them within their shoots and roots.

Aeration within the ponds on which FTWs are established is thought to enhance removal of nutrients by

FIGURE 1. Mesocosm units in the Water Treatment Technology Laboratory at the Clemson Water Resources Center were assigned treatments (no cover, unplanted FTW mats, or planted FTW mats) to quantify FTW remediation when planted with either *Pontederia cordata* or *Juncus effusus* and exposed to two nutrient loads. The chlorotic plants were in the "low - 3 mg.L-1N" treatments. The healthier plants were in the "high - 12 mg.L-1 N" treatments.



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increasing the volume of water that flows through the plant root system. In a 2018 study, Garcia Chance and White (2018) determined that aeration did not enhance or reduce nutrient remediation efficacy within the water column; rather, nutrient fixation within plant tissues were greater for *Juncus effusus* plants in aerated vs. non-aerated treatments, while *Canna flaccida* plants fixed similar masses of nitrogen and phosphorus in both aerated and non-aerated treatments.

The mass of nutrients in the water flowing into ponds or experimental units established with FTWs influences their remediation efficiency. In some instances, if the concentration of nitrogen and phosphorus within the water column is low, plant growth and survival within the FTW itself is compromised (*personal observation* and *personal communication with Steve Beeman, Beemats LLC*). Therefore, knowing the water quality of the system into which FTWs will be installed is pertinent, as plant selection should be based on whether the water quality of the pond is nutrient-poor or nutrient-rich (Polomski et al. 2008; White et al. 2011).

Planting density is also one factor to consider when establishing FTWs. Garcia Chance and White (2018) reported that planting density was important, and that FTWs established with only half the manufacturer recommended density of plants absorbed 35.9 to 56.6% less nutrients than FTWs established with the recommended density. We also determined that similar masses of nitrogen and phosphorus were remediated by both *Juncus effusus* and *Canna flaccida* when the FTW was established

FIGURE 2. Schematic of nursery where tracer study was conducted. In the nursery schematic (top) irrigation runoff flows from the production area through a vegetated channel and then into pond 1, pond 2 and pond 3, where the v-notch weir and level logger were installed to monitor flow rate. The pond 1 flow rate hydrograph (middle) shows flow rate changes (blue lines) after consecutive irrigation (solid gray vertical lines) and rain events (orange dots) as contrasted with rhodamine detection at the tracer outlet (bottom) after water flows through the FTW in Pond 1.

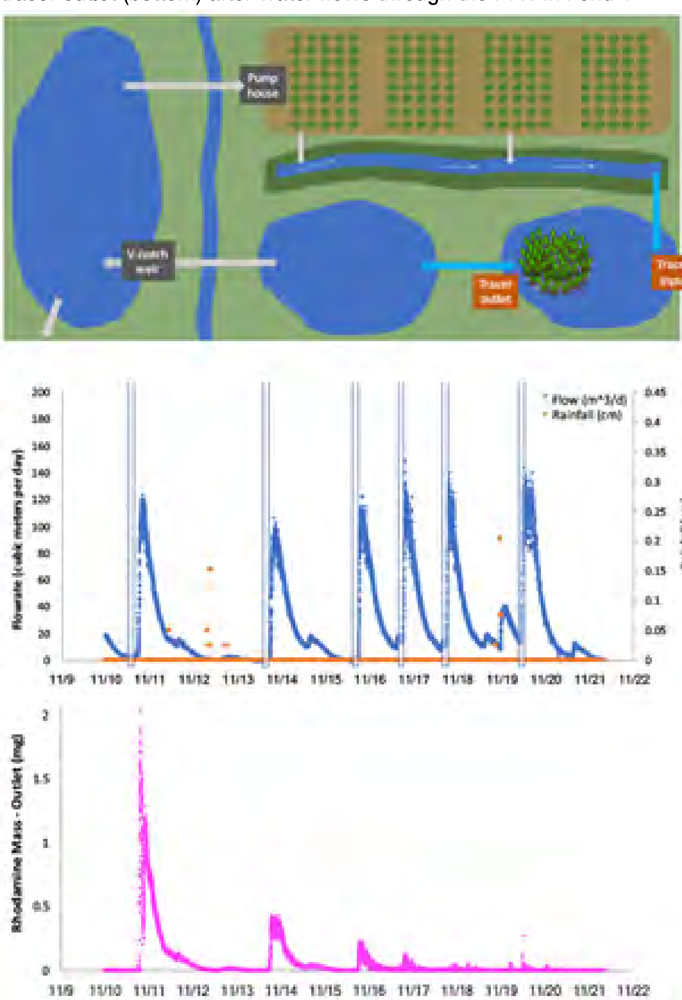
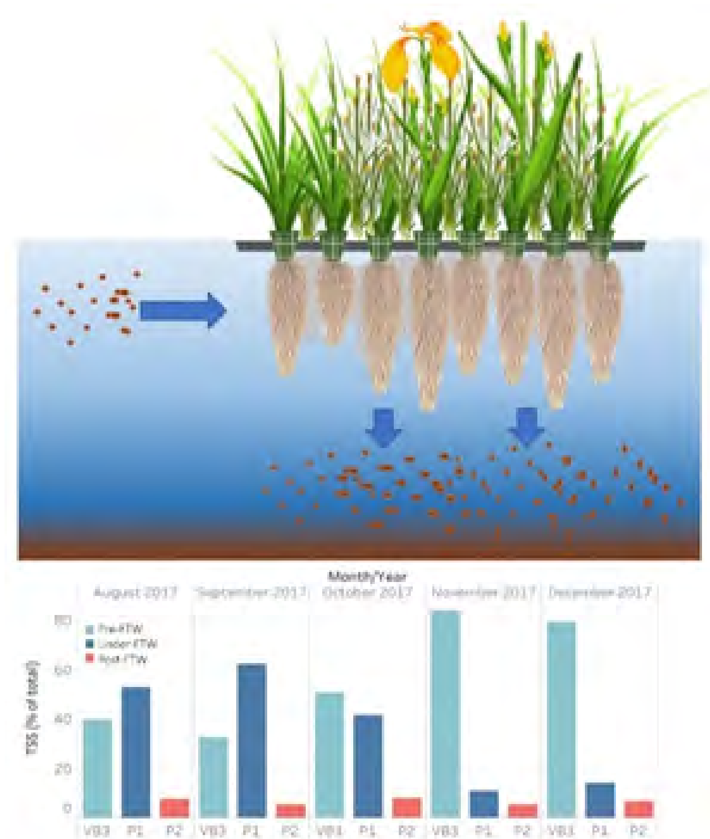


FIGURE 3. Theoretical sedimentation pattern in a pond after a floating treatment wetland (FTW) installation (top image). As water with suspended sediments flows through the roots of plants suspended in the FTW, entrapment and settling of sediment can occur, potentially making sediment settle from the water column below the FTW. We measured total suspended solids pre-FTW (VB-3 = vegetated channel), underneath the FTW (P1 = pond 1), and post-FTW (P2 = pond 2, bottom image) and detected the lowest % of total suspended solids measured in samples collected in pond 2, after the water was filtered by the FTW. In late October, the runoff channel upstream of all sampling points was dredged by the operation to increase flow capacity; thus, the sediment concentrations detected in November and December increased because less vegetation was present to limit erosion.



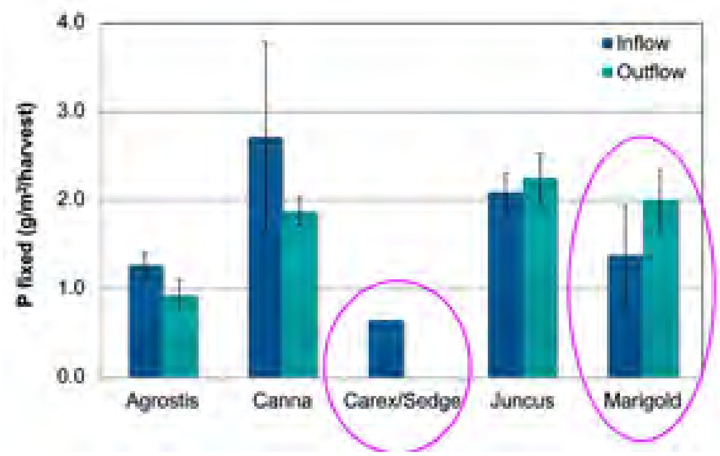
to cover 50 or 100% of the mesocosm surface (Garcia Chance and White 2018). Work by Chang et al. (2012) evaluated 5 and 10% surface-area covered by FTWs; they reported that the most economic sized-FTWs in their outdoor mesocosms were 5%. In 2017, we installed a FTW covering 10% of a 320 m^2 pond at a nursery in SC (Figure 2). Data analyses of pre- and post-installation water quality data are ongoing, but initial findings indicate installation of the FTW aided in up to 80% of phosphorus removal from the pond (phosphorus levels reduced to 0.02 $mg \cdot L^{-1}$ from 0.10 $mg \cdot L^{-1}$).

POND HYDROLOGY & SEDIMENTATION

Ongoing field and laboratory studies are evaluating changes in pond hydrology as influenced by the presence of FTWs. Our first evaluation of FTW influences on pond hydrology were conducted in the pond where we installed a FTW that covered 10% of the pond surface area (Figure 2). We measured physical, chemical, and biological water quality parameters (pH, EC, dissolved oxygen, water temperature, total suspended solids (TSS), mineral nutrients, and the presence of plant pathogens) and hydraulic loading through the system for one year, prior to installing the FTW. We then installed rhodamine sensors on the water quality sondes deployed in the water conveyance structures at the nursery and initiated a tracer study. We also installed a v-notch weir and level logger to constantly monitor flow rate through the system. We wanted to determine (1) if flow through the pond could be characterized as closer to ideal plug flow or completely mixed flow, (2) the actual hydraulic residence time (HRT) of the system (vs. the calculated HRT based on flow rates and pond size alone), and (3) if dead zones were present or if short-circuiting occurred.

Preliminary results of the six tracer runs through the pond and water infrastructure (3 pre- and 3 post-FTW installation) indicate that the presence of FTWs increased mixing in the pond system, but that short-circuiting may also have increased as the HRT was shown to decrease after FTW installation (Figure 2). Recovery of the tracer (rhodamine) was lower (~25% recovery) when the FTWs were present, than when no FTW was present (~125% recovery). It may be possible that the increased mixing caused by the presence of the FTW promoted rhodamine entrapment in dead zones or possible sorption to organic matter, including the roots of the FTW plants. We are repeating this tracer study in Fall 2018 in a more controlled setting to determine if we can better quantify specific effects of FTWs on pond hydrology. Accurate characterization of pond hydrology will allow for more accurate modeling of contaminant removal in FTW systems.

FIGURE 4. Weedy species (circled) that colonized floating treatment wetlands (FTWs) installed at inflow and outflow points of a pond receiving stormwater influent from primarily residential land uses. Nutrient uptake within the weedy marigold was similar to uptake within plants selected for establishing the FTWs.



While evaluating how FTWs influenced pond hydrology, we also began to characterize their contribution to changes in measured TSS (Figure 3). Increasing concentrations of TSS typically correlate with the presence of increasing concentrations of phosphorus or pesticides, as sediment serves as a substrate to which both phosphorus and pesticides bind (Liu et al. 2008). Thus, if we can manage and reduce TSS, we can also reduce the presence of phosphorus and pesticides in the water. The root systems of plants in FTWs serve as living sieves or barriers in the water column that can slow the flow of water through a pond. Slowing water can increase the rate of sedimentation below the FTW, causing TSS to settle below the FTW. Preliminary data from our 2017 field-scale FTW trial at a nursery shows reductions in TSS after water comes into contact with the FTW. More work is needed to clarify where sedimentation occurs after water comes into contact with the FTW and the influence of HRT on sedimentation aided by FTWs.

MAINTENANCE CONSIDERATIONS

Weed management

Depending upon where the FTW is installed, weed control may be needed. In agricultural settings, if there are concerns related to weed seeds in irrigation water, control of weedy species colonizing the FTW may be necessary. However, there is also potential for plants that colonize the FTW to become contributors to the total nutrient remediation efficacy, as plants that colonize and survive within FTWs are likely well-adapted to the nutrient conditions within those systems. In a study conducted in 2011 with field-scale installation of FTWs covering 1% of a residen-

FIGURE 5. Evaluation of secondary uses for plants first grown in floating treatment wetlands (FTWs). Five plant species were trialed in mesocosm-scale FTWs and their nutrient remediation efficacy evaluated (top). At harvest, alternate uses for plants were evaluated and included container production for later sale (middle) or direct use as bare root transplants for riparian plantings (bottom).

tial stormwater pond surface area, we found that one of two weedy-species that colonized the FTWs fixed nutrients as well as or better than species initially planted in the island (Figure 4). Garcia Chance and White (2018) also reported that the mass of nitrogen and phosphorus fixed in weedy species that invaded experimental FTWs was lower than that absorbed by either the *Juncus effusus* or *Canna flaccida* used to establish the experiments. Nonetheless, weedy species (e.g., marigold in Figure 4) could be important contributors to total nutrients fixed in FTWs.

