# U.S.-Iran Symposium on Wetlands

## March 28 - 30, 2016

## Irvine, California

THE UNIVERSITY OF ARIZONA

NATIONAL ACADEMY OF SCIENCES

NATIONAL ACADEMY OF ENGINEERING

INSTITUTE OF MEDICINE
*OF THE NATIONAL ACADEMIES*

Sharif University of Technology

# Preface

## 1. Introduction

To promote science diplomacy and enhance understanding of this important issue, the 'U.S.-Iran Symposium on Wetlands' was held from March 28th to 30th, 2016 at the Arnold and Mabel Beckman Center in Irvine, California (USA). The Symposium was organized by the University of Arizona, National Academy of Sciences, Engineering and Medicine, and Sharif University of Technology. Delegations of U.S. and Iranian scientists participated in sharing current research and knowledge. The goal of the joint U.S.-Iran Symposium on Wetlands was to gather experts in various fields related to wetlands to discuss and inform on the important aspects based on the two countries' experiences.

## 2. Symposium Motivation

Found on almost all parts of planet Earth, wetlands are a critical component of the natural environment, serving varied purposes and providing multiple benefits, including habitat for aquatic and terrestrial species, cycling of nutrients and organics, water purification, and serving as buffers to reduce impacts of storm flooding.

Human activities have exerted multiple stressors on the functioning and existence of wetlands. From diversion and loss of water supply to the variety of impacts caused by pollutant loading, the health and resilience of wetlands is being tested and sometimes exceeded. In addition, climate change-related impacts to natural systems including wetlands are already occurring in some areas and are anticipated to increase in the future. These impacts may be even greater at wetlands located in arid regions of the U.S. and Iran. There is a need to recognize and understand these impacts and to implement appropriate management and mitigation strategies to preserve these important ecosystems.

Given the multiple benefits of wetlands, the construction of artificial wetlands for water purification is increasingly being recognized as a viable method for wastewater treatment. For example, there were over 600 constructed wetlands used for treatment of municipal wastewater in North America by 1998. Research on constructed wetlands for wastewater treatment has examined organics, nutrients, heavy metals, and pathogens in systems utilizing surface flow, subsurface flow, or vertical flow.

The first international treaty on the conservation and sustainable use of wetlands, the Ramsar Convention, was signed in 1971 in Ramsar, Iran. The Convention's ongoing mission is "the conservation and wise use of all wetlands through local and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world." Given the historical context and the present range of issues related to natural and constructed wetlands, there is a clear opportunity for "science diplomacy" on this issue between Iran and the U.S. To that end, the Symposium served as a forum to bring together a diverse group of scholars to discuss wetlands, learn about the latest research, and understand how each country is advancing to address this topic. The spirit of the Symposium was to initiate dialogue about wetlands and facilitate the next steps to take as a collective group.

## 3. Research Fields of Wetlands

The scientific committee of the U.S.-Iran Symposium on Wetlands met several times to plan the meeting and converged on a set of topics that were of mutual interest:

### *3.1. Science of Natural Wetlands*

This broad topic of the Symposium included a diverse set of presentations. Talks discussed nutrient pollution in the Everglades, plant diversity and nutrient cycling in saline wetlands, anaerobic carbon cycling, the "black box" of wetland biogeochemistry, and wastewater effects to a natural wetland in Iran.

### *3.2. Restoration of Wetlands*

The Symposium included several presentations on the increasingly important topic of wetland restoration. Talks discussed efforts to restore the Mesopotamian Marshes in Iraq and the Everglades, restoration efforts at the Salton Sea, determining wetland environmental water requirements, a restoration approach for Lake Urmia, Iran, and a wetland management framework incorporating ecosystem service and social linkage aspects.

### *3.3. Climate Change and Wetland Restoration*

Climate change is already impacting natural systems including wetlands and these impacts are anticipated to increase in the future. Restoration efforts at wetlands impacted by climate change is a growing area of interest and activity. Talks on this topic included restoration of Lake Urmia, Iran, a systems approach for assessing impacts on Parishan Wetland system in Iran, and sediment augmentation to combat sea level rise in coastal wetlands in California.

### *3.4. Management and Regulation of Wetlands*

Effective restoration of wetlands requires proper management and regulation. Presentations on these topics included quantification methods for evaporation estimation, assessment of biological invasions at coastal wetlands, participatory management of mangrove forests to promote restoration, and assessment and planning efforts for regional recovery of coastal wetlands in California.

### *3.5. Constructed Wetlands and Phytoremediation*

Utilization of constructed wetlands for wastewater treatment is another area of growing interest in the U.S., Iran, and around the world. Presentations on this topic included field and laboratory assessments of surface flow and subsurface flow constructed wetlands and their treatment performance for organics, nutrients, pathogens, and trace organic contaminants. Phytoremediation as a green approach for wetlands management and for nutrient reduction of agricultural runoff were also presented.

## 4. WHAT WE LEARNED FROM THE U.S.-IRAN SYMPOSIUM ON WETLANDS

Overall, the content of the Symposium was well-received by all participants, promoting dialogue and interaction among the participants. The significance of wetlands was made clear and similar views were shared by the group about both the urgency of the issue and areas for future work. Scientists from both countries interacted at a high level and discussed how to extend collaborations beyond the meeting. Discussions motivated the development of a special journal issue to present the findings of papers presented at this meeting and the publication of this Proceedings.

Overall, the content of the Symposium was highly appreciated by the participants. The purpose, results and outcomes were regarded as relevant and meaningful. In particular, the broad scope of the presented topics and fields reinforced the need for interdisciplinary thinking and collaboration.

## 5. ACKNOWLEDGEMENTS

We are grateful to the individuals and institutions that have made this symposium and the publication of these proceedings possible. In particular, we would like to thank: the International Visitors Leadership Program, the National Academies of Sciences, Engineering and Medicine, as well as Sharif University of Technology.

Further, we express our gratitude to Mr. Larry Moody of the International Visitors Leadership Program and his colleagues for their dedication and devotion to the promotion of science. We also thank Mr. Glenn Schweitzer of the National Academy of Sciences for his tireless efforts to enhance and support Science Diplomacy. Also our thanks to Dr. Anne Dare from the National Academies of Sciences, Engineering and Medicine for organizing scientific visits to universities and research centers involved in managing wetlands in the United States.

The organizers would like to acknowledge the support of Dr. Mahmud Fotouhi-Firuzabadi and Dr. Masud Tajrishi, the President and Vice President of Sharif University of Technology. In particular, the contributions of the organizing committee at Sharif by Dr. Mehdi Borghei, Dr. Manuchehr Vosoughi, Dr. Golnaz Borghei and Dr Azadeh Hemmati in reviewing the proceedings papers and making the final selection of the participating scientists are greatly appreciated.

The organizers would like to thank the University of California at Irvine and we express our gratitude to Dr. Soroosh Sorooshian for his commitment and efforts towards the success of the Symposium. We also thank the staff at the Arnold and Mabel Beckman Center for their contributions and hospitality.

Additionally, we acknowledge the participating scientists for joining us in Irvine to present the results of their research, take part in scientific discussions, and provide the papers making up this document; their scientific contributions were the basis for the meeting and their eagerness enhanced the conference.

Also, we are thankful to Dr. David Quanrud of the University of Arizona for his excellent work as the Executive Editor of these Proceedings and Coordinator of the Symposium.

Finally, our special thanks to the staff of the University of Arizona Department of Civil Engineering and Engineering Mechanics, in particular Ms. Therese Lane, Senior Business Manager, and Ms. Sierra Lindsay for their assistance in the organization of the Symposium and preparation of the Proceedings.

Kevin Lansey, Co-Chairman

Hassan Vafai, Co-Chairman

David Quanrud, Co-Chairman

December, 2016

# Management of Wetlands and Marshes: A Project for Iran

March 14 - April 1, 2016
*Arranged by World Learning*

**PROJECT SUMMARY**

The Office of International Visitors Leadership Program outlined the following specific objectives for the project:

- Provide a forum for Iranian and American professionals to compare research on wetlands management;
- Investigate the status of wetlands and marshes in the United States;
- Examine cooperation between federal, state, and local governments and universities and research centers in managing wetlands;
- Promote the exchange of ideas and discussions on water management in the United States and Iran; and
- Develop future collaboration and joint research projects.

The project addressed the following themes in each city:

*Washington, DC* *March 11 – 19, 2016*

Scientific approaches and policies toward wetlands management; carbon sequestration, methane emissions, and prescribed fire; planning for sea-level rise and marsh migration; elevation dynamics of marshes; ecological research; intergovernmental cooperation on environmental issues NGO initiatives on wetlands management and preservation

*West Lafayette, Indiana* *March 19 - 22, 2016*

Bioscience and nanotechnology; high diversity restoration; restoring native habitats; water and wastewater treatment

*Salt Lake City, Utah* *March 23 - 26, 2016*

Research on wetlands and marshes; refuge dynamics for wildlife; water quality, management, and planning; wetlands management on the Great Salt Lake

*Irvine, California* *March 26 - 31, 2016*

Symposium on management of wetlands and marshes

*Los Angeles, California* *March 31 - April 2, 2015*

Wetlands projects at regional parks; academic programs in environment and sustainability

**WASHINGTON, DC**

*The National Academies of Sciences, Engineering, and Medicine, Water Science and Technology Board*

Dr. Stephanie Johnson, Senior Staff Officer, Water Science and Technology Board
Dr. Ed Dunne, Staff Officer, Water Science and Technology Board Division on Earth and Life Studies
Dr. Elizabeth Eide, Acting Director, Water Science and Technology Board Division on Earth and Life Studies

The National Academies of Sciences, Engineering, and Medicine are private, nonprofit institutions that provide expert advice on some of the most pressing challenges facing the nation and the world. Its work helps shape sound policies, inform public opinion, and advance the pursuit of science, engineering, and medicine. The National Academies are the nation's pre-eminent source of high-quality, objective advice on science, engineering, and health matters. Most of their work is conducted through seven major programs: Behavioral and Social Sciences and Education; Earth and Life Studies; Engineering and Physical Sciences; the Institute of Medicine; Policy and Global Affairs; the Transportation Research Board; and the NAS Gulf Research Program.

The Water Science and Technology Board was established in the National Research Council to provide a focal point for studies related to water resources accomplished under the aegis of the National Academy of Sciences and the National Academy of Engineering. The board's objective is to improve the scientific and technological basis for resolving important questions and issues associated with the efficient management and use of water resources. In carrying out its responsibilities and to serve the national interest, the board responds to requests for evaluations and advice concerning specific and generic issues in water resources, influences action by initiating studies of issues that merit consideration by public agencies and others, identifies issues and topics of research related to water resources, and cooperates with other units of the National Research Council and groups with mutual interests outside the National Research Council. The board's scope covers all dimensions of water resources, including science, engineering, economics, policy, educational issues, and social aspects.

This meeting focused on some of the work by the WSTB related to wetlands and marshes, including: Edwards Aquifer habitat restoration, the Everglades habitat and ecosystem restoration, graywater and stormwater, and water reuse.

*Blackwater National Wildlife Refuge*

Dr. Matt Whitbeck, Supervisory Wildlife Biologist Blackwater National Wildlife Refuge
Dr. Brian Needelman, Associate Professor of Soil Science, Department of Environmental Science and Technology University of Maryland
Dr. Gerry Galloway, Research Professor, Department of Civil and Environmental Engineering, University of Maryland
Dr. Don Cahoon, Research Ecologist, USGS Patuxent Wildlife Research Center
Dr. Joel Carr, United States Geological Survey

Blackwater National Wildlife Refuge (NWR) was established in 1933 as a waterfowl sanctuary for birds migrating along the Atlantic Flyway. It is home to an incredible amount of plant and animal diversity in its three major habitats – forest, marsh and shallow water. The refuge contains one-third of Maryland's tidal wetlands. These wetlands also provide storm protection to lower Dorchester County, including the town of Cambridge. Recognized as a "Wetland of International Importance" by the Ramsar Convention, Blackwater NWR is currently home to the largest remaining natural population of endangered Delmarva Peninsula fox squirrels and is also home to the largest breeding population of American bald eagles on the East Coast, north of Florida.

In addition to a tour of the refuge, presentation/discussion topics included:

- Overview of the Blackwater National Wildlife Refuge and planning for sea-level rise and marsh migration
- Carbon sequestration, methane emissions, and prescribed fire
- Elevation dynamics of the marshes of the Blackwater National Wildlife Refuge

*Smithsonian Environmental Research Center (SERC)*

Dr. Patrick Megonigal, Associate Director of Research
Dr. Candy Feller, Senior Scientist
Dr. John Parker, Senior Scientist

The Smithsonian Environmental Research Center (SERC) provides science- based knowledge to meet the environmental challenges of the 21st century. SERC leads research on coastal ecosystems – where land meets the sea – to inform real-world decisions for wise policies, best business practices, and a sustainable planet. Headquartered on Chesapeake Bay, its 2,650-acre campus spans forests, wetlands, marshes, and 12 miles of protected shoreline. The site serves as a natural laboratory for long-term and cutting edge ecological research.

The topic of discussion was long-term research on coastal wetland responses to climate change, followed by a tour of the Center that includes research on climate change- driven mangrove migration into tidal marshes and long-term experiments on the tidal marsh elevation gain in a future of elevated carbon dioxide and rising temperature.

*Ecosystem Restoration Project at Poplar Island*

Mr. Justin Callahan, Project Manager, Baltimore District, U.S. Army Corps of Engineers
Mr. Mark Mendelsohn, Biologist, Baltimore District, U.S. Army Corps of Engineers
Ms. Katie Perkins, Civil Engineer, Baltimore District, U.S. Army Corps of Engineers

Poplar Island, located in Talbot County in the mid-Chesapeake Bay, has become a national model of environmental restoration. It is the site where an innovative solution for dredged material management is resulting in the restoration of a once vanishing island. The restoration of Poplar Island includes the creation of uplands and intertidal wetlands offering a diversity of habitats for a variety of Chesapeake Bay wildlife. With less than 20 percent of the habitat creation completed, Poplar Island wildlife goals are already being realized. A number of the region's most sensitive bird species including common and least terns, cattle and snowy egrets, osprey, and the American black duck, are found nesting onsite annually and diamondback terrapins continue to return to the site to nest as well. The restoration of Poplar Island has gained national and local attention, and Maryland and the U.S. Army Corps of Engineers won a "Coastal America" award for their work. The project also has gained international attention with delegations from across the globe visiting the site each year.

The Maryland Environmental Service (MES) is a self-supporting, independent State agency that combines the public sector's commitment to environmental protection with the private sector's flexibility and responsiveness. MES provides services at competitive rates to government and private sector clients and works on projects including water and wastewater treatment, solid waste management, composting, recycling, dredged material management, hazardous materials cleanup, storm water services and renewable energy. With 764 diverse projects located in three states, it couples operational expertise with a commitment to strict environmental compliance and safe work practices.

*Overview of the USDA Natural Resources Conservation Service's work in wetlands and marshes*

Mr. Craig N. Goodwin, National Water Quality Specialist and National Aquatic Ecologist Ecological Sciences Division, USDA Natural Resources Conservation Service

The Natural Resources Conservation Service of the U.S. Department of Agriculture provides farmers, ranchers, and forest managers with free technical assistance, or advice, for their land. Common technical assistance includes: resource assessment, practice design, and resource monitoring. A conservation planner helps determine if someone is eligible for financial assistance. Technical assistance is also available online through the Conservation Client Gateway.

The United States Department of Agriculture (USDA) is the U.S. federal executive department responsible for developing and executing federal government policy on farming, agriculture, forestry, and food. It aims to meet the needs of farmers and ranchers, promote agricultural trade and production, work to assure food safety, protect natural resources, foster rural communities and end hunger in the United States and abroad.

*Dyke Marsh*

Mr. Brent Steury, Natural Resources Program Manager

Dyke Marsh is one of the largest remaining freshwater tidal wetlands in the Washington metropolitan area. Its 485 acres of tidal marsh, floodplain, and swamp forest can be explored by boat or on foot. The Dyke Marsh Wildlife Preserve exemplifies collaboration between a variety of stakeholders, including the National Park Service.

The National Park Service is a bureau of the U.S. Department of the Interior and is led by a Director nominated by the President and confirmed by the U.S. Senate. Since 1916, the American people have entrusted the National Park Service with the care of their national parks. With the help of volunteers and park partners, the National Park Service safeguards these nearly 400 places and to share its stories with more than 275 million visitors every year. Tribes, local governments, nonprofit organizations, businesses, and individual citizens ask for the National Park Service's help in revitalizing their communities, preserving local history, celebrating local heritage, and creating close to home opportunities for kids and families to get outside, be active, and have fun. The National Park Service cares for special places saved by the American people so that all may experience their heritage.

*The Nature Conservancy: Wetlands conservation projects in the United States and abroad*

The Nature Conservancy's mission is to preserve the plants, animals and natural communities that represent the diversity of life on Earth by protecting the lands and waters they need to survive. The Conservancy has developed a strategic, science-based planning process, which helps identify the highest-priority places-landscapes and seascapes that, if conserved, promise to ensure biodiversity over the long term. The Nature Conservancy has seven priority conservation initiatives to address the principal threats to conservation at the sites where it works, focusing on fire, climate change, freshwater, marine, invasive species, protected areas and forests.

**WEST LAFAYETTE, INDIANA**

*Overview of Purdue University*

Prof. Arvind Raman, Associate Dean of Global Engineering Programs and Professor of Mechanical Engineering

Prof. Kashchandra Raghothama, Interim Associate Dean of International Programs in Agriculture

and Professor of Horticulture
Mahdieh Aghazadeh, PhD Candidate, Department of Agricultural & Biological Engineering

Purdue University is Indiana's land grant institution with an enrollment of over 38,000 students, and the fourth largest international student population in the US. Purdue's College of Engineering is ranked sixth in the US and Purdue's College Agriculture is ranked fifth in the world.