Harvest

The necessity of harvest for optimal nutrient remediation by floating treatment wetlands is a hotly debated topic in the floating wetland / island realm. Some manufacturers state that harvest of plant tissues is not required, as normal plant senescence on floating islands will not increase nutrient loads within the water body where the island is installed. Other manufacturers state that harvest is critical to remove nutrients completely from the pond in which they are installed, to reduce nutrients available for the pond nutrient cycle. Researcher recommendations on this topic are split based on the installation location, FTW scaffold (manufacturer) and the relative feasibility of harvest, and the rationale for FTW installation. If enhancing aesthetics and provision of biological habitat and function are the desired endpoint, harvest may not be required. When remediation of contaminants is the desired endpoint, harvest for removal of nutrients may not be feasible, due to the type of scaffold used to support the plants (Headley and Tanner 2012). Over many years within naturally formed floating wetlands internal nutrient cycling occurs, some of the nutrients are released back into the water column and some are stored within aboveground plant biomass or deposited within or upon the floating mat upon plant senescence. Other researchers note that if nutrient removal from the water column is the desired endpoint (along with the other factors), harvest is needed (Wang et al. 2014), as these treatment technologies need to show remediation benefits after short durations. White and Cousins (2013) reported that nearly half the nitrogen and phosphorus fixed by plants (*Juncus effusus* and *Canna flaccida*) were stored in the roots of the plants, and that there is considerable potential for nutrients to be only temporarily removed from the water column if both the plant roots and shoots are not harvested. When remediation of nutrient contaminants from agricultural runoff is the application for the FTW, whole-plant harvest should be considered.

ECONOMICS: COSTS AND BENEFITS

Agricultural producers make decisions related to changing production and management practices primarily on the economics of the decision (Lamm et al. 2017a). Documenting the contributions of FTWs to return on investment from both an economic and environmental standpoint would help in this decision-making process. One method proposed by (White 2013) is the use of FTWs as alternative production areas, where producers can clean their water and grow plants that are saleable.

In 2016, we began evaluating the potential of secondary uses for plants first used in FTWs to clean water (Figure 5). We evaluated whether harvested plant material could be planted either into containers or directly into the soil as a riparian planting. Plants transplanted into containers were grown for 6 weeks and their aesthetic appearance evaluated. Four of the five plant species we evaluated grew well in the containers after transplant and would be considered saleable by nursery producers. Bareroot plants transplanted directly into riparian zones, fared less well long-term, as the transplant intervals occurred during the summer when little supplemental rain occurred. So, while some of the plants survived, it is likely that the potential for bareroot transplants to succeed would be predicated on the season in which transplant occurred or the availability of supplemental irrigation at the site where the plants are transplanted. Container production of harvested materials is feasible, and we are finalizing the economic assessment of the 2016 field study. Data derived from the economic cost-benefit analysis will be used to inform growers about the potential for return on investment with FTWs.

CONCLUSION

FTWs are a viable technology for agricultural producers to clean production runoff. Uncertainty yet remains regarding how FTWs should be sized to best meet the water quality goals of individuals or companies managing water quality in stormwater or production ponds. The economics of harvest are critical - if harvest is not required to manage water quality, then leaving plant materials on the FTW will contribute to long-term nutrient mineralization and fixation, though some nutrients will be contributed to the internal-nutrient cycle of the water body on which they are installed. Developing a secondary use of plants harvested from FTWs will not only allow removal of nutrients fixed by plants from the water, but also allow the grower to have a product that is marketable to another audience (another form of nutrient recycling). We still need information on when to harvest plants from FTWs if harvest is needed, and better methods of selecting plants for use in FTWs based on site-specific remediation goals. All of these gaps are being evaluated, but ensuring the scalability of the research is also critical, as mesocosm trials may over- or under-estimate FTW performance, and economic decisions need to be made on reliable data. ■

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Structural Floating Wetlands: Achieving Ecosystem Services in Heavily Modified Waterbodies

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INTRODUCTION

Floating ecosystems are now being employed in waters and along waterways around the globe. They provide "natural ecosystems" in these heavily modified environments. They beautify urban shorelines, help improve water quality, all while providing habitat for fish, birds, and other wildlife (Figure 1.) In this paper I present some examples of my company's applications of this technology with an emphasis on the ecosystems provided to these urban landscapes. Let's begin by introducing one of our projects in France.

The resounding blast on the conch shell echoes out from beneath the concrete covered section of the River Vilaine, as the floating orchestra emerges from the darkness of the concrete covered river onto the open water channel (Figure 2). The river is walled with tall hard edges of stone, built to protect the city from seasonal floodwaters. After decades of standing as a stark grey channel at the centre of the historic French town of Rennes, the river is beginning to come to life again. The floating orchestra strikes up a resounding tune and moves upstream between the soft green edges of a series of floating riverbanks.

The floating riverbanks curve along both sides of the watercourse supporting rushes, sedges and bulrush (*Juncus, Carex,* and *Scirpus*) and many other species that thrive by absorbing nutrients from the water. Blossoms of devil's bit (*Succisa pratensis*), Valerian (*Valeriana officinalis*) and Joe-Pye weed (*Eutrochium* spp.) provide a new and welcome soft foreground to the stone façade of the Musee des Beaux-Arts. Arrayed along the riverbank and its bridges some 300+ people are gathered for the inauguration of "les jardin flottant." As the music plays, bees sip nectar from the water mint (*Mentha aquatica*), while damselflies zip from stalk to stalk. Fishermen cast their lines along the wetland's sheltering edge overhung with European water-plantain (*Alisma plantago)* and marsh marigold (*Caltha palustris*).

FIGURE 1. Overview of floating ecosystems.

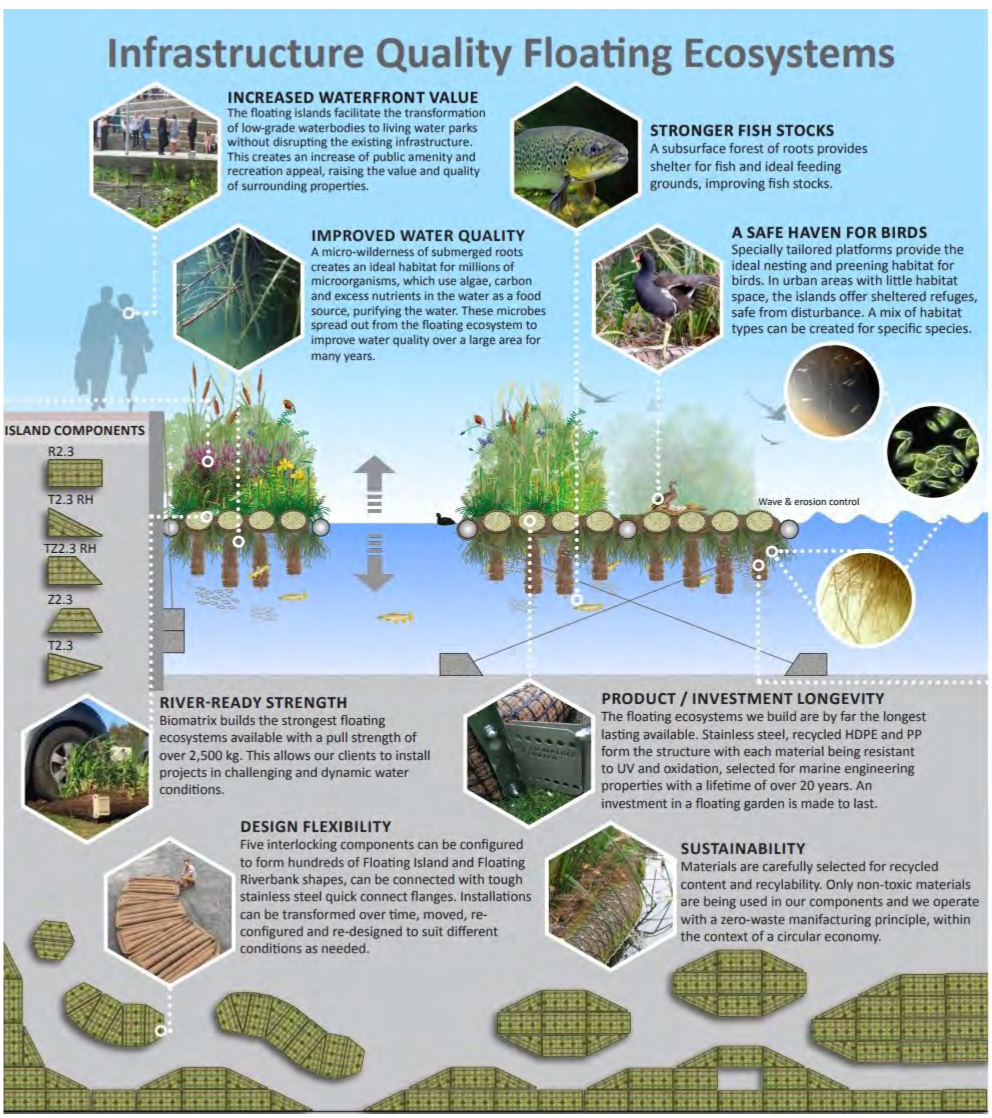

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FIGURE 2. The “Floating Orchestra” in Rennes, France.

FIGURE 3. Floating riverbanks in Rennes.

FIGURE 4. Launching a new ecosystem in Paris.

Today the water is calm, with a gentle steady flow, but a few weeks ago, heavy summer rains turned the river into a fast-flowing channel, with flow velocities of over a meter per second increasing the water level by nearly two meters within a few hours. The floating riverbanks rose to the occasion – as they were engineered to – rising vertically with the water guided by vertical cables anchored to the ancient stone riverbank at the top of the embankment and secured to concrete counter weights below water level (Figure 3). Protecting the floating riverbanks from woody material and other floating debris that accompanies flood waters are deflectors, built into the prow of each ecosystem like the bow of a ship. This new floating ecosystem contains over 6800 native aquatic plants supported by 268 interlocking structural floating ecosystem modules. It was installed over the course of a few weeks with no major engineering work or modifications to the historic city infrastructure, providing the ancient city of Rennes with a living wetland ecosystem, the largest “floating riverbank” of its kind ever constructed.

ACHIEVING EFFECTIVE ECOSYSTEM SERVICES FROM FLOATING WETLANDS

The floating riverbanks of Renne demonstrate how engineered and biological design can soften the hard edges of heavily modified waterways to create a vibrant transition between urban and wild. This kind of floating wetland project provides local governments and urban planners with a template for increasing and enhancing functional green spaces that improve habitat, biodiversity and water quality along with quantifiable ecosystem service benefits.

On a chilly morning this February 2019 on the Canal Saint Martin in Paris, ecosystems enthusiasts arrive and a truck rolls up and out come the building blocks of a new

FIGURE 5. The floating park in Manchester. A spring day beside the Flaming Gardens Bridgewater Classical Concert Hall, Manchester, UK.

structural Floating Ecosystem, ready to launch on the Canal. Submerged fish shelters manufactured by Ecocean are inserted in to the Biomatrix Modules in a few hours, and suddenly Paris has a new wetland ecosystem (Figure 4).

A series of floating ecosystems installed in Hastings (United Kingdom, UK) is actively treating sewage-contaminated runoff and has been key to improving water quality and reopening a public beach. Water treatment by the floating wetlands reduced enterococci by over 80% and E. coli by more than 90%. In Manchester (UK) a series of floating ecosystems on a public pond has been key to reducing chemical oxygen demand (COD) from >40mgl to <10mgl while increasing the water clarity from 0.3m to over a meter (Naismith 2014). In this industrial context floating ecosystems integrated with aeration and circulation work to provide primary water treatment, reducing brewing and distilling wastewater from biological oxygen demand (BOD) of 1263mgl inflow down to 83mgl outflow. From the habitat perspective floating ecosystems provide safe nesting areas for terns, ducks, swans, and loons. On the public well-being side, multiple studies are showing the health benefits which green space, particularly in urban areas, can provide (Figure 5; e.g., Gianferrara and Boshoff 2018).

VERSATILITY OF CONSTRUCTED FLOATING WETLANDS

Fully structural floating wetland ecosystems can now effectively meet rigorous environmental and material challenges, allowing engineered wetland ecosystems to be established on the waterscape in literary thousands of potential locations. They can be constructed along hard-edged brick, steel or concrete sheet pile walls in city centers (Figures 6 and 7). Flooding conditions with fast flows and changing water levels are increasingly the norm due to climate change (Vitousek et al. 2017) and the increase of impervious areas within the watershed (Shuster et al. 2005). In order to effectively establish wetland ecosystems within this dynamic environment, floating wetlands require a support structure which will rise up, sometimes as much as 3-7 meters during flood conditions, and the capacity to deflect debris and surging flood flows. These wetlands can be planted and established to resist the grazing pressures of local and migratory bird species and to be stable enough to walk on for access, pruning and litter collecting purposes.

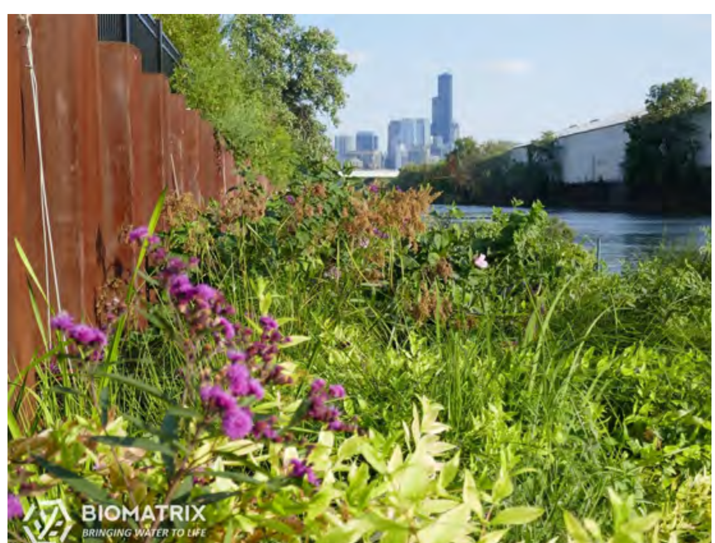
The strength of materials and construction has significantly increased with structural systems providing adjustable rigidity and or pivoting flexibility for wavy sites variable and adjustable across two axes. The latest round of independent destructive testing of Biomatrix Floating Ecosystem modules achieved a tensile interlocking strength over 4 tonnes per module (Figure 1). The tesselated interlocking components make design and installation both robust and user-friendly and over 70% of the new wetland creation projects that Biomatrix designs now being installed by volunteers and local wetland enthusiasts.