*Discovery Park: Bindley Bioscience Center, Birck Nanotechnology Center, and Burton D. Morgan Center for Entrepreneurship*

Discovery Park is an interdisciplinary and multidisciplinary research park established in 2001, with eight cross-cutting centers (nanotechnology, bioscience, entrepreneurship, modeling, policy, education, information science, and IT), five global health-related centers (immunology and infectious disease, neurobiology and drug discovery), and five centers working on global challenges related to the nexus of water, energy, food, and the environment. Discovery Park centers extend campus infrastructure to the entire University, allowing multidisciplinary groups to come together and respond to grand challenges and opportunities.

The Bindley Bioscience Center brings together an interdisciplinary group of life sciences and engineering researchers to explore new technologies and scientific knowledge that impact the broad boundaries of plant, animal and human diseases. Major focus areas include: 1) diet and disease prevention, 2) drug discovery and delivery, 3) health and disease biomarkers, and 4) nanomedicine.

The Birck Nanotechnology Center leverages advances in nanoscale science and engineering to create innovative nanotechnologies for computing, communications, the environment, security, energy independence and health. Using the most advanced nanoscale instrumentation, members also pursue answers to fundamental questions in the life and physical sciences.

The Burton D. Morgan Center for Entrepreneurship is home to the Purdue Foundry. The Foundry exists to help Purdue students, faculty and local alumni move ideas to the marketplace more quickly. It is a place to transform innovators into entrepreneurs by providing advice on entity formation, ideation, market analysis and business model development. We are focused on helping individuals at Purdue who have business or product ideas and want to turn them into a company. The process and passion for the success of each company is driven by the entrepreneur and while the Foundry provides support, education and additional tools to help each client reach success.

*Meetings with faculty in the Colleges of Engineering and Agriculture*

Chad Jafvert, Professor of Civil Engineering and Environmental and Ecological Engineering
Ernest "Chip" Blatchley, Professor of Civil Engineering and Environmental and Ecological Engineering
Zhao Ma, Assistant Professor of Sustainable Natural Resources Social Sciences
Sara McMillan, Assistant Professor of Agricultural and Biological Engineering
Ali Shakouri, Director of Birck Nanotechnology Center, Professor of Electrical and Computer Engineering
Tomas Höök, Associate Professor of Fisheries and Aquatic Sciences
Jeff Holland, Associate Professor of Entomology
Venkatesh Merwade, Associate Professor of Civil Engineering
Jay Gore, Professor of Mechanical Engineering
Arezoo Ardekani, Assistant Professor of Mechanical Engineering
Kevin McNamara, Professor of Agricultural Economics/Assistant Director of International Programs in Agriculture

*Kankakee Sands Prairie Wetlands Restoration Project*

John Shuey, Director of Conservation Science, The Nature Conservancy, Indiana Field Office
Ted Anchor, Kankakee Sands Manager, The Nature Conservancy, Indiana Field Office

Kankakee Sands Prairie Wetlands Restoration Project in Newton County, IN is comprised of nearly 7,000 acres of prairie and wetland habitat. Kankakee Sands, as a very high diversity restoration as a strategy to restore ecological connectivity is very different that anything the visitors are likely to experience elsewhere in the US. The point of this restoration was not to restore wetland and prairie, but to reduce stressors that were negatively impacting a highly fragmented, but important series of habitat remnants. The Nature Conservancy (TNC) is in the process of working through a data set to assess how well the restoration is performing. TNC works with organismal ecologists at Purdue University on a fairly regular basis to study the return of native species and control invasive species. Kankakee Sands is owned by TNC, but the restoration has been conducted in partnership with Division of Fish & Wildlife, Division of Nature Preserves, Indiana Department of Environmental Management, Indiana Heritage Trust, Indiana Grand Company, Lilly Endowment, National Fish & Wildlife Foundation, and the USDA Natural Resources Conservation Services.

*Indiana Dunes National Lakeshore / Cowles Bog Wetland Complex*

Dr. Dan Mason, Botanist, Resources Management, Indiana Dunes National Lakeshore, National Parks Service
Dr. Ralph Grundel, Animal Ecologist, Lake Michigan Ecological Research Station, USGS
Dr. Young Choi, Professor of Biological Sciences, Purdue University-Calumet

In the early twentieth century, Cowles Bog Wetland Complex was drained and ditched to make way for a golf course, grazing lands, and crop land, and the timber and native plants were harvested and sold in neighboring Chicago. Later in the 1960s, industrial development along the shores of Lake Michigan further degraded the state of the wetlands and ushered in the establishment of invasive plant species. Now, efforts are underway to remove the invasive species, and restore native habitats and provide a rest stop for migratory birds. Currently about $800,000 has been dedicated for the restoration effort by the National Park Service and the Great Lakes Restoration Initiative. Other funding has been provided by Dune Acres Civic Improvement Foundation, Shirley Heinze Land Trust, Indiana Lake Michigan Coastal Program, and Friends of Indiana Dunes. In kind services have been provided by the Town of Dune Acres, The Nature Conservancy, Indiana Dunes Environmental Learning Center, and volunteers.

**SALT LAKE CITY, UTAH**

*Interactive discussion on water management and planning*

Officials of the Division of Water Resources of the Utah Department of Natural Resources; the Department of Environmental Quality of the Utah Division of Water Quality; and representatives of CH2M, an environmental and engineering consulting firm, participated in this discussion.

*Antelope Island*

Antelope Island, the largest island located within the Great Salt Lake, is home to free-ranging bison, mule deer, bighorn sheep, pronghorn antelope, and many other animals. Millions of birds also congregate along the shores surrounding the island. Discussion included wetlands management research being conducted on the island.

*Bear River Migratory Bird Refuge*

Nearly 80,000 acres of marsh, open water, uplands, and alkali mudflats. Bear River is one of over 550 refuges in the National Wildlife Refuge System – a network of lands set aside and managed by the U.S. Fish and Wildlife Service specifically for wildlife. The refuge and other wetlands associated with the Great Salt Lake provide critical habitat for migrating birds. As part of the Bear River Bay, the refuge is designated as a Western Hemisphere Shorebird Reserve Network site, a globally important shorebird area.

**IRVINE, CALIFORNIA**

*Symposium on Management of Wetlands and Marshes*

The National Academies of Sciences, Engineering, and Medicine and the University of Arizona arranged a symposium at the Arnold and Mabel Beckman Center of the National Academies of Sciences, Engineering, and Medicine. Together with American specialists in wetlands management, presentations on critical issues with regard to wetlands, marshes, and water management were given and future collaborations were explored.

**LOS ANGELES, CALIFORNIA**

*Prado Wetlands*

The Orange County Groundwater Basin is managed by the Orange County Water District and provides 72 percent of the water for 2.4 million residents in north and central Orange County. OCWD owns 2,150 acres behind Prado Dam in Riverside County where it operates the Prado Wetlands, the largest constructed wetlands on the west coast of the United States. The visit included discussion of wetland restoration efforts.

*Friends of Ballona Wetlands*

This non-profit, tax-exempt organization was formed in 1978. Representatives discussed their activities promoting wetlands restoration. The Ballona Wetlands are the last major wetlands in Los Angeles County. Friends of Ballona Wetlands have prevented development that would have destroyed the wetlands. The organization's activities fall into three major categories: community environmental monitoring, environment education and stewardship, and wetland restoration/natural habitat enhancement.

*Institute of the Environment and Sustainability, University of California, Los Angeles*

This visit included meetings with representatives of the Water Resources Group. The discussion will focus on the Group's objective to foster communication and collaboration, develop new research synergies, quickly and effectively inform policy makers about the latest in science, technology and policy options, and communicate and work with the private sector and the public to develop sustainable water resources in southern California.

**ACKNOWLEDGMENT**

The organizers would like to acknowledge the efforts of individuals and institutions involved in the planning and the execution of very interesting and educational visits. In particular, the contributions of Dr. Anne Dare are greatly appreciated.

# Event Program

## Monday, March 28

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| 9:00 – 9:15 a.m. | **Welcoming and Introductory Remarks** – Dr. Kevin Lansey, University of Arizona |
| 9:15 – 9:30 a.m. | **Welcoming Address** – Dr. Michael Clegg, United States National Academy of Sciences, University of California Irvine |
| 9:30 – 10:30 a.m. | **Keynote Address: The Role of Wetlands in Mitigating Pollutants in Our Landscape and Globe** – Dr. William Mitsch, Everglades Wetland Research Park |
| 10:30 – 11:00 a.m. | ***Break*** |
| 11:00 – 11:10 a.m. | **Commentary** – Dr. Hassan Vafai, University of Arizona |
| 11:10 a.m. – 12:00 p.m. | **Iran Wetlands: Development Needs and Conservation Management** – Dr. Gary Lewis and Dr. Ali Nazaridoust, UNDP, Iran |
| 12:00 – 1:15 p.m. | ***Lunch*** |
| 1:15 – 2:15 p.m. | **Keynote Address: Stormwater Capture, Treatment and Recharge for Water Supply -** Dr. Richard Luthy, Woods Institute for the Environment at Stanford |
| | **Session I: Science of Natural Wetlands**<br>Chairperson: Dr. David Quanrud |
| 2:15 – 2:35 p.m. | **Plant Diversity of Saline Wetlands and Salt Marshes of Iran** – Dr. Hossein Akhani Senejani, University of Tehran |
| 2:35 – 3:15 p.m. | **Resilience Benefits of Coastal Wetlands** – Dr. Costas Synolakis, University of Southern California |
| 2:55 – 3:15 p.m. | ***Break*** |
| | **Session II: Science of Natural Wetlands**<br>Chairperson: Dr. Hossein Akhani |
| 3:15 – 3:45 p.m. | **Nutrient Cycling in Coastal Wetlands and Estuaries** – Dr. John White, Louisiana State University |
| 3:45 – 4:05 p.m. | **Investigation of Sanitary and Industrial Wastewater Effects on Anzali Reserved Wetland -** Dr. Bita Ayati, Tarbiat Modares University |

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| 4:05 – 4:25 p.m. | **General Comments** – Dr. Glenn Schweitzer, U.S. National Academy of Sciences |
| 4:25 – 5:00 p.m. | ***Breakout/Discussion Session I*** |
| 6:30 p.m. | **Dinner** – Hosted by the Center for Hydrometeorology and Remote Sensing (CHRS), UC-Irvine, and the Rosenberg International Forum on Water Policy, UCOP |

## Tuesday, March 29

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| 8:30 – 9:30 a.m. | **Keynote Address: Restoration of the Salton Sea -** Dr. Timothy Bradley, University of California at Irvine |
| | **Session III: Restoration of Wetlands**<br>Chairperson: Dr. Naser Agh |
| 9:30 – 9:50 a.m. | **Developing a Comprehensive Approach for Determination of Environmental Water Requirements for Wetlands -** Dr. Somayeh Sima, Tarbiat Modares University |
| 9:50 – 10:20 a.m. | **The Use of Ecological Principles in Restoring the Mesopotamian Marshes in Iraq and the Everglades** – Dr. Curt Richardson, Duke University Wetland Center |
| 10:20 – 10:40 a.m. | **Management of Wetlands using DPSIR Framework: Case of Hor-Al-Azim Wetland, Iran -** Dr. Sharareh Pourebrahimadi, University of Tehran |
| 10:40 – 11:10 a.m. | ***Break*** |
| | **Session IV: Restoration of Wetlands**<br>Chairperson: Dr. William Mitsch |
| 11:10 – 11:30 a.m. | **Introducing the Hydroclimatological Data Products of CHRS-UCI –** Dr. Soroosh Sorooshian, Dr. Andrea Throstensen, and Dr. Phu Nguyen, University of California, Irvine |
| 11:30 – 11:50 a.m. | **How to Save a Dying Lake?** – Dr. Naser Agh, Urmia University |
| 11:50 a.m. – 12:10 p.m. | **Restoration Implementation in Practice** – Dr. Mary Small, State of California Coastal Conservancy |
| 12:10 – 1:30 p.m. | ***Lunch*** |

## Session V: Climate Change and Restoration of Wetlands

Chairperson: Dr. Curt Richardson

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| 1:30 – 1:50 p.m. | **Restoration of Lake Urmia** – Dr. Davood Reza Arab, Sharif University of Technology |
| 1:50 – 2:10 p.m. | **Understanding Anaerobic Carbon Cycling in the Face of Global Change** – Dr. Jason Keller, Chapman University |
| 2:10 – 2:30 p.m. | **Investigating Human and Climate Change Impact on Parishan Wetland Water System using System Dynamic Approach** – Dr. Azadeh Hemmati, Islamic Azad University, Science and Research Branch |
| 2:30 – 2:50 p.m. | **Managing Sea Level Rise in Coastal Wetlands: Testing Thin Layer Sediment Augmentation as an Adaptation Strategy** – Dr. Richard Ambrose, University of California at Irvine |
| 2:50 – 3:20 p.m. | ***Break*** |

## Session VI: Biogeochemistry and Constructed Wetlands

Chairperson: Dr. Roya Mafigholami

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| 3:20 – 3:50 p.m. | **Biogeochemistry: The "Black Box" of Wetland Ecosystems** – Presented by John White for Dr. Ramesh Reddy, University of Florida |
| 3:50 – 4:20 p.m. | **Application of Constructed Wetland in Wastewater Treatment** – Dr. Roxana Moogouie, Islamic Azad University, North Tehran Branch |
| 4:20 – 4:40 p.m. | **Survey on Constructed Wetlands Applications in Wastewater Treatment in Iran** – Dr. Golnaz Borghei, Biotech Consultant, Gesco Company, Waste and Water Treatment, Iran |
| 4:40 – 5:10 p.m. | ***Breakout Session II: Research Needs and Potential Collaborations*** |

## Wednesday, March 30

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| | **Session VII: Management and Regulation of Wetlands**<br>Chairperson: Dr. John White |
| 8:30 – 8:50 a.m. | **Evaporation from Wetlands: Estimating and Suppressing** – Dr. Seyed Farshid Chini, University of Tehran |
| 8:50 – 9:10 a.m. | **Unnatural History: Biological Invasions into Coastal Ecosystems –** Dr. Jeff Crooks, Tijuana River National Estuarine Research Reserve |
| 9:10 – 9:30 a.m. | **Participatory Management of Mangrove Forests towards Ecosystem Restoration, Bio-Cultural Diversity Conservation and Achieving Sustainable Livelihoods in Coastal and Marine Protected Areas** – Dr. Mina Esteghamat, Center for Conservation and Development of Sustainable Ecosystems (ZIPAK), and Member of Academic Council, Azad Islamic University |
| 9:30 – 9:50 a.m. | **Historical Wetland Losses and Planning for Regional Recovery** – Dr. Eric Stein, Southern California Coastal Water Research Project |
| 9:50 – 10:20 a.m. | ***Break*** |
| 10:20 – 10:40 a.m. | **Phytoremediation, A Green Approach for Wetlands Management** – Dr. Mohsen Soleimaniaminabadi, Isfahan University of Technology |
| 10:40 – 11:00 a.m. | **The Constructed Ecosystems Research Facility: A Treatment Wetland in Arizona** – Dr. David Quanrud, University of Arizona |
| 11:00 – 11:20 a.m. | **Study of Nitrate and Phosphorous Reduction from Agricultural Runoff by Constructed Wetland using Vetiveria Zizaniodes** – Dr. Roya Mafigholami, Islamic Azad University, Ahvaz Branch |
| 11:20 – 11:45 a.m. | **Closing Remarks** |
| 11:45 a.m. – 1:00 p.m. | ***Lunch*** |
| 1:00 – 2:30 p.m. | ***Iranian Delegation Program Evaluation*** |

Attendees of the U.S.-Iran Symposium on Wetlands, March 28, 2016

**U.S.-Iran Symposium on Wetlands**

March 28-30, 2016

Irvine, California

# Iran Wetlands: Development Needs and Conservation Management

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## *Abstract*

The most important environmental challenges in Iran are: climate change, which includes the water crisis (water scarcity and water quality, energy); land degradation, which includes land use conversions, desertification and rangeland and forest management; air pollution, which includes sand and dust storms (SDS); biodiversity loss and protected area management; and the urban environment, which includes solid waste and air quality. In terms of temperature change, there is an expectation that temperature will increase significantly in populated areas. In the case of the water problem, the country is transcending the threshold from water stress to water scarcity. Iran is the 9th largest emitter of $CO_2$ on the planet and the average rate of soil erosion in Iran is equal to 17 tons/ha/yr, three times greater than the global average. In addition, livestock pressure is 4-7 times greater than the rangeland carrying capacity. In the case of wetlands, problems there is 700 kilometers up, originating from dust storms in Iran to Afghanistan caused by drought in Hamoun. Consequently, international practices, strategic planning, and several urgent and medium term actions are necessary to manage the environmental crises in Iran.

This paper was delivered as a video presentation by G. Lewis and A. Nazaridoust and was further developed by UN Resident Coordinator in Iran and does not include references.

## 1. Introduction

The presentation structure is as follows: I'd like to share with you a perspective on how I think we who are interested in the environment ought to be looking at the issue of security. Human security, therefore, is the point that I would like to draw attention to. Then we'll look, in part two, at the environmental challenges we see in Iran - and these are all of the environmental challenges - your event is about wetlands, but we would like to use the opportunity of speaking to you to share a broader perspective on some of the elements. Then we will focus on the wetlands - problems, solutions, as well as what the UN is doing on the ground, and then finally we will conclude with a single slide of suggesting how you can be partners with us in what we're trying to do.