There are now multiple technical component options for such systems including modules with submerged gravel beds and others with wetland trees and complex shapes, walkways, open water sections and increased buoyancy areas (Figure 8).

Floating Ecosystems are increasingly being explored for application in areas with heavy pollution loading, and subsequent low dissolved oxygen levels. In this instances, Floating Ecosystems incorporating more advanced features including multiple stages of aeration, circulation, containment membranes, engineered biofilm carriers, and on-board controls.

FIGURE 6. Floating wetland along flood alleviation wall, Northwich.

FIGURE 7. Floating riverbank – part of "Wild Mile Chicago" in the United States. (See https://www.wildmilechicago.org/about-us for additional information.)



These active floating islands can either be powered by mains electricity or by solar power to achieve a water quality management system that captures the sun's energy both through photovoltaic energy generation as well as through photosynthetic energy generation from the plants (Figure 9).

For example, a solar powered "active island reactor" was recently launched in one of the world's most polluted rivers - the Adyar River in Chennai, India. The river water, has a typical BOD over one hundred milligrams per litre and a dissolved oxygen level less than 0.1 mgl (Biomatrix field testing January 2019).

The island integrated 2.2k2 of solar panels bolted to the structure of the floating ecosystem modules.

The 48-volt DC current from the solar panels is converted to 400 volts alternating three-phase current to drive two industrial submersible aerators. The aerators pump the river water into a 35,000-litre submerged membrane containment "tank" for treatment by a combination of aeration, floating wetland root systems, and engineered biofilm media carriers. The internal process can be characterized as solar powered floating ecological version of the well-known integrated fixed film activated sludge (IFAS) process.

24-hour time controls manage energy consumption, influent filling, and aeration stages, while the control system is web-linked via Global System for Mobile communications (GSM). The island floats independency in the river without cables to the shore, whereas real-time monitoring and control can be carried out via GSM from anywhere in the world. The system has a Person Equivalent treatment capacity of 200 PE.

With increased concern for material sustainability, particularly to plastics in the ocean, the utmost attention to the engineering details and use of materials must be applied. Effective floating ecosystems must incorporate a combination of biological as well as long-lasting marine engineered materials, which provide structural integrity to satisfy the rigorous planning requirements of engineers, municipal planning agencies, and navigation and waterway authorities.

Contemporary floating ecosystem construction must incorporate a circular economy approach in its material selection, using materials that can be recycled and which do not contaminate the environment. There is also awareness of some of the impurities which some materials contain, such as polystyrene (Huff and Infante 2011), polyurethane foams, polyvinyl chloride PVC, among others.

CONCLUSION

The development of engineered, reliable floating wetlands, like the Biomatrix Floating Ecosystems, provides new opportunities for wetland scientists, engineers and urban designers to establish wetlands in challenging urban locations. The primary drivers motivating the increased implementation of floating ecosystems include: a) increased urban population and expanding urban areas (United Nations Population Division 2014), b) an increased awareness of the benefits ecosystems can provide to people, and c)

FIGURE 8. Floating wetland walk, Royal Dock, London, England.

significant water quality challenges in urban areas, with stormwater pollution, wastewater overflows, and lack of habitat in heavily modified waterways.

Urban areas are one of the most beneficial locations where such wetlands can be established to mitigate the negative effects of urbanization and climate change. Biomatrix Water has experienced a significant increase in demand for robust structural floating ecosystems in urban areas, with over 800 modules being manufactured in 2018 almost entirely for implemented in the built environment (see http://www.biomatrixwater.com/casestudies/case-studies/ for highlights of some projects). Floating wetlands are now becoming a common feature in the contemporary urban planner and landscape architect's palette of green infrastructure solutions.

Along with "living roofs" and "living walls" now come "living waterways" with their floating wetlands. One important difference from the others is that floating wetlands require no watering or fertilizer while actually improving water quality and producing the myriad other benefits associated with wetland functions (e.g., ranging from supporting pollinators, birds, and butterflies, providing habitat for fish and ducks, and recreational amenities for people).

The World Health Organisation report on Urban Green Space Interventions and Health (WHO 2017) emphasizes the value that contact with natural systems can provide to human wellbeing. This uplift is particularly significant in areas where contact and exposure to natural systems would otherwise be substantially limited – urban areas. The urban ecosystem projects can inspire and integrate cultural and artistic events. For example, the floating ecosystems at Bridgewater Hall in Manchester will have a new symphony composed in their recognition in early 2019 which will be played at the water's edge, thereby bringing together, ecology, art, and urbanism for a unique sound and experience. We will have to wait to report back on how the plants respond to the music. ■

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FIGURE 9. Floating island with solar power to drive aeration through submersible Venturi aerators all managed and powered completely onboard the island with GSM remote controls and monitoring.

Fish Fry Lake: Perspectives from an Inventor on the Application of Created Floating Islands for Water Quality Renovation

Bruce Kania[1], Floating Island International, Inc., Shepherd, MT, USA

Today Fish Fry Lake is a highly productive wild fishery, and also a long-term experiment tracking how the resource of nonpoint nutrient-loaded water can be optimally managed. The Fish Fry Lake story has relevance to water stewardship across much of the developed world where water quality is impacted by agricultural-based nutrient loading.

Fish Fry Lake is located on the east side of Yellowstone County in south-central Montana. The lake covers 6.5 surface acres, is 28 feet deep at its deepest point, and contains about 55 acre-feet of water at full pool. Groundwater influenced by agriculture infiltrates to the lake and discharges at a typical rate of 65-85 gallons per minute.

When the lake was converted from a seasonal pond to a perennial one in 2005, it displayed the typical attributes of a eutrophic waterway. The lake surface was occasionally completely covered with filamentous blue-green algae, with occasional patches of cyanobacteria (Figure 2). Accordingly, dissolved oxygen (DO) levels could swing wildly. Not even the ubiquitous fathead minnow could survive in the original lake, as DO levels would drop to as low as 0.1 mg/L during seasonal turnover events. The water would typically stratify at about six feet, where anoxic conditions (oxygen present, but not in breathable form by aerobes) would persist to about a 20-foot depth, then slip into an anaerobic (no oxygen) zone. At least twice a year when the water turned over, anoxic conditions would persist across the entire lake, killing most forms of oxygen-breathing aquatic biota.

FISH FRY LAKE – THE EXPERIMENT

As an inventor and owner of the property upon which the lake resides, I selected it as a demonstration site for a long-term experiment. The primary question being asked was: Can water be made less eutrophic by practical methods of cycling nutrients into beneficial forms of life? In other words, can a healthy food web replace a near-monoculture of blue-green algae and cyanobacteria in a eutrophic waterway? Can we grow fish instead of algae? What other forms of biota could replace the system that was then dominated by blue-green algae and cyanobacteria in Fish Fry Lake? And finally, could tools be developed that would help achieve these ends?

We hoped to answer a range of additional related questions which included:

1. Could the lake be recovered organically, without use of bactericides or herbicides?
2. Since Secchi disk-derived water clarity readings were as low as 14 inches, due in part to the presence of colloidal clay, could water clarity be substantially improved?
3. Could the inflow and inventoried nutrients be cycled into healthy, fast-growing game fish?
4. Given that inflow groundwater total dissolved solids (TDS) concentrations were around 1600 mg/L, and mainly consisted of calcium, magnesium, carbonate and sulfate, could the TDS concentrations present in the lake be somehow mitigated?
5. Could the lake serve as a template for water quality improvement in other nutrient-impaired waterways?

People Who Inspired Us

Environmental journalist, Janine Benyus, published “Biomimicry” in 1997. The book was a compendium of examples of product that copied forms and systems present in nature. This view of nature as the premier inventor inspired much of our ensuing work. With ongoing assistance from a network of scientists and engineers, a wide range of sub-experiments were run over the following decade. Scientists and engineers associated with the Fish Fry Lake experience are too numerous to list, and sincere apologies for any grievous omissions, but did include: Frank Stewart, Chris Tanner, Bob Lusk, Al Cunningham, Bruce Condello, Mark Osterlund, Otto Stein, Tom Maechtle, and scientists from China’s CRAES.

NUTRIENT POLLUTION AS AN OPPORTUNITY

Fertilizer-derived orthophosphate is the primary form of phosphorus infiltrating into Fish Fry Lake via groundwater and runoff (Figures 3 and 4). Typical concentrations are about 0.065 mg/L but can be several times higher, particularly after a precipitation event. Typical total phosphorus concentrations are 0.020 mg/L in Fish Fry Lake

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outflow. Nitrogen and ammonia concentrations of inflow water are also highly variable but in outflow, are typically near the detection level. We view these numbers as reflective of improved water quality, but still target lower total phosphorus concentrations..

TECHNOLOGY DEPLOYED

"Floating Treatment Wetlands" (FTWs or floating islands) are a breakthrough technology that addresses several of the major water quality challenges our world faces today. Floating islands are a versatile form of constructed wetland since they can be positioned on nearly any waterway, without adjusting that waterway's footprint. They are modular and can be cost-effective. In fact, today, an embodiment of BioHaven floating islands is designed to leverage Water Resource Recovery (WRR), meaning it can generate revenue in the form of commercial solar electric power, harvestable landscape trees, or forage fish like the fathead minnow, used as biological mosquito larvae control or as a commercial bait fish. Essentially, water quality enhancement could become a byproduct associated with island systems that pay for themselves by providing a return on investment (ROI). This has positive implications for lake restoration internationally, and specifically became the primary tool with which we transitioned Fish Fry Lake.

Nutrients in a waterway, left unmitigated, will limit biodiversity, will enhance for monoculture of extreme biota, and will ultimately result in hyper-generation of greenhouse gases (Floating Island International, Inc. et al. 2016). Fish Fry

FIGURE 1. Aerial view of Fish Fry Lake. (Source: Google Earth)

FIGURE 2. Massive carpets of filamentous algae led to dissolved oxygen deficits early in the history of Fish Fry Lake. (Note: All figures in this article are from Floating Island International, Inc., courtesy of the author.)

FIGURE 3. Soil profile depicting how ground water perks into Fish Fry Lake.

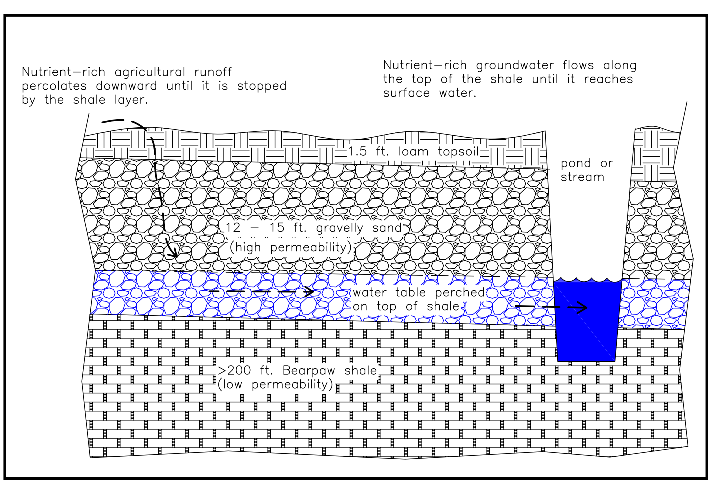


FIGURE 4. Foam associated with phosphorus-rich runoff.