## 2. HUMAN SECURITY

About twenty years ago, UN development program popularized the notion of human security as something that needs to go beyond the focus of battalions and tanks and borders, and so forth. And I personally subscribe to this view - I believe that if we can feel secure in our culture, in our homes, we have enough food, and water, clean air to breathe, jobs and dignity, health and education - these are things that matter. These are really what makes us feel secure and safe from harm. And I believe that we as policy makers and people with decision-making power need to ask of ourselves a number of searching questions, and focus on the issue of security from the human dimension. That's going to be very important into the future. So, it's with that in mind that I have the whole focus of this presentation looking at human security.

## 3. ENVIRONMENTAL CHALLENGES IN IRAN

This next screen is going to show the overall perspective - we focus on climate change, we look at water, energy, land degradation, air pollution, biodiversity loss. Protected areas, management, and urban environment. So we kick off with climate change: mitigation and adaptation.

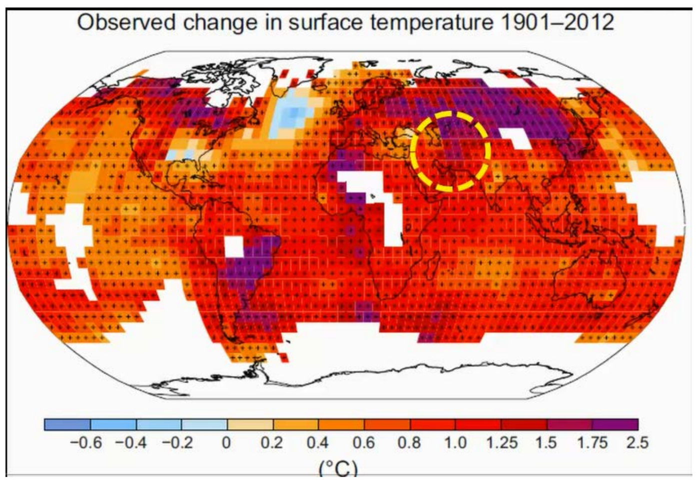


*Figure 1: Observed change in global surface temperature 1901-2012.*

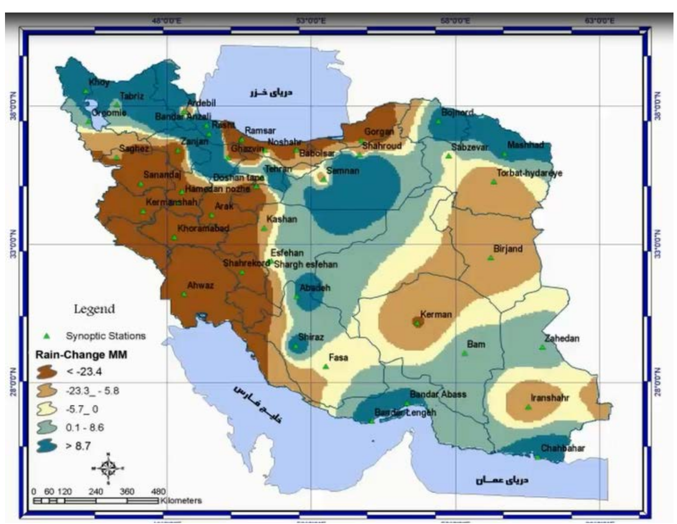


*Figure 2: Rainfall change 2010-2039, versus 1976-2005.*

This slide (Fig. 1), showing the observed change in surface temperature for the past hundred years or so does give us a sense of where things stand in regards to Iran. We are in the zone where there is an expectation that not only has there been significant change but there will continue to be significant change, and we will come to that in a little while. These are slides from the second national communication to the UN and Triple C (Fig. 2). You can see that - in the period between 2010 and 2039 we are expecting a significant variation and change - we expect that there will be a decrease in precipitation in the part of Iran, the brown part there, which is essentially a food basket, and also the north. Around the Caspian Sea, that's where most of the rice and some of the other grains are grown. So you see a significant decline in there, as a result of the onset of climate change, which will basically make the region hotter and drier.

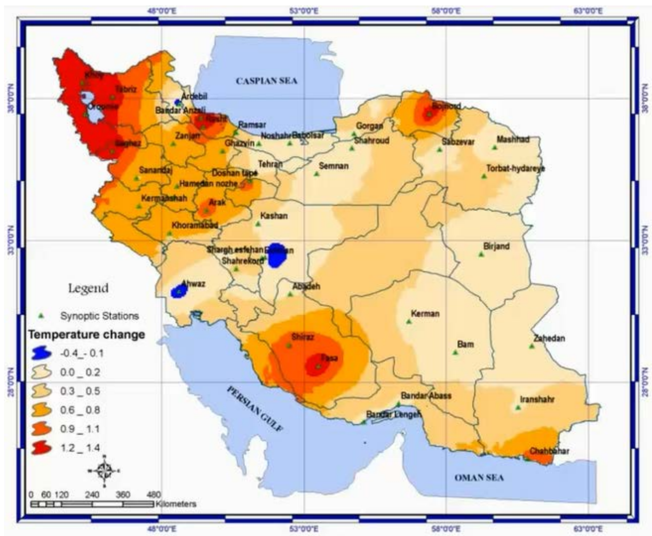


*Figure 3: Temperature change - 2010-2039 versus 1976-2005.*

Same perspective, but looked at in terms of temperature change (Fig. 3). You can see that there is an expectation that temperatures will increase again, significantly, in areas where crops are grown, but also where significant populations exist.

## 4. WATER

Looking at water (Fig. 4), now, this slide is I think quite telling.

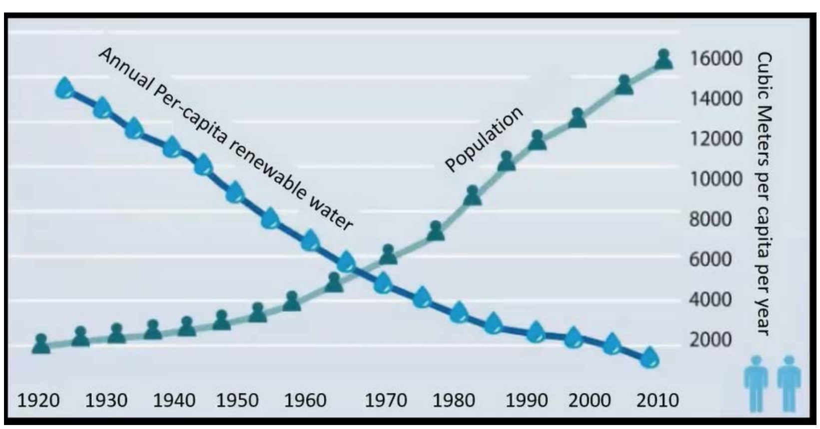


*Figure 4: Tehran renewable water resource.*

You see a juxtaposition of population moving from left to right upwards, and the cubic meters per capita per year, annual per-capita renewable water resources declining. We are at the stage now where we are, in 2016, are just about 1,500 cubic meters per year. We count on transcending the threshold between stress to scarcity, using various metrics. But it is a dramatic problem; a lot of the ancient aquifers is being overpumped as is happening in huge countries like India and China as well, and lost masses of water reserves. One of the problems that we have in the countries is that the population has not adapted its consumption style to respond to this situation, and therein lies a significant problem part of the future water problem - as we all know, without water, life does not continue.


*Figure 5: Water crises in Iran.*

During the course of the presentation we are going to focus on a couple of areas: Lake Urmia, and Hamouns (Fig. 5), but they are not the only places where we see water featuring as a human security drama. Some of the other places are Mashhad and we'll get to a couple of other cities.

Mashhad is important because as the Iranians in the audience will know, it is a significant city of pilgrimage. It holds many millions of people - the population is about 3 million people - and holds three or four times that amount during the course of the year, when pilgrims come to one of the holy shrines. The water situation is as follows: the Kashafrud River flows through Mashhad, but there's hardly any water in that left, and the Kashafrud basin, most of those aquifers have been overpumped and water is dropping by about 0.6 of a meter per year. That's a sustainability issue, in which people have to keep drilling and drilling further down. One other source of water for the city to drink is coming from the Harirud River in Afghanistan feeding the Doosti Dam, on the border between three countries. The water is then pumped uphill to Mashhad, but the Harirud River and the Doosti Dam itself is not increasing, in fact it was flat for a while and is dropping. Water availability, to be consumed by Mashhad citizens is a pretty precarious situation. And of course, higher up, the Afghans are constructing a dam that will lead to the use of a diversion of water within Afghanistan to feed crops, so that may cause additional problems for Mashhad and the pilgrims coming there every year.

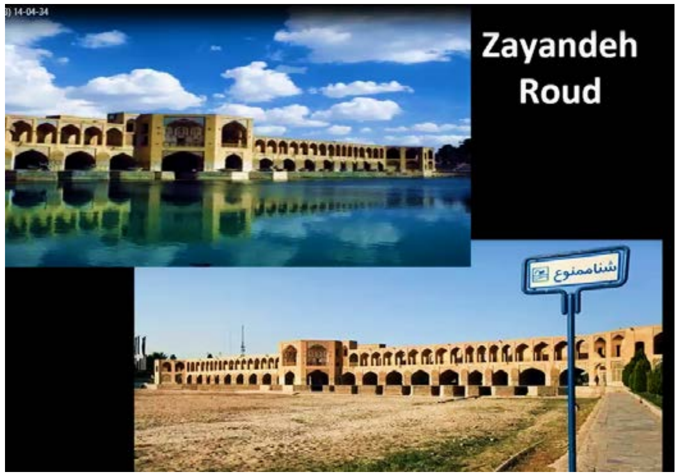


*Figure 6: Zayandeh Roud water crisis.*

In Shiraz, we have, again, a very strenuous situation where the water has been overpumped from the surrounding agricultural areas - a lot of it is becoming saline. In Isfahan, the cultural center of a lot of Iran's history, the Zayandeh Roud River (Fig. 6) [top picture vs. bottom picture - over 20 years has dried up immensely. Pretty serious situation - I think water is the most serious human security challenge facing us here in Iran.

## 5. ENERGY

This image represents the carbon dioxide emissions on the planet (Fig. 7). Essentially, you see the size of the circle representing the volume of carbon dioxide emitted into the atmosphere. China is first, U.S. is second, and so forth.

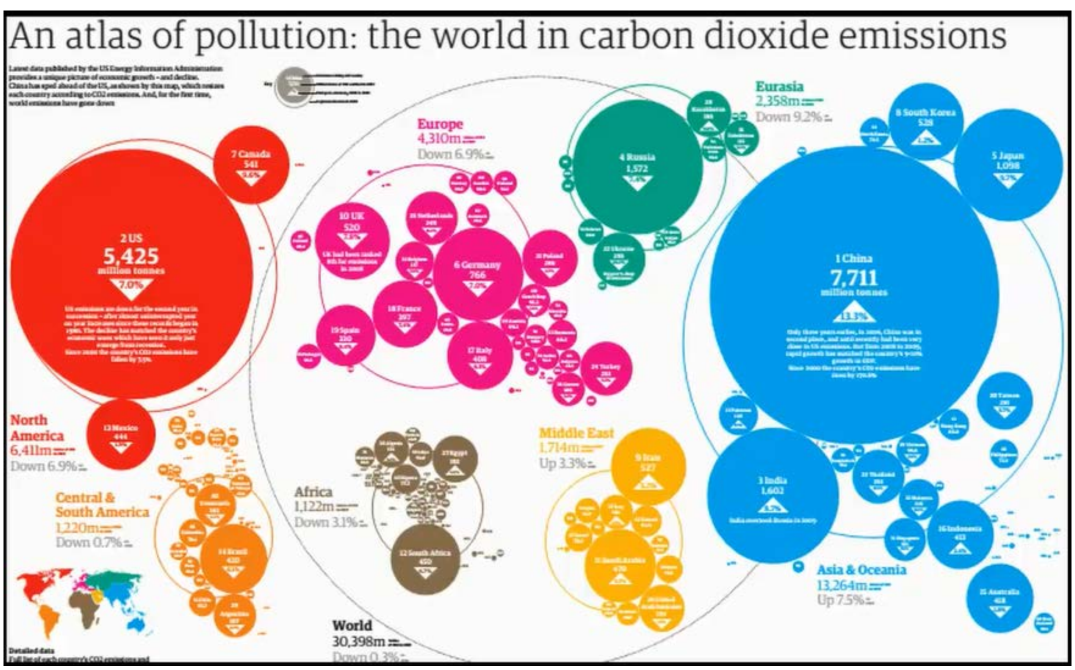


*Figure 7: The world in carbon dioxide emission.*

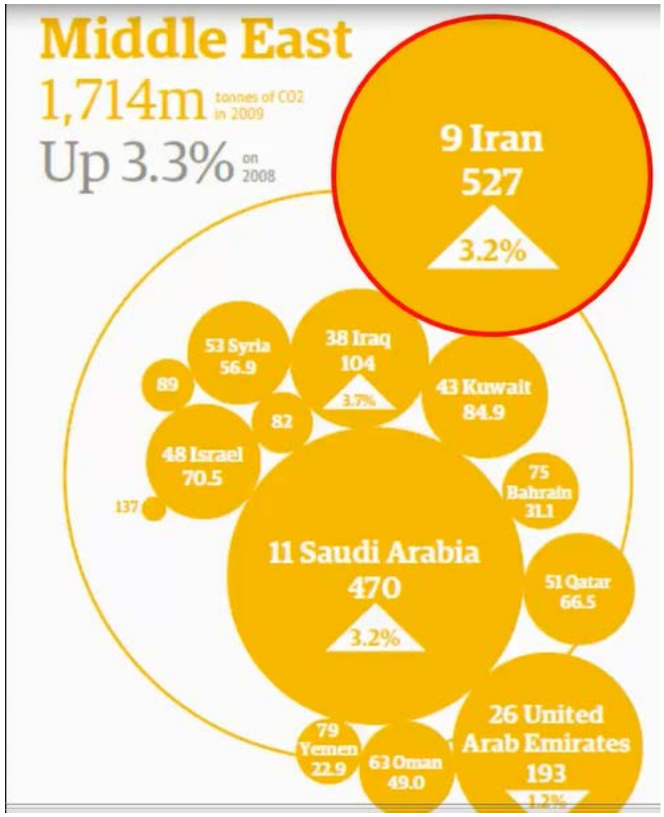


*Figure 8: Carbon dioxide emissions in the Middle East.*

The essential issue if we zoom into the Middle East is the Iran is the 9th largest carbon dioxide emitter on the planet (Fig. 8), with 527 million tons, and increased from the previous year. You compare the other countries in the region and the problem is essentially this: Iran has invested its entire energy infrastructure - or, most of its energy infrastructure - in utilizing ancient sunlight in the form of oil and natural gas that was buried for millennia under the ground, and is not invested in renewable energy: wind, solar, other forms of geotectonic energy sources. The greed of sanctions has prevented them from modernizing so they've got, essentially, an old infrastructure still using fossil fuels, and the proclivity of decision makers to move straight back into that with the resumption of the reduction sanctions is going to be pretty strong. So, what a lot of Iran would need is help from outside in terms of renewing its technical capacity and moving away from fossil fuels.

## 6. Land Degradation

Here are some of the dimensions of the global average of soil erosion: 5x per hectare per year. And in Iran - which is a country that can ill-afford to lose topsoil - we have this particular situation, and the livestock pressure in the country is significantly higher than the rangelands' carrying capacity.

- Global Average Soil Erosion: 5 tonnes/ha
- Average Soil Erosion in Iran: 17 tonnes/ha (3 times more than global average)
- Livestock pressure: 4-7

*Figure 9: Massive run off caused dam to be silted.*

So, a lot of what happens is when it rains, we get massive runoff (Fig. 9). This is also a problem because the dams themselves have become silted up, and are not functioning like they should. This is a major problem in the dam construction and dam operating in the country.

## 7. Air Pollution

We have a significant problem here, and it takes two dimensions. One is the actual pollution in cities like Tehran, Ahvaz, Sanandaj, Kermanshah, and others, where, because of the topography, a lot of the pollution from vehicles and factories and so forth gets caught over the city and people suffer significant help problems from this. We also have sand and dust storms, which we call SDS, which is something quite difficult and prevalent here in the country (Fig. 10).

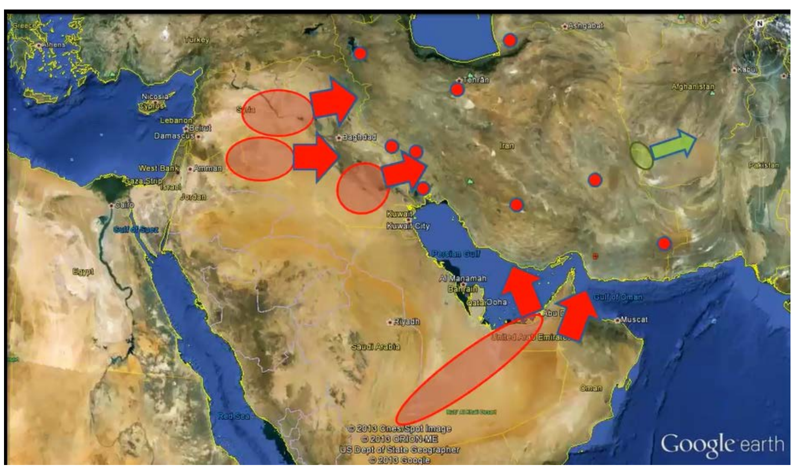


*Figure 10: Key SDS hot spots in the region.*

These, to the extent that we can ascertain, are the sources of where they are. Prevailing winds of course, from west to east, and you can see a number of the hotspots in Syria, Iraq, Jordan, and southern Iraq, and some to a degree also coming from the empty corridor in Saudi Arabia. But most of the winds and dust are coming from the top hours, the hours in the top of the diagram. I'd say probably about three-quarters of the sand and dust storms coming in to Iran are coming from Iraq, and there are solutions at play that can be used that are agriculture techniques: mulching, water management, and other forms of solutions. However, to be able to be applied, people need to be able to be present on the ground there, and because of the situation of Diash, in many of those areas, it is simply not secure for people to go and try to solve the problems. So we have a commingling of a physical security situation and an environmental security situation. Before we move off this slide (Fig. 10), let’s look at the part by Afghanistan and Iran, that green arrow, again, prevailing winds west to east. But you see that, that is just the Hamouns area that we will talk about in a little while, and because of the problem with the drying out of the Hamouns, we have dust storms entering Afghanistan and Pakistan.

*Figure 11: Ahvaz Bridge with and without dust and sand storm.*

This is what it looks like: on a good day, and on a day - increasing days that are like this during the course of the year - and that’s basically what a sand and dust storm looks like, and it’s not good for health, the ecology doesn't do wonders for agriculture; dust is settling on the drops; doesn’t do wonders for computer equipment or other types of equipment (Fig. 11).

## 8. Biodiversity Loss and Protected Areas Management

We have now a situation where as a result of all the above things, and the encroachment of modernization - building, construction, and so forth - biodiversity is under severe pressure.

*Figure 12: An Asiatic Cheetah lies dead along a roadside of Semnan.*

This image of a dead Asiatic cheetah is symbolic of something bad happening (Fig. 12). We tend, in the UN, to focus on saving the cheetah because it's an emblematic species. The only habitat it still has is here in Iran, there's only about a hundred of these animals left. We're doing what we can to protect them, but there are other animals also under pressure and that is something that we are hoping to wake up Iranians and the world to the danger of.

*8.1. Urban Environment*

Just a few slides to give you a sense of how things have changed (Fig. 13).

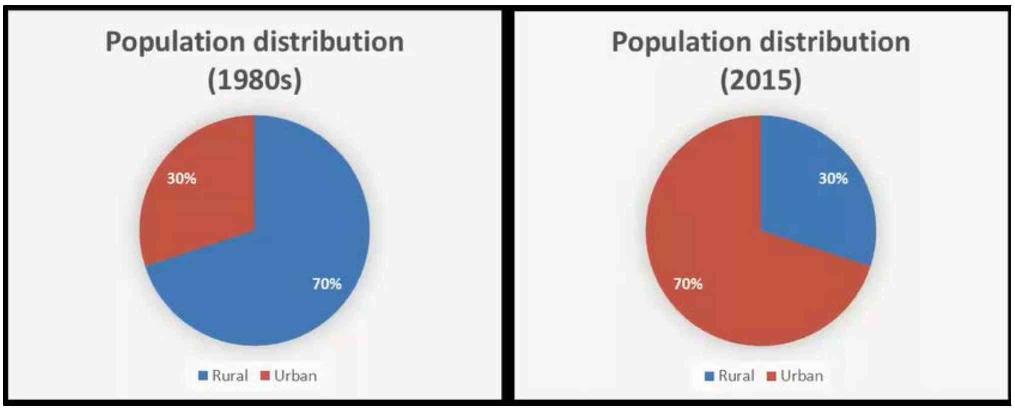


*Figure 13: population distribution in rural and urban environment of Iran.*

In the 1980s, the population distribution, majority rural minority urban, it's flipped around now. And Iran as a country: 70% right now of its population are in the urban areas and that has an impact on a number of things.

This results in:

- More consumers than producers
- Consumer population concentration in limited areas
- Pollution (air, water, waste disposal, etc.)
- More pressure on natural resources

This indicates the kind of pressures we are witnessing and also results of a number of factors that give a dimension of pressure; pressure on the urban space, pressure on human security, so that's what we have.

- Tehran and 7 other cities facing serious air pollution problems.
- Solid waste management challenges:
    - About 7,000 tons waste disposal each day in Tehran
    - Lack of proper waste management in many cities is one of the key environmental challenges
    - Habitat destruction in the landfill sites
    - Pollution:
    - Soil contamination
    - Ground water contamination and surface water pollution
    - Air pollution (mainly methane and other GHS gases)
    - Visual pollution

## 9. IRAN'S WETLANDS

We talked about Lake Urmia and Hamouns, let me focus on the Hamouns for you. This is the essence of the problem: your Helmand River is coming in like this from Afghanistan past the Kajaki Dam, through the area of Kandahan Helman where a number of things grow, including a poppy species, and enters Iran. It feeds the Hamoun Sabouri and from there it feeds other Hamouns and so forth. If there is enough spillover water from the Hamoun and Helmand it goes back into Afghanistan. Iran has also developed a number of reservoirs. The Reservoir System and the water from the Hamoun, after it enters Iran, is diverted to those. The combination of all of this means that we have very little in those three circles (on the map). This is where you will see the consequences of the lack of water as depicted in the images to come.

### *9.1. Hamouns*

This is where we have the Hamouns twenty years ago (Fig. 14).

*Figure 14: Hamouns wetland twenty years ago.*

This is what it looked like - it was an active and vibrant water system which allowed people to survive, gather meats, make handcrafts, water the buffalo, fish extensively, and survive.

*Figure 15: Hamouns – today.*

This is what it's like today (Fig. 15). I took this photograph about two years ago. That was once an entire water course - you can just see a boat there on the extreme left. These are more boats, basically it's all over. If you look at - this is where the depth of the water, where it used to come on the wharf, where boats were riding, and tethered.

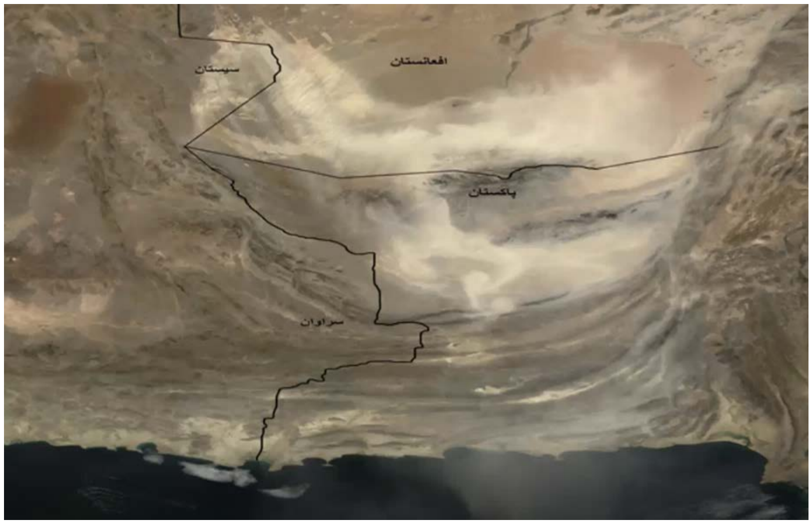


*Figure 16: DSS blowing from the Hamouns into AFG and PAK.*

This is an image from several hundred kilometers up (Fig. 16), of the dust and sandstorms that blow, originating from Iran into Afghanistan. Again you see the swirling dust, and this is what it looks like when you're in it. People's lives have basically been destroyed by a combination of the lack of water and the resulting of particularization of the soil, and this blows around.

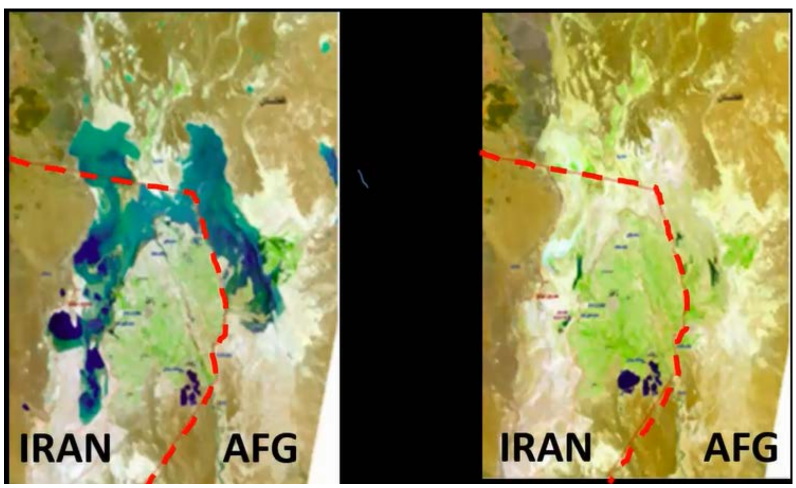


*Figure 17: Hamouns in 2005 (left) and 2013.*

These are images from the air again: 2005 (Fig. 17), so still some water there, and that's it now (2013). It's amazing what human beings can do to an environment when they set their minds to it. Not intentionally, but as an expression of their own interest in securing their own security.

The next slide talks about the consequences, the findings, of a seminar we had in March 2014 here in Tehran, looking at both the Hamouns and the Lake Urmia situation. And Ali was there, he organized the mission of people to those two locations. Both sets came back to Iran on the third day and came up with a number of ideas as to what we could do to address these problems. I'd like to ask Ali to take it from here: tell us a little bit about what we concluded as ways of moving forward.

These slides show a summary of what we concluded after this international conference, focusing on Iranian wetlands, mainly on two Iranian wetlands of international importance, which are Hamouns and Lake Urmia. During this period we have tried to first capture the international best practices and see what experience we can learn from in the other parts of the world. We have come up with a few general points where we can learn more from other countries as well as what we are also experiencing in Iran. As you can see here, one of the main problems when you face a wetland that is being dried out is always blaming climate change and blaming climate extreme situations, like drought. We don't consider that a part of drought is also a consequence of our mismanagement. So we always try to shift our thinking to the drop and natural phenomena, but we also have a big share in the wetland and its drying out. The lessons we have learned from this practice was that we should consider the natural consequences and events like drought and climate change, but we should also recognize that we also have a role in our management - namely our water management - to result in a wetland drying out. Also, in many other countries, we saw the share of water demand in agriculture sector which is using, in Iran, about 90 personal (percent?) water sources and around the country. (can't understand the rest of this sentence) the sector of the GDP into the country, economic wise, is less than 20%, so we can see that 90% scarce water of the country, in Iran, like many other countries, is being used in favor of 20% of the GDP production the country, which is not something a manager would rather to decide when, if any macroplanning or any landuse planning is being done in the country.

<u>International Best Practice</u>

- Don't use "drought" or "climate change" for poor water use management
- Reform agriculture to conserve water
- Don't let water "savings" feed new demand

When you are trying to save wetlands you are always try to focus on water saving, which has big room in many places including Iran, where water efficiency has evolved into 40%, so there is a big area of water saving but unfortunately, in many cases, when you save water, this saved water is not being directed to the wetland. It's being used for additional expansion of the agriculture land, or additional crop production in the same sector which is guilty for the situation. Again, being used by agriculture.

Engaging local communities was one of the international best practices we have learned and we have learned to allocate it and tried in our wetlands project, which is yet in place in many places in Iran. So, there is no cost-free solution. Many times, most of the scientists sitting around the table are engineers and environmentalists. What we should also look into is engineering high-cost solutions, at the same time there are very cheap and maybe low-cost or no cost solutions where we can focus on them, rather than going for infrastructural solutions, where we will still need some money but not so much as engineering or harder solutions. So, by the way there is some cost and some pain to recover this, and we should tolerate it.

Restoration needs piloting first, then upscaling, which is what we are experiencing on Lake Urmia where we have piloted some agriculture initiative called the sustainable agriculture saving the water, 40% water, while keeping the crops the same, even increasing it, and increasing the income of the farmers without any threat to their livelihood. Then, if we want to go to the key recommendations we have gained from this workshop: what we can see here for Hamouns, we will have to focus on some short-terms activities while we should also have some medium-term or long-term solutions as well, maybe the short-term solutions, which we are trying to implement, at least at the pilot in the area we are mainly trying to focus on the adaptation solutions and trying to recover the local community and their income, economy, and social elements at the same time in the longer term we should focus on the way we are managing our water sources and all we are going to need with a neighboring country is more water to come to Iran.

Hamouns
Urgent Actions:

A3: Share water in a way that will maintain essential ecosystem service
A4: Reduce evaporative losses from Chanimeh

Of course these are the selected solutions - there were long sets of long-term, mid-term, and short-term solutions and we have collected a few numbers to save more time.

Hamouns
Medium Term:

A6: Improve trans-boundary cooperation
A7: Adopt an integrated wetland basin management approach

*9.2. Lake Urmia*

We will focus now on Lake Urmia.

*Figure 18: Lake Urmia in 1998 (left) and 2014 (black parts are water).*

This is what it looked like from the air in 1998 and this is what it looks like pretty much now (Fig. 18). And in fact much of that is also gone. The black part is essentially the water and you can see the extent of the damage. We've lost well over 90% of the water from that, and essentially it's because in the surrounding areas that water that used to feed the lake from surrounding mountains has been diverted for agriculture. If you look at the green to the west, you can see significantly larger amount of green - that represents agriculture - than in 1998, and that's where the water has gone, basically.

*Figure 19: Lake Urmia 20 years ago vs. Lake Urmia today.*

This is what it looks like now (Fig. 19). I was there on two occasions in the past couple years and it is absolutely staggering. What you taste in your mouth as you walk around, when the wind is up, is salt air blasting around in your face, everywhere, including on the actual surrounding agricultural land which basically salinates the crops from above. Also, the overpumping of the aquifer means that the salt underneath the body of the lake seeps into the surrounding land around the lake and is then sucked out as saline water and put onto the agricultural land. So the whole thing is just wrong, and it's getting worse and worse. This is how the situation looks right now. They're actually dredging salt and using it for industrial and commercial purposes.

<u>For Lake Urmia</u>
Urgent Actions

B5. Mobilize a public campaign to conserve water
B4. Reduce agricultural water use
B7. Implement health protection measures

There are some solutions that we have proposed with the inputs of counterparts for Lake Urmia. For Lake Urmia there are several suggestions, some of which we are implementing already, and we are also advising governments that are focusing on some of these solutions. The first thing we have recognized and learned from is other experiences, around the world as well as our own experience here in Iran. Solution mobilization and public participation is one of the main elements where we can urgently address a problem. People's residence of the basin are using this water, they are farmers working, there are industries, and they are drinking this water. If they save water, it will happen in a night, but it's not so easy that they can advocate everyone to use less water. If everybody used 10 liters less water, the result would be something like Iran saving more than 50 million liters of water in a night, with more flowing in the basin going to the lake. So also it's an urgent thing, but the result won't happen in a night, as I mentioned - it takes time but we have started several campaigns, first of all, in the region. At the same time we have tried to set some platforms for public participation, because when you make people available for other problems it's not enough for the participation. At the same time we should also establish a platform for them to take part in the restoration of the lake, and we have also tried to focus on the main water consumers in the basin, and this is agriculture. As I mentioned before, we have tried some sustainable agriculture practices using 11 different techniques together combined in different farmlands, and we have been able to showcase and then upscale an average record of 35% water saving in the farmland, while the crop yield is the same and the income generation of the farmland is even more, because they are doing less irrigation, they are using less workers, and they are spending less money on their farming while receiving the same crop, if not more.

Medium Term

B9. Prepare a long-term development vision for the basin
B12. Optimize the water allocation system

We will focus on preparing the long-term development vision of the basin, which is very important: the land-use planning, the way we are going to invest on water resources, this sector is going to use more water that generates more money and more livelihoods and more jobs in the basin. That's what the decision makers in the basin level should be decide, because there are two provinces competing with each other in the basin to receive more water, and that's one of the other problems for Lake Urmia.

*9.3. For All Iranian Wetlands*

General recommendations for all Iranian wetlands is to develop a public awareness or national awareness campaign for wetlands and water saving.

Urgent

C1. Implement a national awareness campaign and program to conserve water
C3. Build capacity for ecosystem-based management of wetlands

Medium Term

C4. Introduce water pricing
C5. Review and adjust land and water use planning and strategies

*9.4. On-the-Ground work of the United Nations*

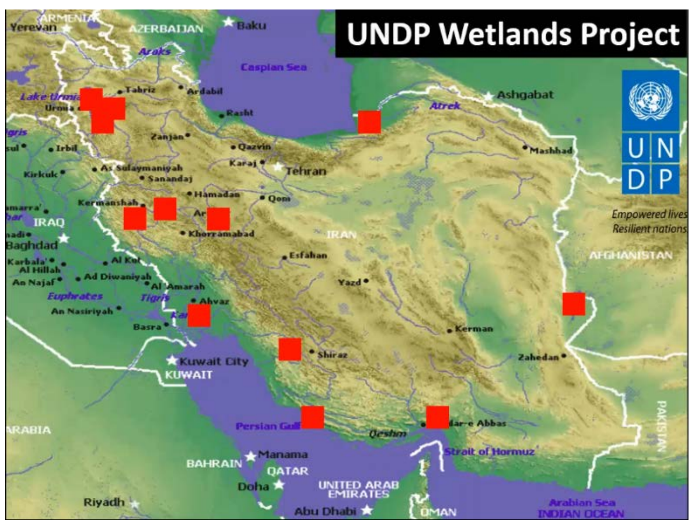


*Figure 20: UNDP Wetlands Project.*

This indicates the kind of work - the locations of the work that we are undertaking in the environment (Fig. 20). We have started out work on the wetlands project more than ten years ago, and the dots you are seeing on the screen are the upscaling phase of the wetlands projects. The first phase was successfully done. What we have been trying was the capacity building and manager planning, which are in place now. The lessons learned and the water we have generated out of that experience has been captured and is being upscaled in additional wetlands around the country.