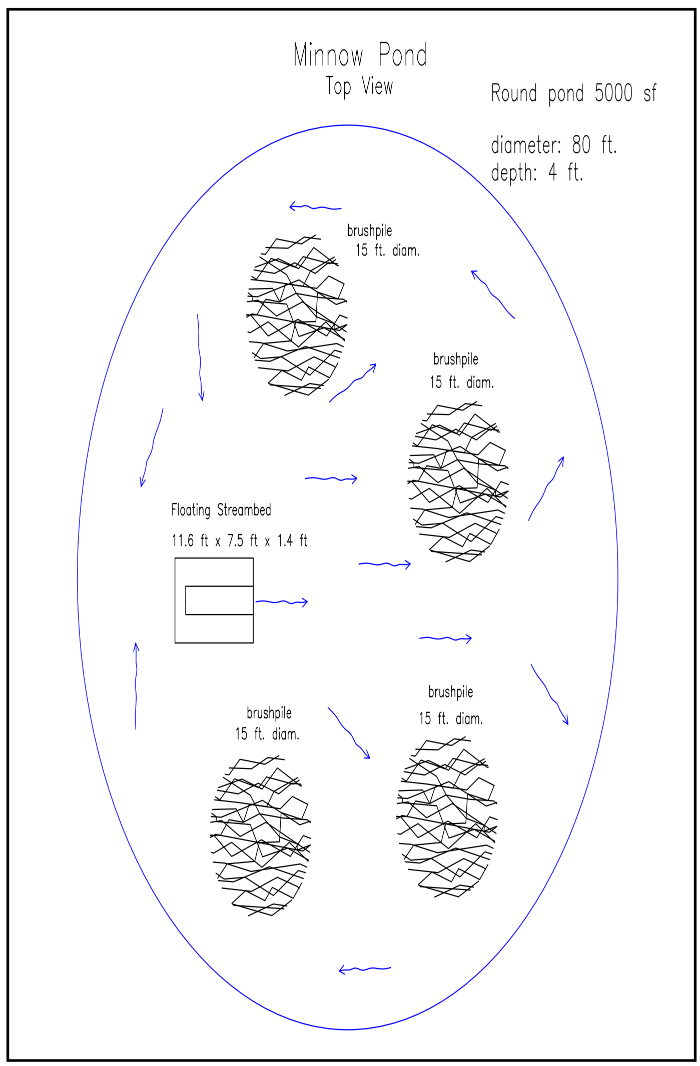
Lake has taught us that these same nutrients can be stewarded – managed by growing and harvesting plants and fish. For example, nutrients can energize a food web when guided into forage, which, in turn, naturally cycles into high-order biota such as game fish. The following examples depict this:

- Floating islands grow biofilm, upon which various forms of phytoplankton, including diatoms occur (Figure 5). This mix, called "periphyton," is the foundation of the aquatic food web; it is colonized by zooplankton, which in turn feed a vast range of other invertebrate life, like damselfly nymphs, mayfly nymphs, dragonfly nymphs and scuds – food for larger aquatic organisms. Plant roots extending through the island feed other forms of biota (Figure 6). Freshwater sponge growing in island matrix filter out total suspended solids (TSS) and TDS, in some instances. Endophytes present in plant roots that grow through islands phyto-extract other nutrients, minerals and metals. Bacteria occurring in biofilm do the same.
- In a 5,400-square foot pond ("Minnow Pond") just above Fish Fry Lake we use an embodiment of BioHaven floating island called the "floating streambed" to circulate end-of-irrigation ditch water through aged, deciduous brush, practicing a variation of Brush Park polyculture (Azim 2005; Figure 7). In the process we grow and harvest on average 400 pounds of fathead minnow, five-prong stickleback cyprinids, and crawfish annually. No feed is associated with this system other than nonpoint nutrients present in the inflow water, and the floating island that provide biofilm reactive surface area with which to cycle nutrients into biofilm/periphyton. The island also provides spawning habitat for the fatheads, which lay eggs on the underside of submerged structure.
- Beds of aquatic vegetation, rock, cobble, tree stumps and other structures, especially when combined with circulation, are relatively passive but highly effective forms of surface area that grow other forms of

FIGURE 5. Sponge colonizes the underside of many BioHavens in Fish Fry Lake.

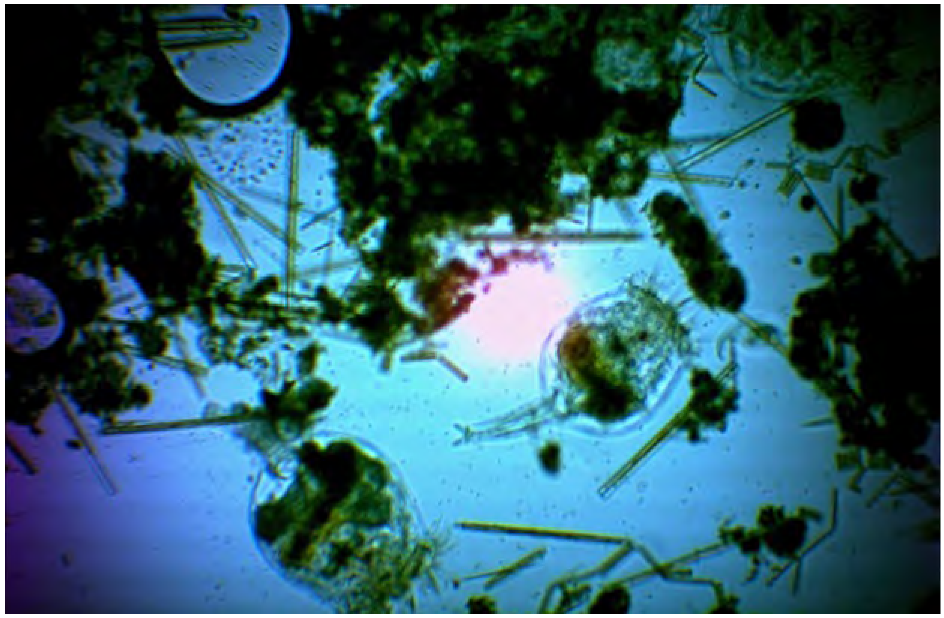
FIGURE 6. Luxurious root growth on this research BioHaven in France.

FIGURE 7. Overhead view of Minnow Pond Brush Park configuration.



periphyton. Nutrients contained within periphyton will cycle through a waterway's food web at least four times faster within the aerobic zone than within anoxic or anaerobic zones, which argues for added aeration/circulation, especially in eutrophic settings (Cunningham et al. 2010).
- A plant-like form of algae, *Chara*, naturally occurs in Fish Fry Lake and is used heavily by yellow perch, probably as security habitat. We occasionally harvest other forms of aquatic vegetation to bias in favor of *Chara*. While an indirect strategy, we believe our nurturing of *Chara* contributes to maintenance of a healthy yellow perch population, the harvest of which represents a means by which to cycle nutrients out of Fish Fry Lake.

FIGURE 8. Floating island-derived periphyton viewing with a microscope.



We employ a slot limit harvest program, where year-one, -two and -three fish are consistently harvested, while older fish are released. Year-five and older large female perch can produce as many as 65,000 eggs each, while one-tenth that number is associated with two- or three-year-old fish (Floating Island International, Inc. 2012).

On Fish Fry Lake, small bluegill up to five inches in length are caught by hook and line and turned into cut bait, then fed to black crappie and yellow perch in the form of chum. Currently, an average of 25 of these small bluegill are processed per day during the warmest six months of the year, from a single test location on the lake. Crappie and perch were conditioned to accept cut bait by blending cut bait with fathead minnows, a preferred forage species. A similar strategy has been employed to enhance growth of largemouth bass in other settings and could possibly be applied on Fish Fry Lake. Since our focus has been more on yellow perch that is a unique phosphorus-cycling form of fish and a hyper-accumulator of sorts, we are likely to stay focused on them. It is noteworthy, however, that only a handful of fish species have been tested for phosphorus accumulation, and there could be other species to consider for management.

TRACKING PHOSPHORUS

On Fish Fry Lake, phosphorus is present in groundwater infiltrating into the lake. Since there was no reasonable way to prevent the phosphorus from entering the lake, we chose to cycle it aggressively into a variety of biota which includes native, woody and perennial macrophytes grown on floating islands, fast-growing and prolific warm- and cool-water species of fish like fathead minnows, northern yellow perch, bluegill, sunfish and black crappie, other aquatic organisms like American bullfrog, native crawfish, other invertebrates, and diatom-based periphyton.

Note that biofilm in the floating islands is the base material of periphyton (Figure 8), and biofilm-generating bacteria are one of the few forms of life capable of out-competing cyanobacteria and filamentous algae for phosphorus (personal communication, Dr. Al Cunningham, Montana State University, Center for Biofilm Engineering). And further note that both these forms of phytoplankton are limited by sunlight, while a primary limitation of biofilm generators is surface area. The BioHaven floating island essentially responds to both of these factors by blocking light from the waterway while providing surface area for biofilm generating microbes.

Every living cell will contain a fraction of phosphorus, and it can be stored in sediment as well. Under some circumstances, it can be released from sediment. When this happens, it can trigger a phytoplankton bloom. To circumvent these issues on Fish Fry Lake, floating islands are used to function as biofilm reactors, and compete with the free-floating forms of phytoplankton for phosphorus. Without this, Fish Fry Lake would experience massive algae blooms, like it did before the islands were deployed. Without the islands, Fish Fry Lake would be just another eutrophic waterway poised for periodic fish kills.

Diatoms are a low-light capable form of phytoplankton, and are thought to also be a relatively stable net positive source of dissolved oxygen (Azim et al. 2005). Biofilm-based periphyton occurs on and within BioHaven matrix in the low-light setting that is beneath and within BioHaven floating islands.

WATER STEWARDSHIP REQUIRES BROAD-SPECTRUM SCIENCE

In the U.S., much of our water stewardship has been delegated to engineers. But only a fraction of engineers have accompanying life science in their educational portfolio, with biofilm engineers being one example. Fish Fry Lake has utilized both engineers and scientists. Our list of contributors includes biofilm engineers, fisheries biologists, civil engineers, horticulturists, plant and soil scientists, geomorphologists, limnologists, entomologists and environmentalists, as well as environmental engineers. The lesson is clear - no single science or engineering field is sufficient to steward a waterway optimally. And if the current movement toward "Water Resource Recovery" becomes mainstream, the blend of science with engineering will become even more fundamental.

Invention occurs across the spectrum. Design engineering, and what is gleaned from science, can come together as invention. Here at Fish Fry Lake, invention resulted in BioHaven floating islands, the airlift Floating Streambed, BioCoral, and much more (Figures 9 - 11). As an inventor, I must acknowledge that both engineering and science are fundamental. Does this mean that the creative energy around invention is a fundamental stewardship requirement? As I think back on the numerous conversations I've had with water stewards, my sense is that "yes." As we face a rapidly-changing environment, creative solutions are required.

THE FUTURE

My hope is that Fish Fry Lake inspires creativity. The idea of cycling nutrients into fish instead of algae was our starting premise. Now we are going beyond that…we are asking just what are the limits of biodiversity, beauty, and productivity for the lake? Can large waterways like Lake Erie or Chesapeake Bay also be transitioned back to health? Can this be achieved via projects that pay for themselves? Is it appropriate to consider commercialization of stewardship, which is essentially what "Water Resource Recovery" targets? Such questions represent the next phase of research and development here on Fish Fry Lake. As we consider how to cycle nonpoint-sourced orthophosphate into appropriate forms of autotrophic life like diatoms and perennial native aquatic vegetation, we must also consider nature's staircase design, which we can facilitate by incorporating two primary variables, surface area and circulation, to ensure ample heterotrophic cycling of organics. Today we have many new tools, we have the science, the engineering, and potential commercial systems. Integrating these factors and scaling up suggests that providing a green, sustainable solution for all waterways may be possible. While Fish Fry Lake is a microcosm, it will continue to serve as an experimental model targeting sustainable water resource stewardship. ■

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FIGURE 9. Pollinator islands on Fish Fry Lake exemplify a form of water resource recovery.

FIGURE 10. BioHaven streambed, where aeration and circulation through biofilm reactive surface area are combined in one system.

FIGURE 11. BioHaven floating island launched in 2004 still going strong in 2019 (photographed in year 9), Shepherd, MT.

BOOK REVIEW

Eden Again: Hope in the Marshes of Iraq

Richard C. Smardon[1], SUNY Distinguished Service Professor Emeritus, SUNY College of Environmental Science and Forestry, Syracuse, NY

Every once in a while this reviewer discovers a book that peaks one's curiosity, addresses wetland restoration, is not a wetland science book per se but incorporates human wetland lifestyle dependency. Examples of such would include those catching crayfish the Atchafalaya in Louisiana or those fishing on the Georgia coastal wetlands. This reviewer has long been intrigued with human ecology, and the roles of nongovernment organizations in wetland management (Smardon 2009). Suzanne Alwash's book *Eden Again: Hope in the Marshes of Iraq* is such a book. This book reveals the history of the Southern Iraq wetlands fed by the Tigris and Euphrates rivers from ancient times to about 2012. This reviewer became familiar with the marsh dependent dwellers with Wilfred Thesiger's classic book the *Marsh Arabs* first published in 1964 and than again in 1967 and 2007.

Alwash covers the key periods of the Southern Iraq Marsh history within the first three chapters. Chapter 1 – the *Ma'dan and the marshes* recounts the natural history and the indigenous culture of the marshlands. Much of this is drawn form Wilfred Thesiger's (1964) work as he traveled through the southern Iraq region from the 1940s to the 1960s. Chapter two is a depressing account of the near total destruction of the wetlands in the 1990s (Figure 1) as Saddam Hussein pursued the rebel forces within the marshlands. Ironically Chapter three is a historical regression to the last ice ages, wetland formation and the early human history of the area.

The next four chapters cover the efforts to restore the Southern Iraq Marshlands after the devastation of the 1990s. Chapter four addresses the efforts of those outside of Iraq to garner international support to stop the marshland dewatering and the forced migration of the marsh dwellers. Chapter five covers the efforts of marsh dwellers, and local government to re-flood the marshes in 2003. Chapter six addresses the beginning of Iraq's first environmental organization, *Nature Iraq*, and its work to build an environmental ethos in a country still reeling with civil war.

The next four chapters address the physical aspects of the Southern Iraq wetlands and challenges for restoration. Chapter seven is a description of the re-flooded wetlands and partial ecosystem rebirth from 2003 through 2007. Chapter eight covers the bird life of the wetlands and chapter nine covers efforts to restore indigenous fish communities. Chapter ten is a critical chapter in addressing hydrologic issues of water supply plus upstream water use and management by Turkey, Syria an Iran that constrains marsh restoration.