There are some good practices that we have developed and with the support of the government we are getting to address a number of issues in the country, in wetlands. So, the knowledge is here, there's things that we can do, and what we're looking for is partnerships with the international community. In this particularly important time whereis transition in which the international community is trying to engage with Iran, this affords us some opportunities for technical cooperation.

### 10. Lake Urmia: Solutions

This outlines where we are operating in Lake Urmia and the ways we save water in this location, and let it save and divert the water back into the lake and thereby increasing it.

<u>How You Can Help</u>

1. A "new narrative" about Iran
2. Learn more about the catastrophe in the Hamoun Wetlands
3. GEF funding - for Round 6
4. Technical cooperation and partnerships - including through the UN and UNDP

Please consider the way in which we develop or impressions of engaging with Iran. there is a lot of history that is now hopefully receding, with the passage of time. We see a number of new initiative happening: the nuclear deal last year, and recently developed here on the ground, they give us a great sense of optimism. And for that new engagement to work, we also need to develop a new narrative. We hope that your voices, through your increased knowledge and understanding of what's happening on the ground can be added to a chorus of positive energy about how we can cooperate for the future

I'd also suggest that the Hamoun wetlands is a devastating situation. UN, UNDP is going to put a lot of attention on it in the coming weeks and months and try to find - with the government and with participants and communities on the ground - find solutions. Including engaging the Afghans, because that is where the water is coming from, and that's a big part of the problem. But learn more about that - most people have never heard of the Hamouns, and it's actually one of the biggest human security challenges we face in South or West Asia.

Global Environment Facility funding for a number of initiatives for Round 6 has been made difficult to access, and that is for political reasons, and that is something that we hope will also stop from being the case in the near future. Iran has been granted star allocation access to about 17 million dollars, and projects have been written up and reviewed for that money, and these projects can help. The environment is a neutral issue and it is something that we believe should not be held hostage to larger concerns. So we're hoping that the narrative will become unblocked and the access to this funding will arrive so that work can get going on the ground.

And finally, technical cooperation and partnerships including through the UN and UNDP - think about ways in which you might want to engage with us. There is a lot to be done and we will be happy to partner with those in the outside world, outside of Iran, who have things that they believe they can offer. There is endless amount of knowledge that has been acquired elsewhere, dealing with the same sorts of problems we face here. I know that many Iranians would love to embrace that knowledge, partnership, and collaboration in these new and heavy days.

**U.S.-Iran Symposium on Wetlands**

March 28-30, 2016

Irvine, California

# Integrated Use of Stormwater, Recycled Water, and Agricultural Processing Water to Replenish Urban Aquifers in California

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## *Abstract*

Due to growing population and climate change pressures in California, municipalities are seeking to diversify their potable water portfolios with aquifer recharge systems. Managed aquifer recharge (MAR) systems either inject water underground or percolate water through spreading grounds. However, further research on the cost-effectiveness, design feasibility, and water quality concerns of these systems need to be investigated. To gain insight into the transition to more resilient urban water supplies, it is instructive to consider three specific urban aquifer recharge water supplies–stormwater, recycled water, and agricultural processing water–and their potential to augment future supplies. Integrated use of these three water sources will help make California's water supply more resilient to future challenges and uncertainties due to climate change, population growth, and competition among water sectors. This will enable less reliability on imported water, improved water quality, adaptation to climate change, and flood mitigation.

***Keywords: Stormwater, Water Reuse, California, Managed Aquifer Recharge***

## 1. STORMWATER FOR WATER SUPPLY

As described in the recent National Research Council's report on beneficial use of stormwater for enhancing local water supplies [1], many parts of the United States face chronic or episodic water shortages and are looking at stormwater anew as a water supply resource. For example, in California, multi-year droughts resulted in reservoirs at record low levels in 2015, forcing statewide mandatory water conservation efforts. At the same time, urban stormwater is increasingly viewed as a resource to supplement scarce water supplies rather than as something to be collected and discharged as rapidly as possible. Harvesting stormwater has many potential benefits including water conservation, energy savings and reducing the impact of urban development on water quality and ecosystems. Unlike inland areas, coastal cities in California may harvest urban stormwater without undo concern over water rights because the stormwater is flowing to the ocean rather than to a lake or river. When done properly, beneficial use of stormwater is popular with the public, city planners and architects by embracing the concept of low impact development and green infrastructure [1].

## 2. STORMWATER AND LOS ANGELES' WATER SUPPLY

Currently, Los Angeles receives about 50% of its water as imports from Northern California and the Colorado River. But future water supplies from distant sources are becoming less reliable owing to competing demands, judicial decisions and climate change impacts. The stormwater capture master plan for Los Angeles is illustrative of how stormwater can contribute to the city's water supply and reduce dependence on imported water [2]. The concept is to expand the current stormwater capture system and use that to replenish local water supply aquifers.

In Los Angeles, managed aquifer recharge with stormwater has been practiced for nearly a century since the first spreading basins were installed in the 1910s. This was expanded in 1938 to the Central Basin portion of Los Angeles when the Rio Hondo and San Gabriel Coastal Spreading Grounds were opened by the Los Angeles County Flood Control District [3]. The existing spreading basins in Los Angeles are located downstream of dams and areas that capture hillside runoff from the San Gabriel Mountains. Today, urban stormwater from built-up areas in the San Fernando Valley and the Los Angeles Coastal Plain is viewed as an underutilized, locally-controlled water resource. Capturing and using stormwater can offset the need for imported water. But, as more facilities are constructed to capture and use runoff, there are concerns about contaminants in runoff from highly urbanized areas.

To address these concerns, the concept of "stormwater capture, treatment and recharge" envisions neighborhood or larger facilities that would hold urban runoff and process the water through natural systems, e.g., wetlands, and engineered features, e.g., filters, prior to groundwater recharge. These designs can incorporate treatment features to remove metals, pathogens, nutrients and trace organic contaminants as well as achieve related benefits, including community acceptance, aesthetics, and creation of habitat. This is an area of ongoing research.

The ability of stormwater to augment water supply depends on the size and number of systems installed, including both centralized and distributed projects. Centralized projects have the ability to capture more water but are limited in terms of siting. Distributed systems have less potential to replenish deeper groundwater aquifers but can be implemented in more areas throughout a city. The differences between centralized and decentralized systems are important to understand in the context of optimized water reuse and overall costs. Depending on assumptions about sustained political, financial and social prioritization, stormwater capture for Los Angeles could expand nearly four-fold from today's baseline [2]. Optimistically, this could provide 25% or more of the city's water supply by the end of the 21st Century.

## 3. LINKING STORMWATER RECHARGE AND WATER REUSE

Groundwater is considered a "drought-proof" supply unaffected by short-term droughts, but its reliability is at risk in many places due to overdraft, reduced natural recharge due to urbanization, and changing precipitation patterns due to climate change. As described above, the City of Los Angeles plans to simultaneously reverse chronic groundwater overdraft and halve its current dependence on uncertain imported water supplies [4].

With cities increasingly interested in enhancing groundwater recharge, one strategy is to augment managed aquifer recharge with additional water supplies. Los Angeles' countywide spreading basin network currently recharges groundwater primarily using hillside runoff and imported water. However, the spreading basins are underused because of LA's Mediterranean climate in which rain occurs primarily in the winter and the decreasing availability of imported water. Historically the spreading basins have performed at only 12% of their annual recharge capacity [5,6]. Since Los Angeles is eager to reduce their imported water [4], the city would benefit by expanding MAR systems to supply more of their current water needs.

To reverse overdraft and increase water security, Los Angeles and other cities like Fresno, CA, have initiatives to recharge groundwater with stormwater and recycled water (Fig. 1). In these systems, both stormwater and recycled water would be directed to spreading basins. However, the lack of design and operational guidance for such systems remains an impediment to implementation and adoption in these cities and elsewhere, limiting the extent of Los Angeles' and Fresno's plans [7-9]. The situation in Fresno is complicated further because, unlike Los Angeles, groundwater rights in Fresno have not been adjudicated, and Fresno consequently must comply with new sustainable groundwater management regulations.

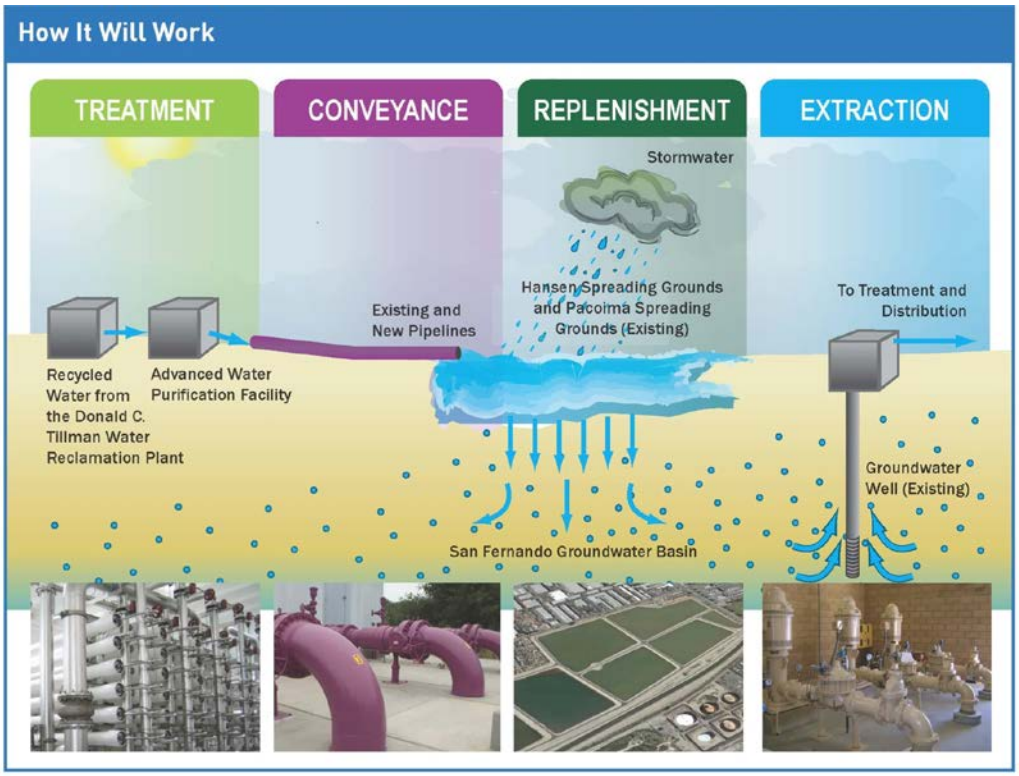


*Figure 1: Diagram illustrating the MAR and recovery process using recycled water and stormwater, specifically the planned application in the City of Los Angeles. Source: Los Angeles Department of Water and Power 2014.*

Planning groundwater recharge systems beyond a limited scale requires advanced modeling to incorporate many variables in planning and engineering design. For example, there are questions about how to connect facilities in the most cost-effective way. Our preliminary research shows how it is not obvious what type of connection design could recharge the most groundwater at the lowest cost. Modeling is needed to describe and optimize the costs and benefits of small-scale recharge systems with recycled water and stormwater. This is useful for gaining insights at the sub-regional scale, such as the most cost-effective way to operate a single water recycling facility that connects to one or two spreading basins. But models are needed also to optimize more complex, larger-scale systems, such as the regional-scale networks currently being discussed in Southern California. For example, in September 2015 the Metropolitan Water District of Southern California (MWD) – the regional wholesaler of imported water – proposed a large centralized system, in which a single facility would be constructed to produce recycled water for use throughout the region (Fig. 2). A more cost-effective system would likely take advantage of more decentralized designs, in which smaller, satellite recycled water facilities are used to produce and distribute water, thereby reducing distribution costs. However, the absence of appropriate modeling tools hampers planners' understanding of which decentralized designs would be the most cost-effective in real-world contexts.

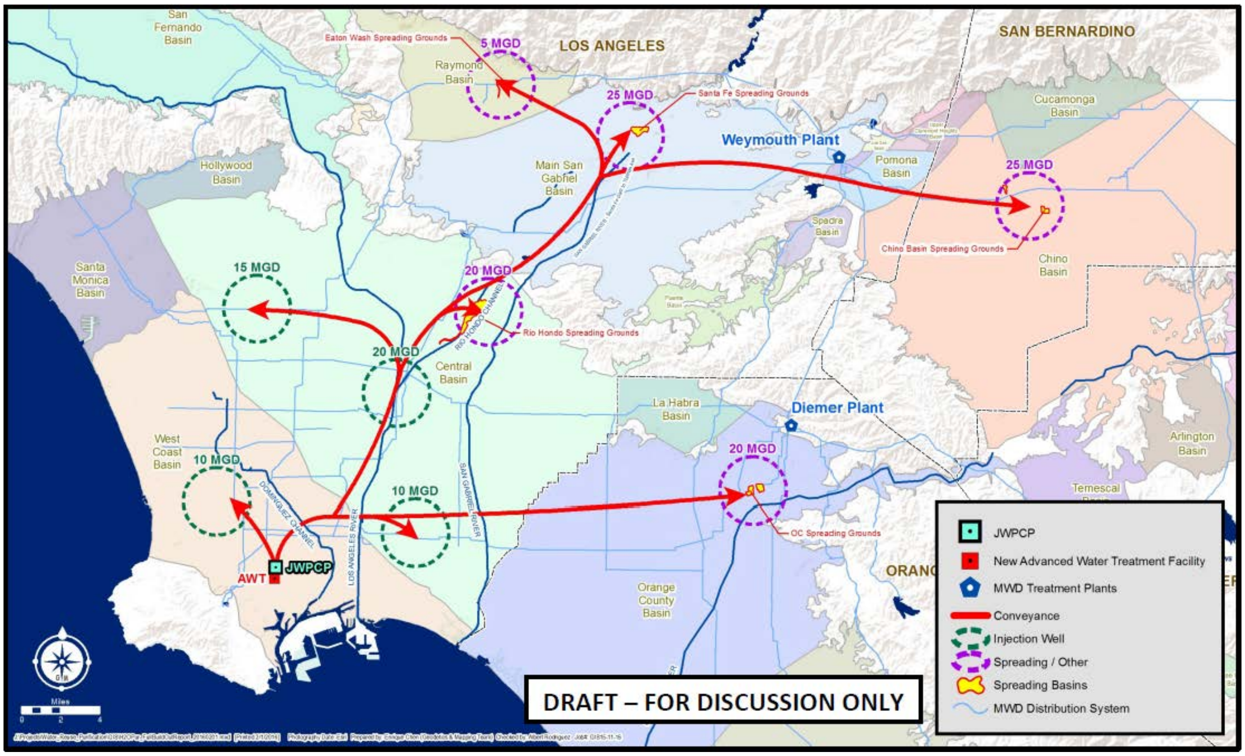


*Figure 2: Map of a centralized recycled water system proposed by the Metropolitan Water District of Southern California [10].*

In addition to the technological questions, these systems also raise questions about water rights and the implications of sustainable groundwater management regulations. Groundwater basins in chronic overdraft – such as Fresno's – will have to bring their groundwater use in balance with renewable supply. The only real option for accomplishing this is some combination of reducing pumping, finding alternative sources of water, and increasing aquifer recharge. Supplies of surface water are already strained by increased scarcity. Consequently, managed aquifer recharge with combined stormwater and recycled water potentially represents one of the most viable ways for cities to comply with sustainable groundwater management regulations by increasing recharge. But increasing use of stormwater and recycled water may draw legal challenges from downstream water users who may be affected by this practice. In addition, there remain questions about assigning and protecting groundwater rights in MAR systems.

## 4. Efficiency at the Agriculture-Urban Interface

For California, its numerous food-processing facilities are frequently located in periurban areas where unique synergies are possible. The city of Salinas (population: 156,000) in the county of Monterey, California is known as the "salad bowl of the US" for the volume of lettuce it grows. The agricultural industry in Monterey County accounts for $4 billion/year and consumes over 90% of the total water demand in the region [11]. When drought conditions decrease this percentage, the agricultural industry relies on groundwater pumping, which lowers groundwater levels and increases energy consumption. To protect future groundwater levels and provide adequate amounts of water for the agricultural sector, Salinas can integrate agricultural processing water into their water reuse system. With ideal growing conditions and water insecurity from the current multi-year California drought, there exists an opportunity to address optimization of water management at the interface between the agricultural and urban water sectors.

Salinas and the Monterey Peninsula receive a majority of their water from the Carmel River and the Seaside Groundwater Basin [12]. However, the amounts of water from these sources are scheduled to be reduced by half by 2017 due to environmental and agricultural demands. In Monterey County, water extractions exceed recharge by 40,000-50,000 acre feet per year in places where seawater intrusion is likely to contaminate water utilized by the urban and agricultural sectors. Although the water use by the residents in Monterey are among the lowest in the state, future water reliability in the face of climate change and population growth will limit its resilience. The ordered cutbacks to the existing water supplies themselves cannot be met without a replacement source of water.

One way to introduce a replacement source of water is agricultural reuse. Innovative methods of agricultural reuse can be identified throughout the food processing system [13]. One source of agricultural reuse water is from the washing of produce, which is a critical part of the preparation process since most produce in the region is sold as "ready to eat" [14]. Agricultural washwater in the area, which accounts for 3-5 million gallons per day (MGD), is sent to the Salinas Industrial Wastewater Treatment Facility and eventually released into the ocean. Currently, the regional wastewater agency has the capability of treating 29.6 MGD, however, only half of that capacity is utilized. Since the capability of treating more wastewater is present in the area, the reuse of washwater can be highly beneficial to restoring groundwater levels in Salinas.

As seen in Fig. 3, Salinas agricultural wash water, in addition to stormwater and wastewater in Monterey County, can be taken to the regional treatment plant (RTP) and to an advanced water recycling facility after which the water can be used to replenish groundwater in the Seaside Basin. The regional treatment plant water and replenished groundwater could then be used to benefit both agricultural and urban use.

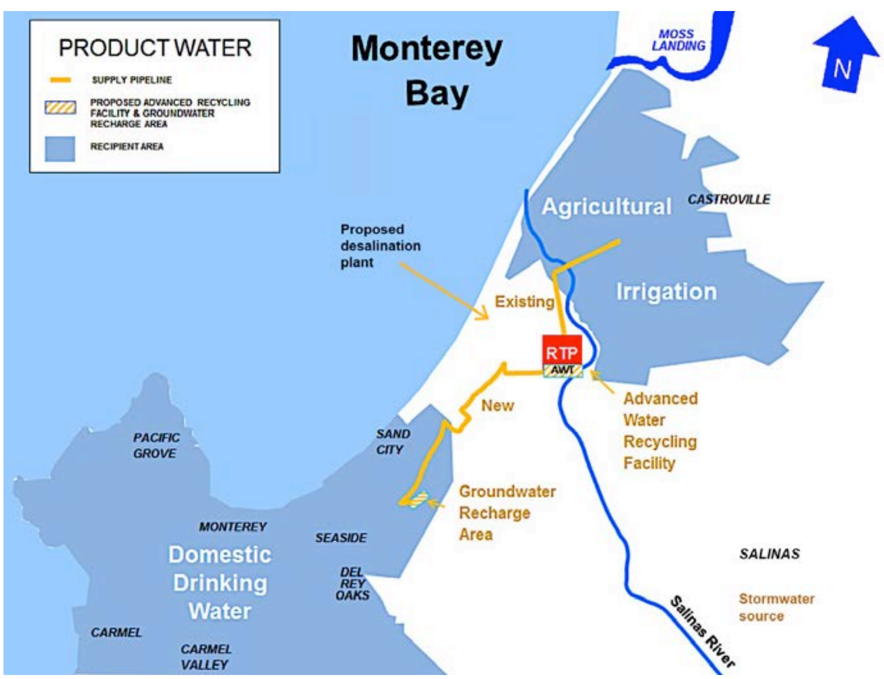


*Figure 3: Map of project facilities overview in Monterey County, CA, that illustrates efficiencies by combined stormwater, wastewater and agricultural washwater management [11]*

As one of the most productive farmland locations in the US, it is imperative to provide enough water for the continued viability of these agricultural systems, as well as ensure urban populations are not threatened by water scarcity. Stakeholders must work to improve water management at the urban-agricultural interface in a time where population and agricultural growth are competing for limited water supplies. Combined stormwater, wastewater and agricultural washwater management will help ensure greater efficiency for both water and energy use and help sustain urban and agricultural systems.

## 5. CONCLUSION

California faces a mounting crisis of increasing water scarcity driven by recurring drought, climate change, population growth and ecosystem demands. To address this crisis, more sustainable urban water use, reuse and management solutions are needed. Sustainable water goals require a new vision that decreases reliance on imported water. Beneficial use of urban stormwater and agricultural washwater are one such strategy. Properly designed "capture, treat and recharge" systems can remove contaminants while providing other amenities for improving the urban environment. Implementing these approaches requires demonstration projects to accelerate innovation along with decision-making tools to assess system-level solutions.

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# Plant Diversity of Saline Wetlands and Salt Marshes of Iran

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## *Abstract*

As the great Middle Eastern biogeographist Michael Zohary stated "Iran is the country of great salines and kavirs." Most of the Iranian wetlands located in the lowermost watersheds are brackish or salty. This is because of transport of salt by running water passing through salty formations and accumulation of salt at soil surfaces by capillary effect in arid environments. The impacts of irrigation and drainage for agricultural activities, diffusion of salt from salty rivers and marine marshes are additional contributing factors supporting saline habitats in Iran. Iran is a very diverse country with regards to growing large number of halophytes and salt tolerant plants. So far 528 species, 230 genera, and 56 families of halophytic and salt tolerant plants have been known from Iran. These species show a large diversity in morpho-functional types. The main traits evolved in these species include succulent assimilating organs to reduce toxicity of salt in photosynthetic tissues. In a salinity gradient under high temperature, usually a large number of $C_4$ plants occur. The diversity of $C_4$ plants in Iran fascinate the biologists in which a very unique system is discovered in the genus *Bienertia* by functioning $C_4$ photosynthesis in a single cell. *Salicornia* is another diversified genus in Iran in which at least six species are growing. *Tamarix* species are shrubby species growing along most river and wetland margins with c. 30 species and many hybrids increasing the growing capacity of these species under riparian habitats and saline biotopes. The Iranian saline wetlands are under severe human and climate change impacts. The water shortage mostly caused by dam construction has resulted in drying of many such ecosystems such as Urmia and Bakhtegan Lakes. The desiccation of saline wetlands is a disaster not only for the unique biodiversity of the Old World, but also for the loss of their ecological role. Conversion of such habitats is a main source of saline dusts in the country.

***Keywords: Saline soils, Halophytes, C4-Plants, Chenopodiaceae, Poaceae, Biodiversity, Desertification***

## 1. INTRODUCTION

Iran is a country of great salty playas and saline ecosystems [1]. Large parts of the country suffer from extra salinity where most conventional crops cannot be grown [2]. The salinity in Iran is caused by a number of natural and anthropogenic factors including presence of saline geological formations, running of rivers and transporting salts from higher altitudes to the interior basins, irrigation activities, transport of salt by wind, evaporation leading to salt accumulation on the upper soil layers and diffusion of salt from marsh areas along the northern (Caspian Sea) and southern shores (Persian Gulf and Gulf of Oman) [3]. Saline wetlands and saline rivers are among the unique ecosystems in Iran characterized by rich and dense vegetation [4].

Investigations on the diversity of halophytes in Iran date back to some records of salt tolerant plants in classical references such as Zohary [1] and individual contributions on the desert habitats of Iran [5-8]. The identification of halophytes was always a challenge among botanists. This mainly is because of difficulty in identification of most diversified spinach family by lack of taxonomic characters which mostly disappear by conventional methods of drying plants. The different phenology is an additional reason that such plants have not been much collected by botanists. A first synopsis of Iranian salt tolerant plants in 1993 introduced 10 main vegetation units and 165 species of halophytes [9]. Subsequent studies increased the number of halophytes and salt tolerant plant species of Iran to 365 [4].

The flora of saline wetlands has been threatened in the last two decades by water shortage and desiccation of many of them. In this paper an overview on the diversity of flora and vegetation of saline wetlands and salt marshes of Iran is provided by special attention on the diversity of particular groups, highly important taxa and threats to these habitats.

This paper is a summary of a larger review under preparation.

## 2. Geography and Salinity

Salty ecosystems are expanding in most parts of Iran, except in the forested zone of the northern slopes of the Alborz and high mountains (Fig. 1). Large salty habitats can be found in the central Iranian great deserts, the “Dashte Kavir” and the “Kavire Lut”; in the salt flat and salt marshes around Urmia Lake in north-west Iran; in areas along the southeast of the Caspian Sea; in the Khuzestan plain in south-west Iran; and in large parts of the coastal and near-coastal areas along the Persian Gulf and Gulf of Oman. According to Krinsley [10], there are over 60 sabkhas (playas) in the interior of Iran. Most of these playas are either permanent or temporary wetlands such as Heuze Soltan Lake, Arak, Salt Lake, Tashk and Bakhtegan Lakes, and Maharloo Lake.

Urmia Lake and the saline plains in Turkmansahra (Golestan Province) are outside of the interior basin with large areas of saline and brackish habitats. The salty rivers in Iran are other major salty habitats that support diverse halophytic vegetation with their intermittent or permanent water supply. The halophytic habitats in Iran are located at low and medium altitudes. Large parts of the interior inland saline ecosystems have altitudes between 600 and 1,000 m above sea level. There are some saline areas with higher altitudes, such as the Urmia Lake shore (1,313 m); the Kavire Meyghan (1,680 m); the salty river 26 km south of Delijan (1,820 m); and the Shurtangeh located 65 km north-west of Damghan (1,830 m). The highest known saline area in Iran is in the salt meadow and adjoining salty gypsum hills 80 km south-west of Kashan in the Zagros Mountain at an altitude of 2,200 m.

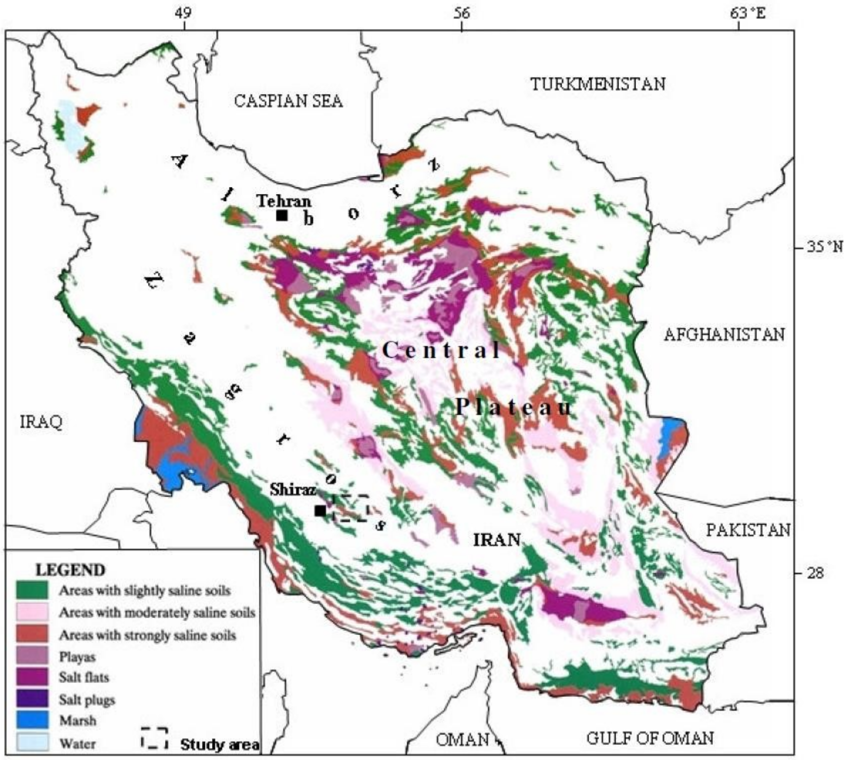


*Figure 1: Distribution map of saline soils in Iran [11].*

## 3. VEGETATION ALONG SALINITY GRADIENT

The vegetation pattern of Iranian saline wetlands and marshes strongly corresponds with the salinity and moisture. Other factors such as habitats on the inland or littoral saline habitat, soil texture, phytogeographical area and temperature play additional roles in site. Along a salinity and moisture gradient [12], the following zones can be distinguished: (1) Mangrove communities (*AvicennioßSonneratietea*); (2) Submerged aquatic plant communities (*Ruppietea maritimae*); (3) Annual obligatory hygro-halophytic communities on sea, lake and river marshes dominated by stem or leaf succulent $C_3$ chenopods (*Thero-Salicornietea*); (4) Semi-woody or perennial halophytic communities on muddy or coastal salt flats dominated by stem succulent $C_3$ chenopods (Salicornietea fruticosae); (5) Hydrophilous euryhalophytic rush communities: *Phragmitetea australis*; (6) Halophytic grassland and herbaceous perennial sedge communities belonging to genera *Puccinellia* and *Juncus* (*Juncetea maritimi*); (7) Salt marsh and riverine bruchwood communities dominated by salt-excreting halophytes (*Tamaricetea arceuthoidis*); (8) annual halophytic communities dominated by $C_4$ chenopods in temporary moist and inundated, or disturbed salty soils (*Climacopteretea crassae*); (9) Halophytic shrubby, semi-woody or hemicrytophytic communities on salty and dry soils dominated by leaf or stem succulent $C_4$ chenopods (*Haloxylo-Kavirietea tomentosae*); (10) Halophytic shrub communities on salty and sandy coastal or margin of sabkhas with high water table dominated by *Nitraria schoberi* and *Reaumuria fruticose*; (11) Psamo-halophytic shrub communities along sandy coasts of Persian Gulf and Gulf of Oman (*Sphaerocomion aucheri* and communities of *Zygophylluum qatarense* and *Heliotropium bacciferum*; (12) *Annual* Psammohalophytic communities on NW parts of the Persian Gulf coastal vegetation (*Saginetea maritimae = Frankenietea pulverulentae*); (13) annual semi-halophytic communities on inundated plains in SW Iran (IsoetoNanojuncetea) and (14) herbaceous perennial and hemicryptophyte halophytic communities of secondary origin. The distribution of most of these units along salinity and moisture gradients is presented as an ecogram in Fig. 2. In local base the general pattern of vegetation starts from highly halophytic $C_3$ annual succulent chenopods (*Salicornia*), followed by perennial stem succulent C3 chenopod (*Halocnemum*), a transitional zone colonized by many C4 species, and finally ending with C3-dominated xerophytes co-occurring with some $C_4$ species (Fig. 3) [13].

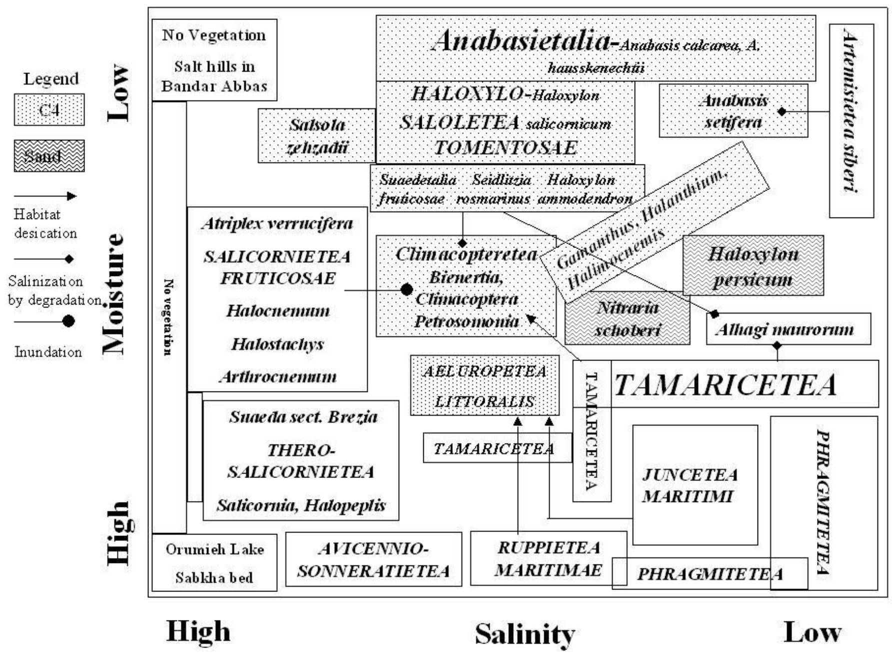

*Figure 2: Ecogram showing the distribution of major plant communities of Iranian saline ecosystems along salinity and moisture gradients [12].*

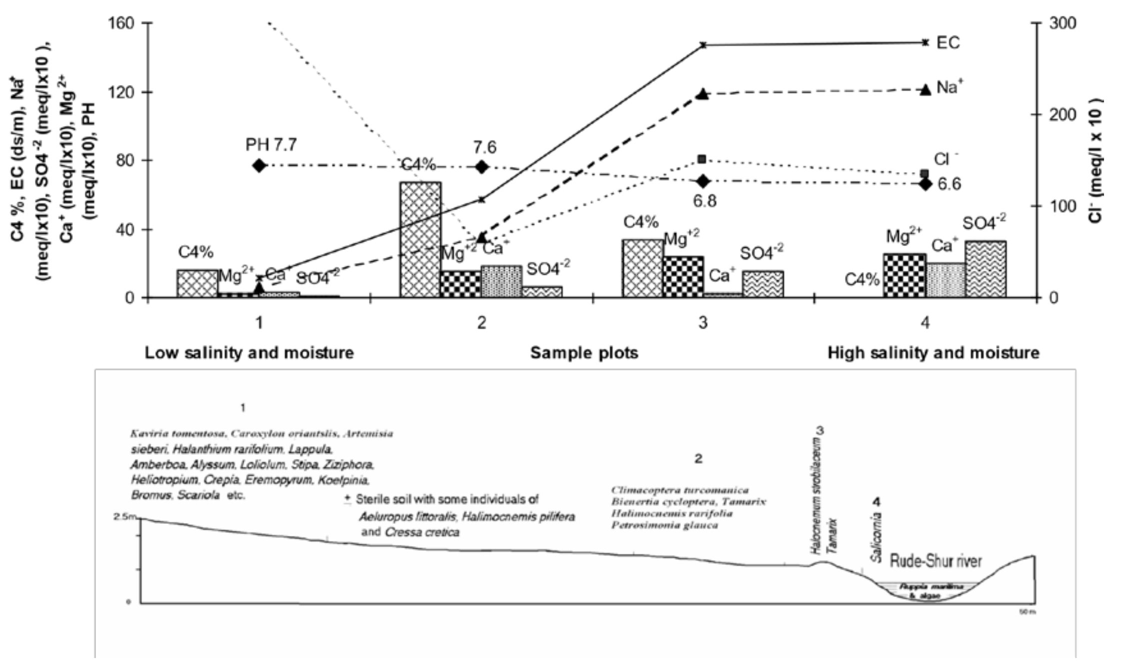

*Figure 3: A vegetation transect along Rude Shur (salty river) located in Mardabad, 60 km W Tehran [13].*

## 4. DIVERSITY OF MAJOR GROUPS

In total, 521 species belonging to 54 families of vascular plants have been known from Iran which inhabit salty habitats (unpublished data). The largest families include *Chenopodiaceae* with 151 species, *Poaceae* with 52, *Asteraceae* with 47, *Fabaceae* with 28, *Brassicaceae* with 26, *Tamariacaceae* with 22, Boraginaceae with 16, and Cyperaceae and Plumbaginaceae each with 14 species, respectively. Genera with higher diversity are *Tamarix* with 18, *Suaeda* with 18, *Caroxylon* with 16, Atriplex with 14, *Limonium* with 11, and *Juncus* with 10 species.