FIGURE 1: 1994 Map of the Mesopotamian Marshes showing drained areas in pink Souce; Wikipedia; https://en.wikipedia.org/wiki/Draining_of_the_Mesopotamian_Marshes

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The last four chapters constitute a "political ecology" of the various factors and factions affecting restoration progress. Chapter eleven addresses the need for Iraq to utilize international treaties such as Ramsar plus national law to protect sensitive areas such as the Southern Iraq marshes. Chapter twelve covers the international and local efforts to support the lives of the marsh dwellers. Chapter thirteen covers the multi-year drought starting in 2007 plus upstream water use and diversions that had a devastating impact on the marshlands. Finally Chapter fourteen is a normative agenda for what needs to be done to sustain the remnant marshes and or partially restore adjacent degraded marshland areas.

The author provided key sources for each of the chapters at the end of the book. There are illustrations throughout the book with a set of color plate illustrations in the middle of the book. This reviewer would like to have seen a few more map-like figures illustrating the various hydrologic changes such as inflows and marsh areas as it is confusing after 2003.

The value of this book is the integrative nature of marsh restoration hydrology and ecology with the human ecology of the marsh dwellers and the political ecology of the key actors. The author's narrative of these key actors – the marsh dwellers, the NGO Nature Iraq, local government, and Iraq national government agencies – is enriched by her first hand experiences with all these actors. Restoration of the Southern Iraq marshes is a truly daunting task but this book provides a hopeful prognosis for partial restoration of this internationally important wetland complex. ■

REFERENCES

Alwash, S. 2013. *Eden Again: Hope in the Marshes of Iraq.* Tablet House Publishing, Fullerton, CA. 211pp.

Smardon, R.C. 2009. *Sustaining the Worlds Wetlands: Setting Policy and Resolving Conflicts*. Springer Science, Dordrecht, Heidelberg, London & New York. 326pp.

Thesiger, W. 1964. *The Marsh Arabs*. Penguin, London. 233 pp.

Photos by Ralph Tiner from recent time spent in Florida. See more of his photos in his *Notes from the Field*, beginning on the next page (page 138).

Mottled Duck

American Bullfrog

Roseate Spoonbill

Sandhill Crane with young

NOTES FROM THE FIELD

During the last two months I had the opportunity to spend a few weeks in Florida. My wife and I visited three National Parks (Everglades, Biscayne Bay, and Dry Tortugas), a couple of National Wildlife Refuges (Loxahatchee and Merritt Island), and a number of state and county parks (e.g., Wakodahatchee, Green Cay, and Wekiva Springs). I used these visits to photograph wildlife and a few landscapes. The Wakodahatchee and Green Cay wetlands are two urban wetlands constructed by Palm Beach County government. The former was named the best park in Florida in 2018 by Money Magazine. Both have long boardwalks for accessing the wetlands and are exceptional places to observe all kinds of wetland birds. They are must see places for folks interested in viewing waterbirds and for capturing close-up images of them. I used a Canon 40D EOS with a 55-250mm lens for close-ups and a 20-35mm for landscape images. I thought readers might be interested in seeing some of these images so a sampling is presented below. I'm also using this piece as an example for SWS members and others to show them that they can use this section of the journal as a place to simply display their nature photography of wetlands and their wildlife. Note: The images have been cropped and are free to anyone to use. If you want a higher resolution image simply contact me at ralphtiner83@gmail.com.

IMAGES FROM EVERGLADES NATIONAL PARK

Everglades Grassland and Hardwood Hammocks

Alligator

Dwarf Red Mangroves

Tree Seaside Tansey or Bay Marigold (*Borrichia arborescens*)

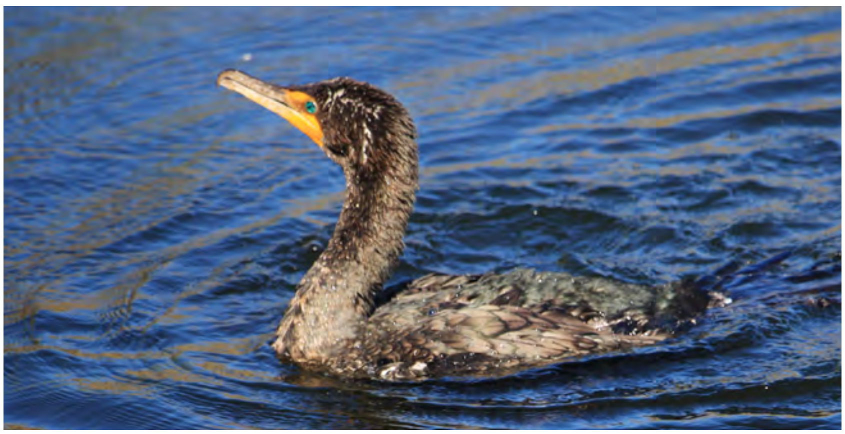
Southern Swamp Lily or Seven Sisters (*Crinum americanum*)

Black-necked Stilts

Osprey (with fish)

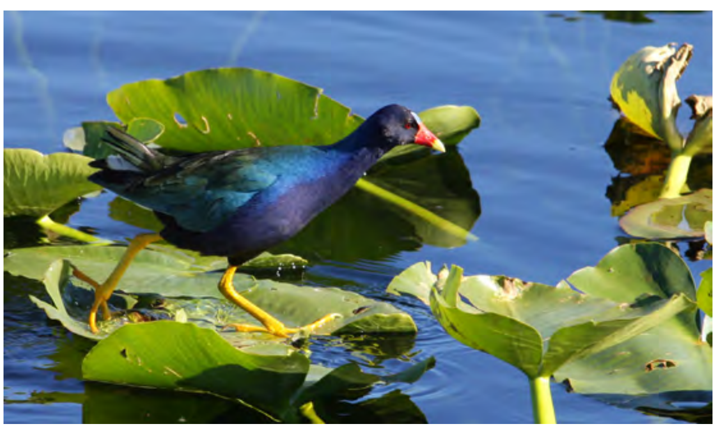
Palm Warbler

Double-crested Cormorant (just after dive)



Anhinga male (drying wings)

Purple Gallinule



Chicken Turtle

Cypress Domes

IMAGES FROM BISCAYNE BAY NATIONAL PARK

Great White Heron

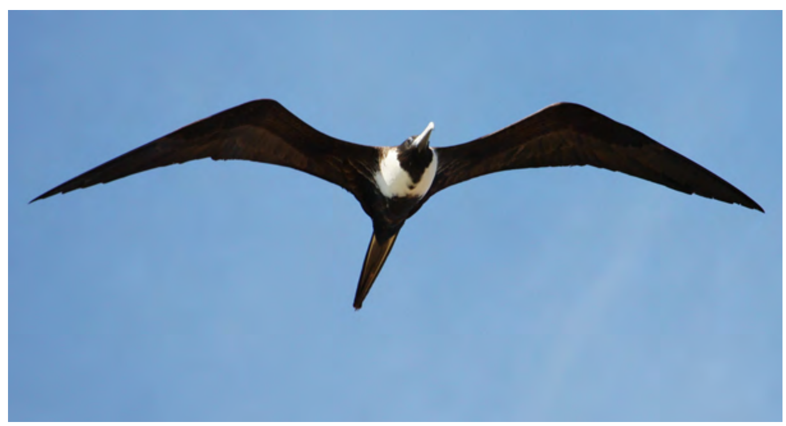
Great Blue Heron

Green Heron adult

IMAGES FROM DRY TORTUGAS NATIONAL PARK

Ruddy Turnstone

Magnificent Frigatebird female



Black Skimmer

Hermit Crab

IMAGES FROM WAKODAHATCHEE WETLAND

Young Great Blue Heron (on nest in rookery)

Tricolored Heron

Black-bellied Whistling Duck

Green Heron juvenile

American Bittern

Wood Stork (swallowing fish)

IMAGES FROM GREEN CAY WETLAND

American Coot

Pied-billed Grebe

Common Moorhen

Blue-winged Teal (pair)

Glossy Ibis

Peninsula Cooter

Snowy Egret

IMAGES FROM MERRITT ISLAND NATIONAL WILDLIFE REFUGE/CAPE CANAVERAL NATIONAL SEASHORE

Gopher Tortoise (a threatened species in Florida)

Laughing Gull

Willet

Sanderling

IMAGES FROM OTHER PLACES

White Ibis

Little Blue Heron adult

Little Blue Heron immature

Limpkin

Brown Pelican breeding adults

American White Pelican breeding adult

Ring-billed Gull

Royal Terns

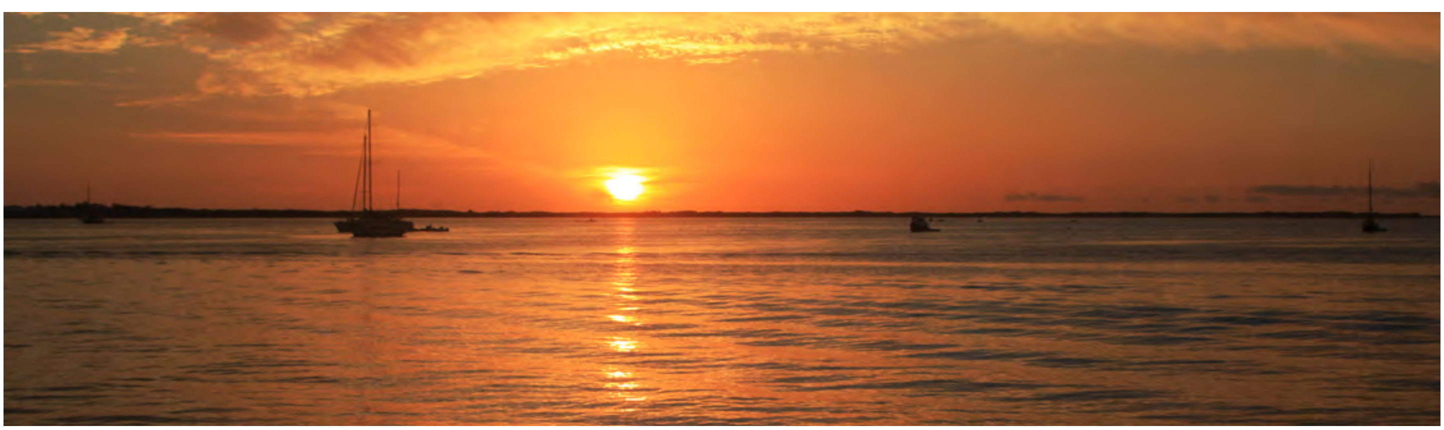
Red-shouldered Hawk

Florida Red-bellied Turtle

Iguana

Four-petaled St. John's-wort (*Hypericum tetrapetalum*)

Sunset at Key Largo



WETLANDS IN THE NEWS

Listed below are some links to some random news articles that may be of interest. Members are encouraged to send links to articles about wetlands in their local area. Please send the links to WSP Editor at ralphtiner83@gmail.com and reference "Wetlands in the News" in the subject box. Thanks for your cooperation. ■

NEW LINKS THIS ISSUE

California adopts new wetlands rules to protect them from Trump rollbacks
https://www.latimes.com/local/lanow/la-me-state-wetlands-protections-20190402-story.html?outputType=amp

Invasive round gobies may be poised to decimate endangered French Creek mussels
https://www.sciencedaily.com/releases/2019/04/190401142207.htm

The Usual Story of the National Park Service Is Incomplete
http://time.com/5562258/indigenous-environmental-justice/

Amphibian 'apocalypse' caused by most destructive pathogen ever
https://relay.nationalgeographic.com/proxy/distribution/public/amp/animals/2019/03/amphibian-apocalypse-frogs-salamanders-worst-chytrid-fungus

Sea level rise: Saltwater intrusion laying waste to Delmarva farms
https://www.delmarvanow.com/story/news/local/maryland/2019/03/29/sea-level-rise-saltwater-intrusion-laying-waste-delmarva-farms/3276897002/

Spring bird migration at Montezuma Wetlands Complex
https://www.democratandchronicle.com/picture-gallery/news/2019/03/22/spring-bird-migration-montezuma-wetlands-complex/3247284002/

Elizabeth Coleman White: Blueberry Queen of the Jersey Pines
https://wednesdayswomen.com/elizabeth-coleman-white-blueberry-queen-of-the-jersey-pines/

Spotted salamanders discovered at Munroe Falls Metro Park as wetlands make a return
https://www.news5cleveland.com/news/local-news/oh-summit/spotted-salamanders-discovered-at-munroe-falls-metro-park-as-wetlands-make-a-return

Study finds people in Ireland and Scotland made "bog butter" for millennia
https://arstechnica.com/science/2019/03/study-finds-people-in-ireland-and-scotland-made-bog-butter-for-millennia/

Marshes Can Adapt To Rising Seas By Trapping More Carbon. Here's What That Means
https://amp.wbur.org/news/2019/03/07/wetlands-sea-levels-carbon-climate-change

As sea level rises, wetlands crank up their carbon storage
https://www.sciencedaily.com/releases/2019/03/190306131401.htm

The Ocean Is Running Out of Breath, Scientists Warn
https://www.scientificamerican.com/article/the-ocean-is-running-out-of-breath-scientists-warn/

The ubiquitous SC coastal marsh grass is no longer called spartina
https://www.postandcourier.com/news/the-ubiquitous-sc-coastal-marsh-grass-is-no-longer-called/article_51f439b4-3916-11e9-a607-abf6634164d3.html