### *4.1. Notes on Highly Interesting Halophytes*

The Iranian salt marsh and halophyte species are very important in keeping the harsh conditions green and serve as important sources for a variety of ecological and economical applications. Among many cases three examples are highlighted here:

- *Bienertia*: This chenopod genus is a hygrohalophytic species. So far three species of this formerly supposed monotypic genus are known, with main range in Iran and surrounding countries (Fig. 4). *Bienertia* are characterized by the unique system functioning $C_4$ photosynthesis in a single-cell [13-17]. The discovery of this unique system has applicability in understanding $C_4$ photosynthesis biology in order to adapt $C_3$ crop plants into $C_4$ efficient photosynthetic systems under hot and drought conditions using genetic engineering.

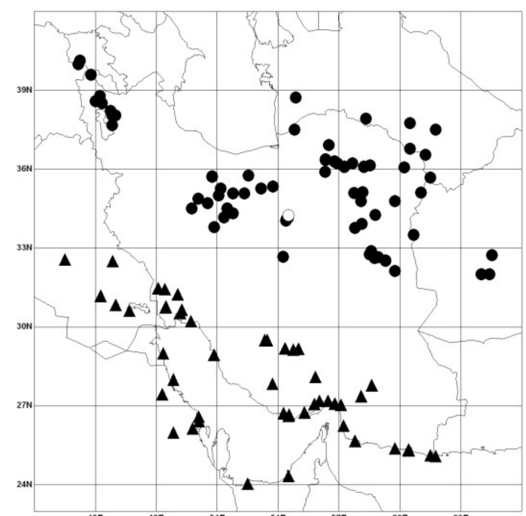


*Figure 4: Distribution map of known species of Bienertia: B. cycloptera (Filled dot), B. kavirense (empty dot) and B. sinuspersici (triangle) [15].*

- *Tamarix*: With ca. 30 known species and many hybrids, this is the most diversified phanerophytic genus in Iran. The presence of many villages and cities named after the name of this plant "Gaz" indicate the importance of magic shrubs and trees living in Iranian deserts. This has long been used by local people in desert environments as a source of timber and forestation. This riparian genus with species capable to tolerate high salinity under extreme hot climate play a major role in carbon sequestration in a steady degrading environment and extremely susceptible to global warming in the Middle East [18, 19].
- *Salicornia*: The highly salt tolerant hygrohalophytic genus *Salicornia* is known as oil sea plant because of high oil contents of seeds for possible cropping using sea water [20, 21]. Iran is a

major center of diversity in this genus by c. 7 species and an evolutionary unique *Salicornia persica*-clade [22, 23].

- *Salicornia persica* is a tetraploid species growing in the central Iranian saline wetlands, extending to Persian Gulf coasts with a high biomass serving as a best candidate to be used as halophyte crop plant using sea water and high saline irrigation [24].

## 5. Threatening of Iranian Saline Wetlands

Iranian saline wetlands have largely been degraded over the last two decades. This is primarily because of shortage of water running to these habitats as a result of expanding agriculture, dam construction and depleting water tables by over-pumping of aquifers [25]. The largest inland hypersaline Lake Urmia has been devastated by the loss of 80% of its water reservoir [26]. Three major saline wetlands in Fars Province (Bakhtegan, Tashk and Maharlou Lakes) desiccated almost completely in this past year (several media reports and own observation). These are among the most important habitats of several extremely rare and endangered endemic halophytes. In Tashk Lake, for example, five different *Salicronia* species were documented in 2001 co-occurring side by side [23]. *Microcnemum corraloides* which was known firstly from Iran as the first botanical discovery of the author in 1986 from Arak saline lake, has disappeared there after drying of the lake and depletion of the water table of the sedge communities around this highly diversified saline wetland [27,28]. Many saline rivers are threatened by extensive damming resulting in massive losses of their biodiversity. In a case around Rude Shur River 60 km W of Tehran, the disappearance of formerly very common *Bienertia cycloptera* happened in just five years. The marsh halophytes are also under extreme damage. The dense occupation of Caspian Sea littoral beaches caused reduction of natural plant communities and replacement by either waste or ruderal and invasive species. In the Persian Gulf coasts, the problem is not as severe as at the Caspian coasts, but here many unique ecosystems are under pressure as in Khore Musa in S. Khuzestan and Asaloyeh coasts, both heavily degraded for oil, gas and petrochemical industries [29].

## 6. Conclusion

Iran is a most diverse country with a large number of halophytes and salt tolerant plants by the rich saline wetlands and marshes in the northern and southern coasts. Some particular evolutionary lineages make the Iranian halophytes internationally very important for the future of our earth and humanity. The rapid devastation of saline habitats not only accelerates endangering and extinction of many plant species, but also it has negative consequences on human life by increasing local temperature and emission of dusts. In recent years dust emissions have caused major problems in most Middle Eastern countries. Water management has largely changed the socio-economics of the area. There is an urgent need for national and international efforts to set a sustainable program to conserve and restore wetlands to assure their functionality for keeping biodiversity and sustainability of life and security.

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# Effect of Directed River Discharge on Differences in Nitrogen Cycling in the Coastal Ocean, Coastal Wetlands and Estuaries

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***Abstract***

Continual loading of bioavailable nutrients to the aquatic environment is primarily through runoff from agricultural lands and discharge of treated wastewater. Consequently, the world's large rivers contain elevated concentrations of nitrate that may be delivered to coastal wetlands, estuaries and the coastal ocean. Both the fate of this N and impacts to the environment are dependent upon the receiving basin. Nitrate in coastal waters is taken up by phytoplankton, leading to springtime blooms coincident with high river discharge. Consequent algal bloom die-off leads to increased aerobic metabolism in the water column triggering coastal hypoxia or anoxia. River discharge into a shallow estuarine setting can also trigger a phytoplankton bloom, but due to the shallow, well mixed nature of these systems, consequent hypoxic is not frequently realized. Coastal wetlands, however, remove nitrate primarily through denitrification, removing N from the system in gaseous forms. Plant uptake is also another major removal mechanism in coastal wetlands which contributes to organic matter accretion in these systems.

***Keywords: Eutrophication, Hypoxia, Coastal Wetlands, Denitrification, Algal Blooms***

## 1. INTRODUCTION

Nitrogen pollution in rivers, lakes and coastal waters has increased dramatically since the discovery and the industrialization of the Haber-Bosch process. This process allows the harvesting of nitrogen gas from the atmosphere and conversion into a bioavailable form as fertilizer. Concomitant with the increased production and use of nitrogen fertilizer, there has been a greater efficiency of food production per hectare as well as the ability to exploit otherwise infertile soils for agricultural production [1]. Therefore, the use of fertilizer has allowed for increased global population growth through increased crop production and it has been estimated that half of the world's population today could not exist without nitrogen fertilization [2]. However, as large quantities of bioavailable N are spread across the landscape, invariably the excess flows into adjacent aquatic ecosystems leading eventually to increased bioavailable N concentrations in the world's large rivers which deliver this N to the coastal ocean [3,4]. Despite these gains in food production and human population, nitrogen pollution of our aquatic environment has led to detrimental impacts on ecosystem functioning and human health [5-7].

The fate of the bioavailable river nitrate is dependent on the biotic and abiotic characteristics of the receiving basin. In general, open water systems (coastal ocean, estuaries) are dominated by phytoplankton uptake of N as long as water column light and temperature conditions are favorable [8]. In this case, the N is conserved within the system and can be released back into the water column during decomposition or become incorporated into the food web [9]. The fate of nitrate in coastal wetlands is dominated by denitrification and plant uptake (immobilization). The process of denitrification is mediated by facultative bacteria in the soil that use nitrate, in the absence of oxygen, as their terminal electron acceptor in respiration [10]. This process leads to the conversion of nitrate to either nitrous oxide gas or dinitrogen gas, effectively removing the bioavailable N from the system. Plant uptake can also be a major N loss pathway as inorganic N is converted to organic N during incorporation into organic matter. This pathway retains the N within the system whereby a portion will be buried in the wetland soil while some N will be released back into the water column through N-mineralization during decomposition [11]. The hydrologic loading rate can ultimately affect the efficiency of N removal processes, as large loading rates into relatively small coastal basins do not provide sufficient residence time for significant N removal. Under this scenario, the majority of the river water N load diverted into estuaries or coastal wetlands may ultimately reach the coastal ocean while lower hydrologic loadings favor N removal in these systems.

There are three basic geomorphic settings for the mass of bioavailable N that rivers deliver to the coastline. The first one is direct delivery to the coastal ocean [7], the second involves discharge into coastal wetlands [12] and finally the third invokes delivery into shallow estuarine systems [13]. The Mississippi River is one such river system which delivers N-rich water to all three different environments with differing environmental responses and N removal rates (Fig. 1).


*Figure 1: The Mississippi River Watershed drains agricultural lands and discharges to the northern Gulf of Mexico (source: US National Park Service).*

## 2. River Inputs to Coastal Ocean

Springtime flood delivery of N directly to the coastal ocean through the Belize “bird foot” delta leads to large phytoplankton blooms, essentially a fertilization or “greening” of the northern Gulf of Mexico waters [4]. As the spring flood wanes and bioavailable N becomes scarcer, the large mass of primary production cannot be sustained and begins a die off. Oxygen is scavenged from the water column as bacteria degrade the sinking mass of organic matter leading to an extensive hypoxic (low $O_2$) zone (Fig. 2) that extends along the coastal waters of the US states of Louisiana and into Texas [7]. Under this scenario, algal uptake is the primary mechanism for N removal but because of density differences in the fresh river water mass and the denser saline marine waters and the bacterial utilization of $O_2$ in the water column, the extended area of hypoxia persists for months. The replacement of $O_2$ into the deeper water column is a gradual, slow process driven by the slow rate of diffusion and a relatively long path length for $O_2$ to travel. The N in this system is converted to organic N primarily and therefore remains in the system until mineralized during decomposition processes or consumed by detritivores.

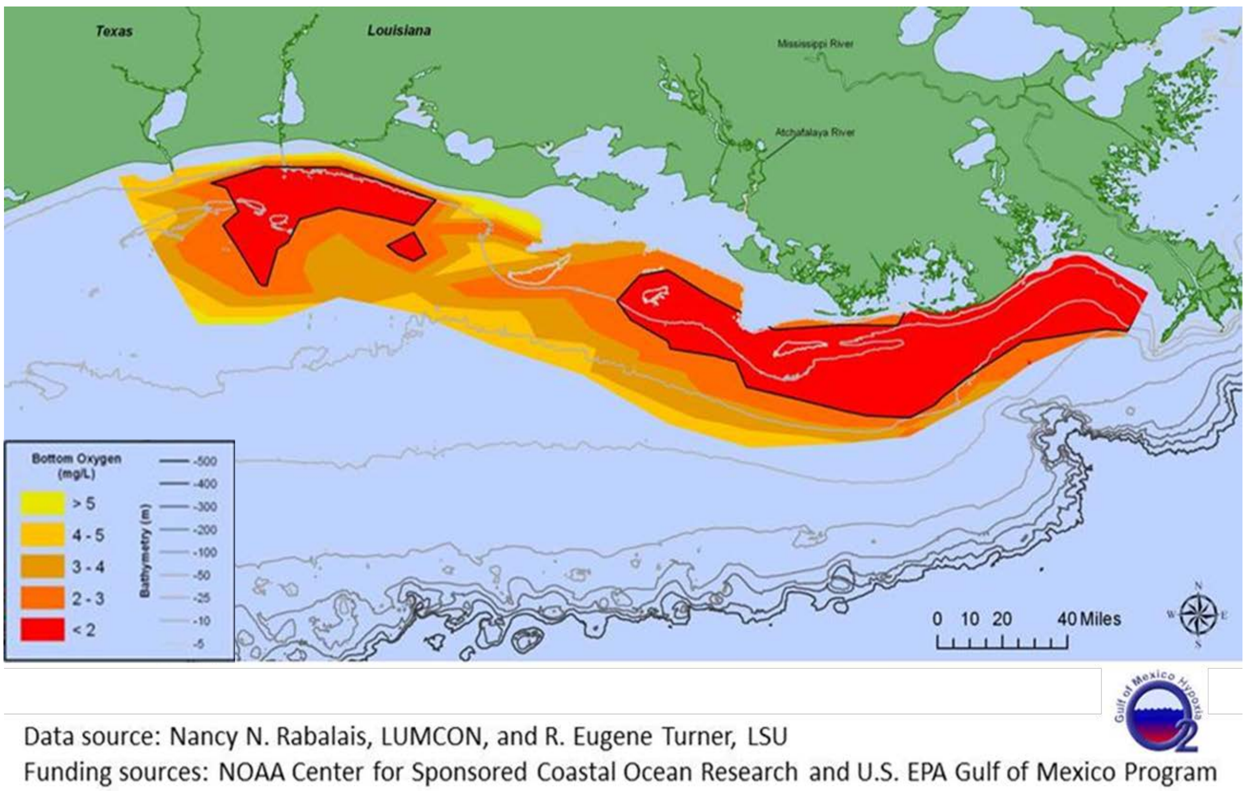


*Figure 2: Distribution of bottom-water dissolved oxygen July 27 to August 1, 2014 west of the Mississippi River delta. Black line denotes dissolved oxygen less than 2mg/L.*

## 3. River Inputs to Coastal Wetlands

The discharges of river water into vegetated coastal wetlands can provide a different environmental response as well as an altogether different level of bioavailable N removal from the systems (Fig. 3). Nitrogen discharge into coastal wetlands is subjected to similar biogeochemical processes exploited in wastewater treatment wetland systems. There is an opportunity for plant uptake of N by the macrophytes [14], which retains the N within the system as well as the microbial-mediated conversion of nitrate to di-nitrogen gas, which is released to the atmosphere and lost from the coastal system [15]. The Caernarvon diversion is one such outlet of the Mississippi River. The Caernarvon Freshwater Diversion is one of the largest diversions and is located south of New Orleans on the east bank of the Mississippi River near mile marker 81.5. The maximum discharge rate of the Caernarvon Diversion is 226 $m^3s^{-1}$ and had been in operation since 1991 [16]. This diversion delivers Mississippi River water into the Breton Sound Estuary, which contains 1,100 $km^2$ of fresh, brackish, and salt marshes [17].

*Figure 3: View of coastal marsh in Breton Sound, LA which receives nitrate-rich, freshwater inputs from the Mississippi River through the Caernarvon Diversion structure.*

A greenhouse, mesocosm study conducted by [18] investigated the fate of the nitrate in the Mississippi river water within the vegetated, brackish coastal marsh in Breton Sound (Fig. 4). The authors collected intact soil cores containing plants, *Spartina patens,* and flooded the cores with filtered site water. A known amount of $^{15}$N-labeled nitrate was added to mimic the Mississippi River spring flood concentrations of 2 mg N $L^{-1}$. After four spike events conducted over 16 weeks, the contents of the cores were partitioned into; aboveground biomass, live belowground biomass, dead belowground biomass and soil. Each component was analyzed for $^{15}$N and compared to the total loading of N to the mesocosms. Plant uptake accounted for ~34 % of the added N with the vast majority (27%) incorporated into the aboveground biomass portion. There was 65% of the added N that was unaccounted for after analyzing all the components of the core [18]. This loss of N was attributed to denitrification since the cores were sealed on the bottom and the only mechanism for removal would need to be through a gaseous pathway (Fig. 5). Therefore, nitrate delivered to vegetated coastal marshes can be removed from the water column, primarily through denitrification which removed the N from the system with additional removal through plant uptake.