What's in a Name? A Lot, It Seems!
https://ncseagrant.ncsu.edu/currents/2019/01/whats-in-a-name-a-lot-it-seems/

Scientists say there's still time to save Minnesota from invasive wetland plant
https://www.mprnews.org/story/2019/02/27/scientists-say-theres-still-time-to-save-minnesota-from-invasive-wetland-plant

Wetland mud is 'secret weapon' against climate change
https://www.bbc.com/news/amp/science-environment-47472602

Continued sea-level rise on East and Gulf coasts detailed: Nearly all non-Alaskan West Coast tide stations also saw higher seas
https://www.sciencedaily.com/releases/2019/02/190225123513.htm

Ancient wetlands provide new insight into global carbon cycle
https://phys.org/news/2019-02-ancient-wetlands-insight-global-carbon.html

WOTUS Rollback: 'No Wetlands, No Seafood'
https://www.coastalreview.org/2019/02/wotus-rollback-no-wetlands-no-seafood/

Why the world needs wetlands
https://eandt.theiet.org/content/articles/2019/02/why-the-world-needs-wetlands/

Neither snow, slush nor sunken ice keeps these scientists from wetland restoration
https://www.mprnews.org/story/2019/02/18/scientists-wetland-restoration

Conserving Carolina working to rehab 100-acre wetland
https://www.blueridgenow.com/news/20190206/conserving-carolina-working-to-rehab-100-acre-wetland

Tulane Study: Sea levels are rising faster than originally thought
https://www.wwltv.com/article/news/tulane-study-sea-levels-are-rising-faster-than-originally-thought/289-f6ca1d44-9167-4243-a337-41e4525c95f1

As EPA Eases Wetlands Rule, California Makes a Countermove
https://www.wsj.com/articles/as-epa-eases-wetlands-rule-california-makes-a-countermove-11549123200

FGCU researcher wants to clean water by flipping lands between wetlands and farm fields in Everglades
https://www.news-press.com/story/news/2019/01/07/everglades-restoration-lake-okeechobee-fgcu-caloosahatchee-river-red-tide-blue-green-chad-gillis/2481016002/

World's Oceans Are Warming Faster, Studies Show, Fueling Storms and Sea Rise
https://insideclimatenews.org/news/10012019/ocean-warming-accelerating-sea-level-rise-hurricanes-climate-change-science-review

Along the East Coast, rainy days, high tides and sea rise make floods a part of life
https://www.nbcnews.com/mach/news/east-coast-sea-level-rise-high-tides-flooding-ncna957241

Wetlands in Wood County to be restored
http://www.wtol.com/2019/01/17/wetlands-wood-county-be-restored/

Stirrings in the Muck: Fiddler Crabs, Yellow-Crowned Night Herons Locked in Climate Change Dance – National Geographic Society Newsroom
https://blog.nationalgeographic.org/2018/08/17/stirrings-in-the-muck-fiddler-crabs-yellow-crowned-night-herons-locked-in-climate-change-dance/

SC wetlands — prized for habitat and flood buffer — lose protection under Trump water rule
https://www.postandcourier.com/news/sc-wetlands-prized-for-habitat-and-flood-buffer-lose-protection/article_e8b1b568-15e7-11e9-9f73-fb66dc7843a5.html

Saving the World's Largest Tropical Wetland - the Pantanal
https://www.ecowatch.com/worlds-largest-wetland-pantanal-2626630113.html

Novato wetlands project cleared for $5.7M infusion
https://www.marinij.com/2018/12/25/state-approves-funding-for-next-phase-of-hamilton-wetlands-project/

City adds to wetlands preservation along Salt Creek
https://journalstar.com/news/state-and-regional/govt-and-politics/city-adds-to-wetlands-preservation-along-salt-creek/article_4c18b7a5-9c5e-59ad-96e6-4f0aa3e61731.html

Global sea level could rise 15 meters by 2300, study says
https://phys.org/news/2018-10-global-sea-meters.html

New Climate Report Was Too Cautious, Some Scientists Say
https://www.scientificamerican.com/article/new-climate-report-was-too-cautious-some-scientists-say/

What's Another Way to Say 'We're F-cked'?
https://www.rollingstone.com/politics/politics-news/climate-change-sea-level-rise-737012/

Cows help battle invasive grass at Great Salt Lake wetlands
https://www.sltrib.com/news/2018/10/13/cows-help-battle-invasive/

Developer cited for violating clean water act after developing part of subdivision in wetlands
http://www.wbrz.com/news/developer-cited-for-violating-clean-water-act-after-developing-part-of-subdivision-in-wetlands/

Rising Seas Threaten Iconic Mediterranean Sites
https://www.scientificamerican.com/article/rising-seas-threaten-iconic-mediterranean-sites/

The future of wetlands: We've been warned
https://forestsnews.cifor.org/57861/the-future-of-wetlands-weve-been-warned?fnl=en

Prevent red tide? Start with more wetlands, experts say
http://floridapolitics.com/archives/277986-wetlands-water-red-tide

Climate change doubters are finalists for Environmental Protection Agency Science Advisory Board
https://www.sciencemag.org/news/2018/10/climate-change-doubters-are-finalists-environmental-protection-agency-science-advisory

Sea level rise doesn't necessarily spell doom for coastal wetlands
https://www.sciencenews.org/article/sea-level-rise-doesnt-necessarily-spell-doom-coastal-wetlands

West Marin wetlands project hits 10-year mark
https://www.marinij.com/2018/10/22/nature-reclaims-giacomini-wetlands-a-decade-after-major-restoration-project/

As Sea Levels Rise, How Best to Protect Coasts?
https://www.yaleclimateconnections.org/2016/07/as-sea-levels-rise-how-best-to-protect-our-coasts/

World's Largest Tropical Wetland Has A Problem With Roadkill
https://www.iflscience.com/plants-and-animals/worlds-largest-tropical-wetland-has-a-problem-with-roadkill/

Rising Seas Forcing Changes on Maryland's Historic Eastern Shore Farms
https://www.voanews.com/a/climate-change-maryland-farms/4633200.html

Climate change: 'Wetlands vital to protect cities'
https://www.bbc.com/news/science-environment-46020176

As Insect Populations Decline, Scientists Are Trying to Understand Why
https://www.scientificamerican.com/article/as-insect-populations-decline-scientists-are-trying-to-understand-why/

Rising sea levels may build, rather than destroy, coral reef islands
https://phys.org/news/2018-11-sea-coral-reef-islands.html

$400,000 grant to plan wetlands restoration between Bucktown and Bonnabel in Jefferson Parish
https://www.nola.com//environment/2018/11/400000-grant-to-plan-wetlands-restoration-between-bucktown-and-bonnabel-in-jefferson-parish.html

Saltese Flats wetlands project underway for wildlife, water
http://www.spokesman.com/stories/2018/nov/15/saltese-flats-wetlands-project-underway-for-wildli/

Industries face closure for polluting wetlands, water bodies
https://www.newtimes.co.rw/news/industries-face-closure-polluting-wetlands-water-bodies

Oasis Lost - With urbanization sprawling west, one of the most important landscapes in the western hemisphere—the wetlands of the Great Salt Lake—is at risk of disappearing.
https://www.cityweekly.net/utah/oasis-lost/Content?oid=10443272

End of an era as Ireland closes its peat bogs 'to fight climate change'
https://www.theguardian.com/world/2018/nov/27/ireland-closes-peat-bogs-climate-change

Bill would roll back wetlands protections
http://www.michiganradio.org/post/bill-would-roll-back-wetlands-protections

Marin gets $520,000 for Novato wetlands restoration project
https://www.marinij.com/2018/11/27/marin-county-gets-520000-grant-to-design-novato-wetlands-restoration-project/

West Coast Wetlands Could Nearly Disappear in 100 Years
https://www.scientificamerican.com/article/west-coast-wetlands-could-nearly-disappear-in-100-years

Wetlands are a natural climate solution. Guess who's turning them into big polluters?
https://grist.org/article/wetlands-are-a-natural-climate-solution-guess-whos-turning-them-into-big-polluters/

Requiem for our wetlands? What's at risk in NE Minnesota
https://www.minnpost.com/community-voices/2018/11/requiem-for-our-wetlands-whats-at-risk-in-ne-minnesota/

Michigan Senate votes to drain wetlands regulations
https://www.detroitnews.com/story/news/local/michigan/2018/12/04/michigan-senate-votes-drain-wetlands-regulations/2206092002/

As he exits, Michigan lawmaker wants to gut wetland protection, boost waste
https://www.bridgemi.com/michigan-environment-watch/he-exits-michigan-lawmaker-wants-gut-wetland-protection-boost-waste

Trump EPA Proposes Major Rollback Of Federal Water Protections
https://www.npr.org/2018/12/11/675477583/trump-epa-proposes-big-changes-to-federal-water-protections

Southeast Long Beach land swap could net more wetlands—and more greenhouse gases
https://lbpost.com/news/coastal-commission-southeast-long-beach-oil-wetlands/

Saving the Graniteville Woods and Wetlands: How a poor community is fighting to save their only open, green space
http://www.sicwf.org/

CLEAN WATER ACT: EPA falsely claims 'no data' on waters in WOTUS rule
https://www.eenews.net/stories/1060109323

LSU wetlands mitigation bank plan moves forward
https://www.businessreport.com/realestate/lsu-wetlands-mitigation-bank-plan-moves-forward

Trump wetlands rule rollback makes about 6 million acres in Florida unprotected
https://www.tampabay.com/environment/trump-wetlands-rule-rollback-makes-about-6-million-acres-in-florida-unprotected-20181213/

In India, Nature's Power Overwhelms Engineered Wetlands
https://e360.yale.edu/features/in-india-natures-power-overwhelms-engineered-wetlands

Controversial wetlands legislation gets scaled back by state Legislature
https://www.detroitnews.com/story/news/local/michigan/2018/12/21/scaled-back-wetlands-legislation-gets-house-ok/2379537002/

Wetland damage from roseau cane plague visible in satellite images
https://articles.nola.com/environment/index.ssf/2018/09/wetland_plague_damage_in_missi.amp

Wetlands disappearing 3 times faster than forests threatening fresh water supplies: Report
https://timesofindia.indiatimes.com/india/wetlands-disappearing-3-times-faster-than-forests-threatening-fresh-water-supplies-report/articleshow/65974012.cms

Why we must save the Endangered Species Act
https://e360.yale.edu/features/why-we-must-save-the-endangered-species-act-from-the-trump-administration-babbitt

Beavers are redefining the landscape at Smith and Bybee Lake Wetlands Natural Area
https://katu.com/news/local/beavers-are-redefining-the-landscape-at-smith-and-bybee-lake-wetlands-natural-area

What the world needs now to fight climate change: More swamps
http://theconversation.com/what-the-world-needs-now-to-fight-climate-change-more-swamps-99198

Proposal for wetland buffers doesn't hold water in Lewes
https://www.capegazette.com/article/proposal-wetland-buffers-doesn%E2%80%99t-hold-water-lewes/165372

Future of tidal wetlands depends on coastal management
https://www.nature.com/articles/d41586-018-06190-x

Moving a floating wetland from a beach in Minnesota
https://www.atlasobscura.com/articles/what-happened-to-the-minnesota-bog

Stop using "Swamp" as a negative term (e.g., "drain the swamp")
https://www.nytimes.com/2018/05/05/opinion/sunday/stop-calling-washington-a-swamp-its-offensive-to-swamps.html

Upcoming ASWM webinar on compensatory mitigation registration
https://attendee.gotowebinar.com/register/7485952740901587715

Restoring wetlands for desert pupfish
https://www.ecowatch.com/desert-fish-endangered-2569323966.html

North Carolina wetland regulations
https://portcitydaily.com/local-news/2018/05/11/3-days-vs-3-months-regulatory-structure-makes-it-tougher-protect-wetlands/

Massachusetts wetland enforcement
https://www.ecori.org/government/2018/5/3/appeals-court-upholds-decision-to-restore-damaged-wetlands

Wetlands for downtown Durham, NC
http://www.heraldsun.com/news/local/counties/durham-county/article209713499.html

Wetland conservation in Texas
http://kfdm.com/news/local/additional-wetlands-protection-provides-defense-against-flooding

Wetland banking in Minnesota
http://www.startribune.com/bank-gives-landowners-committed-to-restoring-minnesota-wetlands-a-financial-incentive/480463381/

Columbian wetlands
http://www.columbian.com/news/2018/apr/18/shoring-up-a-key-wetland-in-camas/

Wetland restoration in Milwaukee
https://www.jsonline.com/story/news/local/milwaukee/2018/04/17/restoration-one-last-wetlands-milwaukees-harbor-estuary-provide-more-public-recreation-ato-restored/522547002/

Kansas wetland park
http://www.kansas.com/news/politics-government/article208500834.html

Walden Pond revisited
https://www.smithsonianmag.com/smart-news/new-study-details-man-made-damage-done-walden-pond-180968700/

Wisconsin Frac mining permit
https://www.wpr.org/dnr-staff-felt-pressure-approve-wetland-fill-frac-sand-mining-project

Minnesota wetland conservation
http://www.startribune.com/federal-project-leader-scott-glup-sees-work-as-the-front-lines-of-protection-for-wetlands-and-waterfowl/479060743/

Hong Kong wetlands
https://www.hongkongfp.com/2018/04/08/trouble-paradise-suspicious-fires-land-battles-afflict-hong-kongs-nam-sang-wai-wetlands/

Spokane County wetland restoration
http://www.spokesman.com/stories/2018/apr/03/spokane-county-central-valley-district-make-saltes/#/0

Florida wetland regulation
https://www.tcpalm.com/story/news/local/indian-river-lagoon/health/2018/03/19/wetland-protection-poised-shift-corps-engineers-florida-dep/417298002/

Sea-level rise threatens local tribe in Louisiana
https://e360.yale.edu/features/on-louisiana-coast-a-native-community-sinks-slowly-into-the-sea-isle-de-jean-charles

Turtles in crisis
http://therevelator.org/turtle-extinction-crisis/

Pantanal wetlands
https://www.worldwildlife.org/stories/5-interesting-facts-about-the-pantanal-the-world-s-largest-tropical-wetland

http://www.worldwaterforum8.org/en/news/brazil-bolivia-and-paraguay-signed-declaration-conservation-pantanal

Penguins seen from space
https://gizmodo.com/poo-stains-seen-from-space-lead-to-discovery-of-massive-1823457294

Wisconsin wetland regulations
http://www.gazettextra.com/news/government/county-officials-say-isolated-wetlands-bill-could-have-adverse-effects/article_7f98b9ef-48eb-55cc-b4b6-f851f1213d3d.html

http://host.madison.com/wsj/news/local/govt-and-politics/politicized-wisconsin-dnr-erasing-rare-wetlands-retirees-say/article_881666fc-f9c0-5cf7-ac2a-272e9c1d4094.html

Ballona wetlands historic images
http://www.businessinsider.com/history-of-los-angeles-ballona-creek-wetlands-watershed-2018-2

Mining impacts proposed for Minnesota
https://search.app.goo.gl/EUQb6

New Books for Identifying Wetland Graminoids Published

For wetlanders with an interest in identifying graminoids, two books should be on your bookshelf: *Sedges of Maine* (Matt Arsenault and others) published by the University of Maine Press (reprint of 2013 book) and *Sedges and Rushes of Minnesota* (Welby Smith, 2018) printed by the Minnesota Department of Natural Resources. Both books are copiously illustrated with color photographs that definitely aid in plant identification. Another graminoid book – Grasses and Rushes of Maine – is in production and should be available in late January.

For the latest news on wetlands and related topics, readers are referred to the Association of State Wetland Managers website. Their "Wetland Breaking News" section include links to newspaper articles that should be of interest: https://www.aswm.org/news/wetland-breaking-news. Their blog – the Complete Wetlander – may also be of interest: https://www.aswm.org/wordpress/. Additional resources are listed below. Please help us add new books and reports to this listing. If your agency, organization, or institution has published new publications on wetlands, please send the information to Editor of Wetland Science & Practice at ralphtiner83@gmail.com. Your cooperation is appreciated. ■

BOOKS

- Sedges of Maine https://umaine.edu/umpress/books-in-print/
- Sedges and Rushes of Minnesota https://www.upress.umn.edu/book-division/books/sedges-and-rushes-of-minnesota
- Wetland & Stream Rapid Assessments: Development, Validation, and Application https://www.elsevier.com/books/wetland-and-stream-rapid-assessments/dorney/978-0-12-805091-0
- Eager: The Surprising Secret Life of Beavers and Why They Matter https://www.chelseagreen.com/product/eager/
- Wetland Indicators – A Guide to Wetland Formation, Identification, Delineation, Classification, and Mapping https://www.crcpress.com/Wetland-Indicators-A-Guide-to-Wetland-Identification-Delineation-Classification/Tiner/p/book/9781439853696
- Wetland Soils: Genesis, Hydrology, Landscapes, and Classification https://www.crcpress.com/Wetland-Soils-Genesis-Hydrology-Landscapes-and-Classification/Vepraskas-Richardson-Vepraskas-Craft/9781566704847
- Creating and Restoring Wetlands: From Theory to Practice http://store.elsevier.com/Creating-and-Restoring-Wetlands/Christopher-Craft/isbn-9780124072329/
- Salt Marsh Secrets. Who uncovered them and how? http://trnerr.org/SaltMarshSecrets/
- Remote Sensing of Wetlands: Applications and Advances. https://www.crcpress.com/product/isbn/9781482237351
- Wetlands (5th Edition). http://www.wiley.com/WileyCDA/WileyTitle/productCd-1118676823.html
- Black Swan Lake – Life of a Wetland http://press.uchicago.edu/ucp/books/book/distributed/B/bo15564698.html
- Coastal Wetlands of the World: Geology, Ecology, Distribution and Applications http://www.cambridge.org/us/academic/subjects/earth-and-environmental-science/environmental-science/coastal-wetlands-world-geology-ecology-distribution-and-applications
- Florida's Wetlands https://www.amazon.com/Floridas-Wetlands-Natural-Ecosystems-Species/dp/1561646873/ref=sr_1_4?ie=UTF8&qid=1518650552&sr=8-4&keywords=wetland+books
- Mid-Atlantic Freshwater Wetlands: Science, Management, Policy, and Practice http://www.springer.com/environment/aquatic+sciences/book/978-1-4614-5595-0
- The Atchafalaya River Basin: History and Ecology of an American Wetland http://www.tamupress.com/product/Atchafalaya-River-Basin,7733.aspx
- Tidal Wetlands Primer: An Introduction to their Ecology, Natural History, Status and Conservation https://www.umass.edu/umpress/title/tidal-wetlands-primer
- Wetland Landscape Characterization: Practical Tools, Methods, and Approaches for Landscape Ecology http://www.crcpress.com/product/isbn/9781466503762
- Wetland Techniques (3 volumes) http://www.springer.com/life+sciences/ecology/book/978-94-007-6859-8
- Wildflowers and Other Plants of Iowa Wetlands https://www.uipress.uiowa.edu/books/2015-spring/wildflowers-and-other-plants-iowa-wetlands.htm
- Wetland Restoration: A Handbook for New Zealand Freshwater Systems https://www.landcareresearch.co.nz/publications/books/wetlands-handbook
- Wetland Ecosystems https://www.wiley.com/en-us/Wetland+Ecosystems-p-9780470286302
- Constructed Wetlands and Sustainable Development https://www.routledge.com/Constructed-Wetlands-and-Sustainable-Development/Austin-Yu/p/book/9781138908994

ONLINE PUBLICATIONS

U.S. ARMY CORPS OF ENGINEERS

- Regional Guidebook for the Functional Assessment of Organic Flats, Slopes, and Depressional Wetlands in the Northcentral and Northeast Region http://acwc.sdp.sirsi.net/client/en_US/search/asset/1047786
- Wetland-related publications:
-http://acwc.sdp.sirsi.net/client/en_US/default/search/results?te=&lm=WRP
-http://acwc.sdp.sirsi.net/client/en_US/default/search/results?te=&lm=WRP
- National Wetland Plant List publications: http://rsgisias.crrel.usace.army.mil/NWPL/
- National Technical Committee for Wetland Vegetation: http://rsgisias.crrel.usace.army.mil/nwpl_static/ntcwv.html
- U.S. Environmental Protection Agency wetland reports and searches: http://water.epa.gov/type/wetlands/wetpubs.cfm
- A Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing Wetland Functions of Forested Wetlands in Alluvial Valleys of the Coastal Plain of the Southeastern United States ERDC/EL TR-13-1
- Hydrogeomorphic (HGM) Approach to Assessing Wetland Functions: Guidelines for Developing Guidebooks (Version 2) ERDC/EL TR-13-11
- Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing the Functions of Flat and Seasonally Inundated Depression Wetlands on the Highland Rim ERDC/EL TR-13-12
- Wetland Plants and Plant Communities of Minnesota and Wisconsin (online publication) http://www.mvp.usace.army.mil/Missions/Regulatory/?Page=12

U.S. FISH AND WILDLIFE SERVICE, NATIONAL WETLANDS INVENTORY

- Wetland Characterization and Landscape-level Functional Assessment for Long Island, New York http://www.fws.gov/northeast/ecologicalservices/pdf/wetlands/Characterization_Report_February_2015.pdf or http://www.aswm.org/wetlandsonestop/wetland_characterization_long_island_ny_021715.pdf
- Also wetland characterization/landscape-level functional assessment reports for over 12 small watersheds in New York at: http://www.aswm.org/wetland-science/134-wetlands-one-stop/5044-nwi-reports
- Preliminary Inventory of Potential Wetland Restoration Sites for Long Island, New York http://www.aswm.org/wetlandsonestop/restoration_inventory_long_island_ny_021715.pdf
- Dichotomous Keys and Mapping Codes for Wetland Landscape Position, Landform, Water Flow Path, and Waterbody Type Descriptors. Version 3.0. U.S. Fish and Wildlife Service, Northeast Region, Hadley, MA. https://www.fws.gov/northeast/EcologicalServices/pdf/wetlands/Dichotomous_Keys_and_Mapping_Codes_for_Wetland_Landscape_Position_Landform_Water_Flow_Path_and_Waterbody_Type_Version_3.pdf
- Connecticut Wetlands Reports:
- Changes in Connecticut Wetlands: 1990 to 2010
- Potential Wetland Restoration Sites for Connecticut: Results of a Preliminary Statewide Survey
- Wetlands and Waters of Connecticut: Status 2010
- Connecticut Wetlands: Characterization and Landscape-level Functional Assessment
- Rhode Island Wetlands: Status, Characterization, and Landscape-level Functional Assessment http://www.aswm.org/wetlandsonestop/rhode_island_wetlands_llww.pdf
- Status and Trends of Prairie Wetlands in the United States: 1997 to 2009 http://www.fws.gov/wetlands/Documents/Status-and-Trends-of-Prairie-Wetlands-in-the-United-States-1997-to-2009.pdf
- Status and Trends of Wetlands in the Coastal Watersheds of the Conterminous United States 2004 to 2009. http://www.fws.gov/wetlands/Documents/Status-and-Trends-of-Wetlands-In-the-Coastal-Watersheds-of-the-Conterminous-US-2004-to-2009.pdf
- The NWI+ Web Mapper – Expanded Data for Wetland Conservation http://www.aswm.org/wetlandsonestop/nwiplus_web_mapper_nwn_2013.pdf
- Wetlands One-Stop Mapping: Providing Easy Online Access to Geospatial Data on Wetlands and Soils and Related Information http://www.aswm.org/wetlandsonestop/wetlands_one_stop_mapping_in_wetland_science_and_practice.pdf
- Wetlands of Pennsylvania's Lake Erie Watershed: Status, Characterization, Landscape-level Functional Assessment, and Potential Wetland Restoration Sites http://www.aswm.org/wetlandsonestop/lake_erie_watershed_report_0514.pdf

U.S. FOREST SERVICE

- Historical Range of Variation Assessment for Wetland and Riparian Ecosystems, U.S. Forest Service Rocky Mountain Region. http://www.fs.fed.us/rm/pubs/rmrs_gtr286.pdf
- Inventory of Fens in a Large Landscape of West-Central Colorado http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5363703.pdf

U.S. GEOLOGICAL SURVEY, NATIONAL WETLANDS RESEARCH CENTER

- Link to publications: http://www.nwrc.usgs.gov/pblctns.htm (recent publications are noted)
- A Regional Classification of the Effectiveness of Depressional Wetlands at Mitigating Nitrogen Transport to Surface Waters in the Northern Atlantic Coastal Plain http://pubs.usgs.gov/sir/2012/5266/pdf/sir2012-5266.pdf
- Tidal Wetlands of the Yaquina and Alsea River Estuaries, Oregon: Geographic Information Systems Layer Development and Recommendations for National Wetlands Inventory Revisions http://pubs.usgs.gov/of/2012/1038/pdf/ofr2012-1038.pdf

U.S.D.A. NATURAL RESOURCES CONSERVATION SERVICE

- Link to information on hydric soils:http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/use/hydric/
- Field Indicators of Hydric Soils of the United States, Version 8.1 (online publication) https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_053171.pdf

PUBLICATIONS BY OTHER ORGANIZATIONS

- The Nature Conservancy has posted several reports on wetland and riparian restoration for the Gunnison Basin, Colorado at: http://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/Colorado/science/climate/gunnison/Pages/Reports.aspx (Note: Other TNC reports are also available via this website by looking under different regions.)
- Book: Ecology and Conservation of Waterfowl in the Northern Hemisphere, Proceedings of the 6th North American Duck Symposium and Workshop (Memphis, TN; January 27-31, 2013). Wildfowl Special Issue No. 4. Wildfowl & Wetlands Trust, Slimbridge, Gloucestershire, UK.
- Report on State Definitions, Jurisdiction and Mitigation Requirements in State Programs for Ephemeral, Intermittent and Perennial Streams in the United States (Association of State Wetland Managers) http://aswm.org/stream_mitigation/streams_in_the_us.pdf
- Wetlands and People (International Water Management Institute) http://www.iwmi.cgiar.org/Publications/Books/PDF/wetlands-and-people.pdf
- Waubesa Wetlands: New Look at an Old Gem (online publication) http://www.town.dunn.wi.us/land-use/historic-documents/

ARTICLES OF INTEREST FROM VARIED SOURCES

- Comparative phylogeography of the wild-rice genus Zizania (Poaceae) in eastern Asia and North America; American Journal of Botany 102:239-247.
  http://www.amjbot.org/content/102/2/239.abstract

LINKS TO WETLAND-RELATED JOURNALS AND NEWSLETTERS

JOURNALS

- Aquatic Botany http://www.journals.elsevier.com/aquatic-botany/
- Aquatic Conservation: Marine and Freshwater Ecosystems http://onlinelibrary.wiley.com/journal/10.1002/%28ISSN%291099-0755
- Aquatic Sciences http://www.springer.com/life+sciences/ecology/journal/27
- Ecological Engineering http://www.journals.elsevier.com/ecological-engineering/
- Estuaries and Coasts http://www.springer.com/environment/journal/12237
- Estuarine, Coastal and Shelf Science http://www.journals.elsevier.com/estuarine-coastal-and-shelf-science/
- Hydrobiologia http://link.springer.com/journal/10750
- Hydrological Sciences Journal http://www.tandfonline.com/toc/thsj20/current
- Journal of Hydrology http://www.journals.elsevier.com/journal-of-hydrology/
- Wetlands http://link.springer.com/journal/13157
- Wetlands Ecology and Management https://link.springer.com/journal/11273

NEWSLETTERS

Two of the following newsletters have been terminated yet maintain archives of past issues. The only active newsletter is "Wetland Breaking News" from the Association of State Wetland Managers.

- Biological Conservation Newsletter contained some articles that addressed wetland issues; the final newsletter was the January 2017 issue; all issues now accessed through the "Archives") http://botany.si.edu/pubs/bcn/issue/latest.htm#biblio
- For news about conservation research from the Smithsonian Institution, please visit these websites:
  -Smithsonian Newsdesk http://newsdesk.si.edu/
  -Smithsonian Insider http://insider.si.edu/
  -The Plant Press http://nmnh.typepad.com/the_plant_press/
  -SCBI Conservation News http://nationalzoo.si.edu/conservation
  -STRI News http://www.stri.si.edu/english/about_stri/headline_news/news
- Wetland Breaking News (Association of State Wetland Managers) http://aswm.org/news/wetland-breaking-news
- National Wetlands Newsletter (Environmental Law Institute) – access to archived issues as the newsletter was suspended in mid-2016 due to the changing climate for printed publications. https://www.wetlandsnewsletter.org/

What's New in the SWS Journal - *Wetlands*?

The following articles appear in Volume 39, Issue 1 of *Wetlands*:

- The Second Warning to Humanity – Providing a Context for Wetland Management and Policy
- Ecological Value of the Sorokaoziorki Wetland Complex in the Steppe of Central Eurasia (Khakassia, Russian Federation)
- Fine-Scale Mapping of Coastal Plant Communities in the Northeastern USA
- Effects of Simulated Treated Domestic Wastewater on Sphagnum Productivity, Decomposition and Nutrient Dynamics in a Subarctic Ladder Fen
- A Daily Water Table Depth Computing Model for Poorly Drained Soils
- The Nativity and Distribution of the Cryptic Invader Phalaris arundinacea (Reed Canarygrass) in Riparian Areas of the Columbia and Missouri River Basins
- Assessing Changes of Habitat Quality for Shorebirds in Stopover Sites: a Case Study in Yellow River Delta, China
- Nitrogen Retention by Sphagnum fuscum in Laboratory Mesocosms: Responses to Experimentally Added NH4 +-N and NO3 −-N
- Effects of River Flow Regulation beyond the Channel: Multifaceted Changes within a Group of Invertebrate Floodplain Specialists
- Wetland Soil Properties and Resident Bacterial Communities Are Influenced by Changes in Elevation
- Decomposition of Standing Litter Biomass in Newly Constructed Wetlands Associated with Direct Effects of Sediment and Water Characteristics and the Composition and Activity of the Decomposer Community Using Phragmites australis as a Single Standard Substrate
- Relative Importance of Landscape Versus Local Wetland Characteristics for Estimating Wetland Denitrification Potential
- Short-Term Effect of Exogenous Nitrogen on N2O Fluxes from Native and Invaded Tidal Marshes in the Min River Estuary, China
- Modeling the Relationship between Water Level, Wild Rice Abundance, and Waterfowl Abundance at a Central North American Wetland
- Effects of Prescribed Fire on Plant Traits and Community Characteristics of Triarrhena Lutarioriparia in Poyang Lake, China
- Are Waterfowl Food Resources Limited during Spring Migration? A Bioenergetic Assessment of Playas in Nebraska's Rainwater Basin
- Soil Conditions Following Hydrologic Restoration in Cypress Dome Wetlands
- Pathways of Water and Sediment in the Biesbosch Freshwater Tidal Wetland

DO YOU WANT TO PUBLISH YOUR ARTICLE IN THIS JOURNAL?

Please visit the homepage of *Wetlands* for full details on aims and scope, editorial policy and article submission.

SIGN UP FOR SPRINGERALERTS!

Register for Springer's email services providing you with info on the latest books in your field. https://www.springer.com/gp?SGWID=0-150903-0-0-0&wt_mc=alerts.TOCjournals&utm_source=toc&utm_medium=email&utm_content=13157&utm_campaign=&countryChange=true

About *Wetland Science & Practice (WSP)*

Wetland Science and Practice (WSP) is the SWS quarterly publication aimed at providing information on select SWS activities (technical committee summaries, chapter workshop overview/abstracts, and SWS-funded student activities), brief summary articles on ongoing or recently completed wetland research, restoration, or management projects or on the general ecology and natural history of wetlands, and highlights of current events. *WSP* also includes sections listing new publications and research at various institutions, and links to major wetland research facilities, federal agencies, wetland restoration/monitoring sites and wetland mapping sites. The publication also serves as an outlet for commentaries, perspectives and opinions on important developments in wetland science, theory, management and policy.

Both invited and unsolicited manuscripts are reviewed by the *WSP* editor for suitability for publication. Student papers are welcomed. Please see publication guidelines at the end of this issue.

Electronic access to Wetland Science and Practice is included in your SWS membership. All issues published, except the the current issue, are available via the internet to the general public. At the San Juan meeting, the SWS Board of Directors voted to approve release of past issues of WSP when a new issue is available to SWS members only. This means that a WSP issue will be available to the public four months after it has been read by SWS members (e.g., the June 2017 issue will be an open access issue in September 2017). Such availability will hopefully stimulate more interest in contributing to the journal. And, we are excited about this opportunity to promote the good work done by our members.

HOW YOU CAN HELP

If you read something you like in WSP, or that you think someone else would find interesting, be sure to share. Share links to your Facebook, Twitter, Instagram and LinkedIn accounts.

Make sure that all your SWS colleagues are checking out our recent issues, and help spread the word about SWS to non-members!

Questions? Contact editor Ralph Tiner, PWS Emeritus (ralphtiner83@gmail.com). ■

WSP Manuscript – General Guidelines

LENGTH:

Approximately 5,000 words; can be longer if necessary.

STYLE:

See existing articles from 2014 to more recent years available online at:
http://www.sws.org/category/wetland-science-practice.html

TEXT:

Word document, 12 font, Times New Roman, single-spaced; keep tables and figures separate, although captions can be included in text. For reference citations in text use this format: (Smith 2016; Jones and Whithead 2014; Peterson et al. 2010).

FIGURES:

Please include color images and photos of subject wetland(s) as WSP is a full-color e-publication.
Image size should be less than 1MB – 500KB may work best for this e-publication.

REFERENCE CITATION EXAMPLES:

- Claus, S., S. Imgraben, K. Brennan, A. Carthey, B. Daly, R. Blakey, E. Turak, and N. Saintilan. 2011. Assessing the extent and condition of wetlands in NSW: Supporting report A – Conceptual framework, Monitoring, evaluation and reporting program, Technical report series, Office of Environment and Heritage, Sydney, Australia. OEH 2011/0727.
- Clements, F.E. 1916. *Plant Succession: An Analysis of the Development of Vegetation*. Carnegie Institution of Washington. Washington D.C. Publication 242.
- Clewell, A.F., C. Raymond, C.L. Coultas, W.M. Dennis, and J.P. Kelly. 2009. Spatially narrow wet prairies. *Castanea* 74: 146-159.
- Colburn, E.A. 2004. *Vernal Pools: Natural History and Conservation*. McDonald & Woodward Publishing Company, Blacksburg, VA.
- Cole, C.A. and R.P. Brooks. 2000. Patterns of wetland hydrology in the Ridge and Valley Province, Pennsylvania, USA. *Wetlands* 20: 438-447.
- Cook, E.R., R. Seager, M.A. Cane, and D.W. Stahle. 2007. North American drought: reconstructions, causes, and consequences. *Earth-Science Reviews* 81: 93-134.
- Cooper, D.J. and D.M. Merritt. 2012. Assessing the water needs of riparian and wetland vegetation in the western United States. U.S.D.A., Forest Service, Rocky Mountain Research Station, Ft. Collins, CO. Gen. Tech. Rep. RMRS-GTR-282.

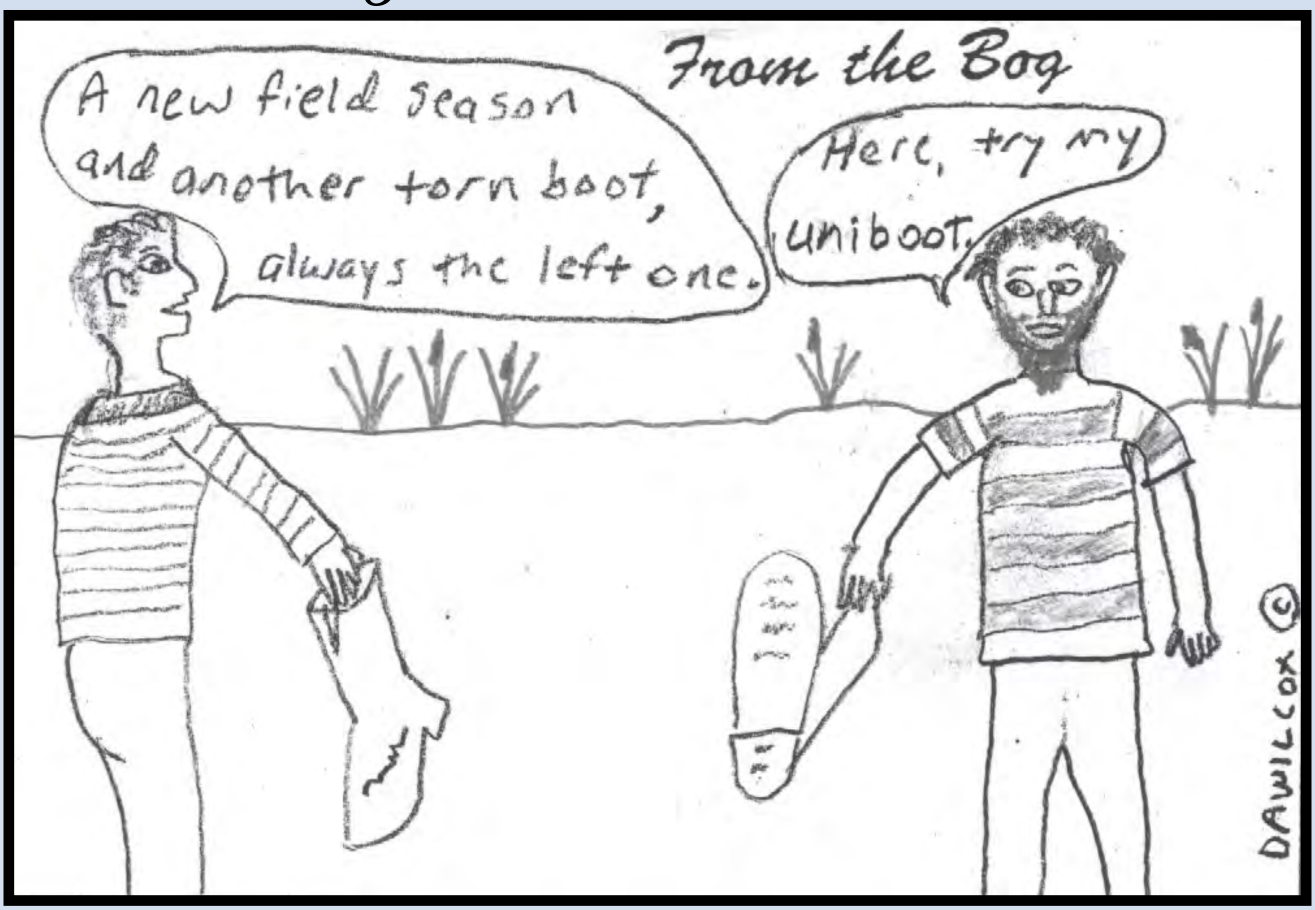
WEB TIP

Resources at your fingertips!

For your convenience, SWS has compiled a hefty list of wetland science websites, books, newsletters, government agencies, research centers and more, and saved them to sws.org.

Find them on the Related Links page sws.org.

From the Bog



by Doug Wilcox

wetland science & practice

WSP is the formal voice of the Society of Wetland Scientists. It is a quarterly publication focusing on the news of the SWS and providing important announcements for members and opportunities for wetland scientists, managers, and graduate students to publish brief summaries of their works and conservation initiatives. Topics for articles may include descriptions of threatened wetlands around the globe or the establishment of wetland conservation areas, and summary findings from research or restoration projects. All manuscripts should follow guidelines for authors listed above. All papers published in WSP will be reviewed by the editor for suitability and may be subject to peer review as necessary. Most articles will be published within 3 months of receipt. Letters to the editor are also encouraged, but must be relevant to broad wetland-related topics. All material should be sent electronically to the current editor of WSP. Complaints about SWS policy or personnel should be sent directly to the elected officers of SWS and will not be considered for publication in WSP. ■