*Figure 4: Experimental set-up of $^{15}N$ dosing study from Breton Sound, LA a brackish vegetated marsh.*

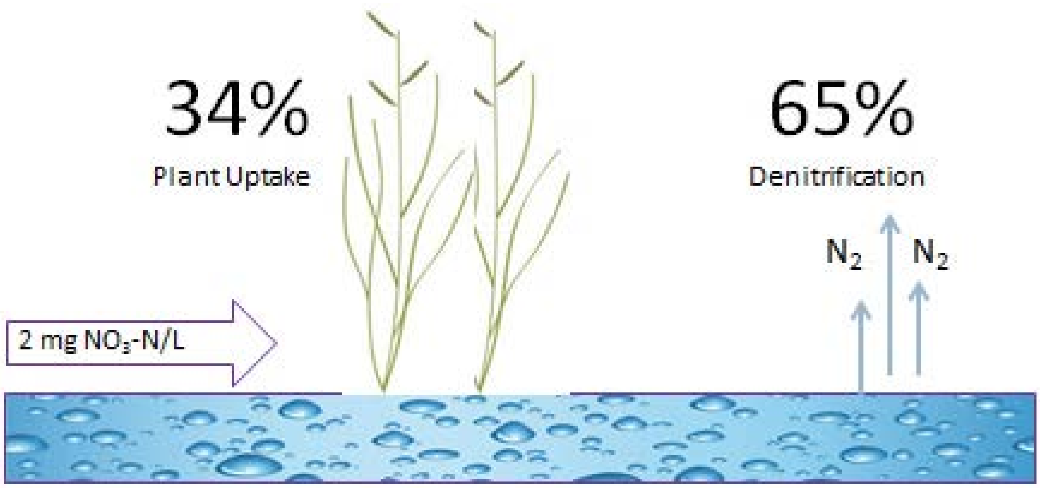


*Figure 5: Fate of added Nitrate to vegetated marsh cores [18].*

A companion study also underscores the importance of the presence of plants for enhanced denitrification. In this study, soil was collected from the brackish marsh and all the plants and roots were painstakingly removed from the soil leaving behind just the soil substrate. A similar nitrate dosing study was conducted to determine the potential of the denitrification pathway in flooded, but non-vegetated soils. The denitrification rates in unvegetated soils were 18 times slower than in the vegetated cores underscoring the importance of both carbon availability and rhizosphere-associated microbial consortia for more rapid denitrification rates [19].

## 4. River Inputs to Shallow Estuarine Systems

Discharge of bioavailable N into shallow, estuarine systems provides for an intermediate environment between direct discharge to the coastal ocean in deeper waters and the discharge of river water into shallow, vegetated coastal wetlands. The Bonnet Carré spillway is a flood release valve located just upriver from the city of New Orleans, LA [20]. The purpose of the structure is to provide a temporary connection between the Mississippi River and estuary only when the river's flood stage threatens New Orleans and downstream communities in the spring, diverting up to 20.8% of the river into the lake.  This is achieved by opening a maximum of 350 "bays" that are normally closed (Fig. 6).  Any number of bays can be opened, allowing a river water inflow rate of up to 250,000 $ft^3\ s^{-1}$ [21].  The US Army Corps of Engineers is the federal agency who operates the structure under threat of impending flooding. The structure discharges into the Lake Pontchartrain is a shallow (mean depth = 3.7 m), oligohaline estuary located in coastal Louisiana with a surface area of 1,637 $km^2$ and a volume of 6 $km^3$ [20].

*Figure 6. The Bonnet Carre spillway is a flood release valve along the low Mississippi River and discharges up to 28% of the flow of the river into the adjacent Lake Pontchartrain estuary (photo credit: Eddie Weeks).*

A number of intensive field studies took place in both 2008 and 2011, when the Bonnet Carré spillway was required to be opened to maintain public safety and prevent levee collapse or flooding of downstream communities (Fig. 7).  The 2008 and 2011 flood events discharged an astonishing ~10,000 and 26,000 metric tons of $NO_3$-N , respectively, over a one month period into the coastal basin [13].  These studies found a two phase response in both N removal and ecosystem impact from the openings.  The first phase is typified by a turbulent and muddy water column.  Under these conditions, phytoplankton uptake is low due to light limitation as well as colder water temperatures [8,21].  When the estuarine sediments were examined, it was found that very little denitrification occurs in these sediments compared to vegetated marsh and therefore significant gaseous release into the atmosphere of the river N does not occur in this system despite the muddy nature of the sediments [22].  Consequently, the river plume moves through the estuary with low attenuation in water column nitrate concentrations and subsequent discharge to the coastal ocean.

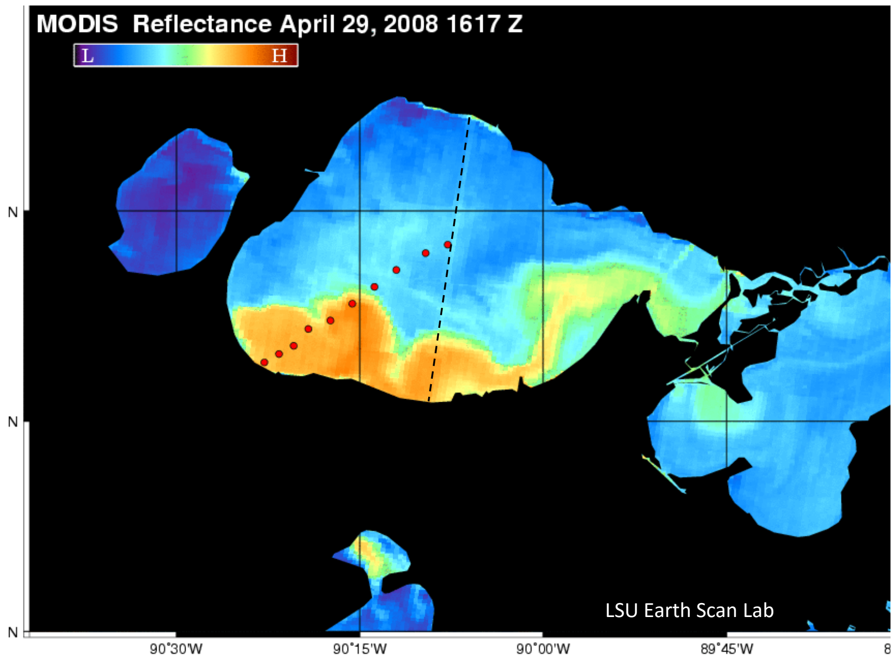


*Figure 7: Modis Satellite image showing Mississippi River discharge into the Lake Pontchartrain estuary in 2008. Dots represent sampling stations along a 30 km transect (source: LSU earth scan lab).*

The second phase occurs when the river diversion is closed and turbid, sediment laden water is no longer being added to the estuary. During this time, the sediment falls out of the water column and light penetration increases [13]. The algae are then poised to take advantage of the abundant N load under optimum light conditions triggering a phytoplankton bloom, primarily composed of diatoms [8]. This bloom, accompanied with increasing chlorophyll *a* values and a dramatic drop in both bioavailable N and P (Fig. 8). However, the estuary becomes a P limited system during the diversion event due to the high concentration of bioavailable N in the river water. The phytoplankton uptake N as long as there is P available due to the Redfield ratio requirements. Once the P is depleted, there is no longer uptake of bioavailable N which was then is released to the coastal ocean. Roy et al. [13] calculated that of the N load added to the estuary ~ 70% was removed by algal uptake, 28 % was exported to the coastal ocean and ~3 % was removed by denitrification.

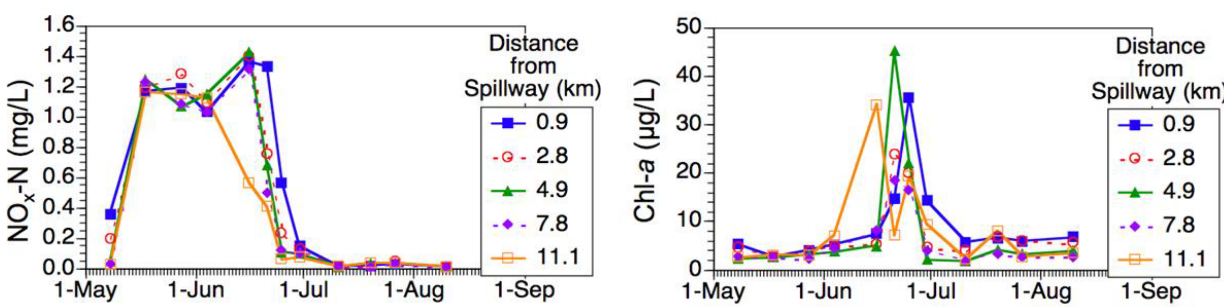


*Figure 8: Graphical depicttions of N concentrations (top panel) with the cooresponding Chlorphyll a data (bottom panel) in 2011. Once the spillway was closed, the nitrate decreased with a increase in primary productivity (adapted from [13]).*

## 5. Conclusion

Globally, large rivers have been disconnected from their riparian wetlands through the historical construction of levees, in order to prevent flood damage and loss of life in communities that border the river's course. This modification along with increased N fertilization has led to discharge of river water with high levels of bioavailable N into coastal waters which can trigger hypoxic or low $O_2$ events. This examination of the Mississippi River discharge has found that inputs into the coastal ocean as well as a semi-enclosed estuary both trigger phytoplankton blooms as the major response to high nutrient loads. In the coastal ocean, this event leads to persistent, low water column $O_2$ events later in the summer. However, in the shallow estuary, there is no indication of any hypoxic events, as any $O_2$ depletion can be quickly restored due to advection by wind and waves and the shallow depth. There is little denitrification, a process which converts the bioavailable N to inert nitrogen gas, which occurs in either system due to the relatively large water column, little contact with the sediment and low microbial activity of the sediment. Consequently, the N is conserved in the system as primary production, which through the process of mineralization can be released back into the water column. The majority of the high bioavailable N loads directed into vegetated coastal wetlands were found to be removed by the microbial-mediated biogeochemical process of denitrification. This wetland system therefore provides the more efficient removal of the N load from the system and river water reaching the coastal ocean would have significantly less N. The other major mechanism of removal in coastal wetlands was uptake through uptake by macrophytes, converting the bioavailable N into organic matter. This primary production and consequent deposition of organic matter is an important process for coastal wetlands in helping keep pace with sea level rise. From a coastal management perspective, reconnecting rivers with their adjacent coastal, riparian wetlands is one of the best ways to help mitigate impacts of high nutrient loads on coastal waters and increasing wetland soil accretion rates.

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**U.S.-Iran Symposium on Wetlands**

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# Investigation of Sanitary & Industrial Wastewater Effects on Anzali Reserved Wetland

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## *Abstract*

Wetlands are vital to the ecological balance of the Earth. They serve many functions for both mankind and wildlife. Humankind has always used them for different socio-economical purposes. Various factors threaten wetland ecosystems and undermine their productivity and functional role. Anzali Wetland Complex is comprised of large, shallow, eutrophic freshwater lagoons, shallow impoundments, marshes and seasonally flooded grasslands in the southwest Caspian lowlands. It consists of different aquatic and terrestrial ecosystems. It is a good example of a natural wetland that supports an extremely diverse wetland flora and fauna. In general the wetland supports huge numbers of wintering ducks, geese, swans and coots, and the riverine area and the marsh support large breeding colonies of Ardeidae, and several species of terns and shorebirds. Anzali wetland supports over 1% of the regional Middle East wintering bird populations. During the last decades, the Wetland has been threatened and destroyed by seven identified sources of environmental pollution including rivers, municipal, industrial, commercial, mines, agricultural and hospitals. Discharge of used oil from ships, illegal construction, drying of the Wetland, discharge of wastewater from fish farms and solid waste disposal were additional factors affecting the Wetland environment. Decrease in water depth from 8-12 to 0.5-3 m, and reduction in water quality from distribution of gases such as hydrogen sulfide and methane and *Azolla pinnata* rapid growth in the nutrient-enriched part of the Wetland has proved the matter. In this study these are reviewed and the protection steps to control the Wetland are discussed.

***Keywords: Azolla Pinnata, Industrial, Management, Municipal, Pollution Sources***

## 1. INTRODUCTION

Wetlands are one of the most important and productive ecosystems on Earth. They serve many roles and functions and are full of life. Humankind has always used them for different socio-economical purposes. Wetlands all have common characteristics, yet each is unique in their hydrology and biodiversity [1].

Various factors threaten wetland ecosystems and undermine their productivity and functional role. These factors include infilling for land reclamation, dam construction, up-stream development (erosion and sedimentation), aquaculture, pollution and nutrient input, water diversion (irrigation), overgrazing, over fishing, as well as uncontrolled recreation and tourism activities.

According to the international terms, Iran is the birthplace of the Ramsar Convention, which focuses on the conservation and wide uses of wetland habitats and in particular their waterfowl. Most of the places of Iran fall into the dry or semi-dry category. In such a climate the presence of wetlands, marshlands and water bodies play an important role in the well being of the natural environment, wildlife and human beings.

250 wetlands have been registered in Iran. The numbers may vary during different seasons and some may also be completely changed every day [2]. Iran has presently designated 24 sites as wetlands of international importance with total surface area of 1,486,438 hectares [3] (The Convention entered into force in 1975 and in January 2013 had 163 contracting parties, or member states, in all parts of the world. Though the central Ramsar message is the need for the sustainable use of all wetlands, the "flagship" of Ramsar Convention is the list of wetlands of international importance– presently, the parties have designated for this list more than 2,060 wetlands for special protection as "Ramsar Sites", covering 197 million hectares, larger than the surface area of France, Germany, Spain, Italy, and Switzerland combined) [4].

Anzali Wetland Complex is comprised of large, shallow, eutrophic freshwater lagoons, shallow impoundments, marshes and seasonally flooded grasslands in the southwest Caspian lowlands. The main wetland covers about 11,000 hectares, and comprises an open lagoon, 26 km long and 2– 3.5 km wide, surrounded by reed-beds, which extend its eastern limits a further 7 km. It fed by several rivers as a large and freshwater lagoon, separated from the sea by a dune system. The site has international importance for breeding, staging and wintering water birds. The massive spread of the exotic floating water fern *Azola* is suppressing native flora, which is important food for water birds. This site was placed on the Montreux Record in 31 December 1993 due to change in water levels and increased nutrient-enrichment, leading to the rapid spread of the reed *Phragmites australis*. (Ramsar site #40) [5]. A Ramsar Advisory Mission (RAM) visited the area in January 1992 and May 1997 [6,7].

Despite being landlocked, the Caspian Sea and the Wetland has been in a "semi-critical" environmental situation in recent years due to the flow of various industrial, agricultural and urban wastes. However, the dangerous pollution which is mainly caused due to oil operations, including exploration, drilling and transfer in addition to heavy metals and substances such as lead and zinc, which constitute part of the industrial waste, are threatening marine life [8]. Today there are many laws and regulations to help save the wetlands. There are also many organizations working to protect, preserve and restore wetlands throughout the world.

The objectives of this study were to investigate pollutant sources and determine the variation of some important parameters in order to control pollution, biodiversity conservation, sustainable development, which is primarily based on the biosphere reserves.

## 2. MATERIAL AND METHODS

In this study after gathering available documents and data regarding to Anzali Wetland from the Iran's Department of Environment (DOE) and other related research institutes, pollutant sources were investigated and the contribution of various pollution sources including domestic, industrial, business offices, and non-point sources were determined. Then variation of some parameters in the main rivers and the Wetland including pH, Dissolved Oxygen (DO), N- $NO_2$, N- $NO_3$, N- $NH_4$, Total Nitrogen (TN), Dissolved Phosphate, Total Phosphate (TP), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Total Solids (TS) , heavy metals, Electrical Conductivity (EC), sulphate and E-Coli were investigated. All analytical tests were done as outlined in the Standard Method Handbook [9].

The analytical equipment used included the following: spectrophotometer Hach DR 2000 & DR 4000, Atomic Adsorption Philips PU9100, COD Reactor Hach DR 2000, BOD meter WTW OxiTop DO meter Crison OXI 45, Electrical Conductivity Metrohm & WTW LF90 and pH meter Metrohm 691.

## 3. RESULTS AND DISCUSSION

### *3.1. Investigation of environmental problems and pollution sources*

Due to lots of organic and nutrient pollution to the Wetland, many environmental problems have resulted. The known effects of pollution to Anzali Wetland are as follows:

- Decrease in water quality
- Decrease in water depth from 8-12 to 0.5-3 m because of Total Solids (TS)
- Release of intensive odor and hydrogen sulphide gas because of anaerobic conditions in some parts
- Decrease in the number of migratory birds and in population of fishes
- Introduction of *Azolla pinnata* from Southeast Asia into Anzali Wetland. Regarding the Azolla, although this aquatic plant was meant to be quarantined in a small pool, it escaped and found its way into the natural environment where it flourished. Now this species has become a pest, competing with the other native species for vital resources such as light and nutrients.

According to the study, the Wetland has been threatened and destroyed by environmental pollution from seven identified sources of rivers, municipal, industrials, commercials, mines, agricultural and hospitals. Discharge of used oil from ships, illegal construction, drying the Wetland, discharge of any wastewater from fish farms and solid wastes disposal were the other reasons, which have affected the Wetland environment. But, the main point and non-point sources of pollution entering into Anzali Wetland can be summarized as follows:

#### *3.1.1. River pollution*

There are 10 major rivers entering the wetland and some of them have large discharges of urban and industrial wastewater. The annual mean discharge rate into the wetland is estimated at 76.14 $m^3/s$ and the average COD is about 26.5 mg/L [10]. This enriches the nutrients as well as increases the amount of heavy metals of the Wetland.

#### *3.1.2. Municipal wastewater*

About 11 million people live around the Caspian shoreline [11]. There are many villages and cities from as small as 10,000 to as large as over 500,000 people living there surrounded Anzali Wetland. One of the main cities is Bandar Anzali. Lots of civilized activities are in this city. Most of the sanitary wastewater from both residential and commercial centers discharges directly into the Wetland without any treatment. The World Bank provides financial support to construct sanitary networks in the cities of Rasht and Anzali, but the progress isn't very acceptable.

#### *3.1.3. Industrial wastewater*

Many industrial factories surround the seaboard and pollute both the sea and the rivers. Among these industries, Wood and Paper Company in Talesh city, Wood Fiber Company in Hassan Rood, many food products and food processing industries are the most important. The lack of proper wastewater treatment system at some of these companies adds pollution to the rivers that will end to the Wetland.

#### *3.1.4. Other sources*

Due to lots of land used in the area for agricultural purposes, excess emission of nitrogen and phosphorus from the area will bring excess nutrition to the Wetland. Besides of the above main sources of pollution mentioned, there are others, which are worth to be investigated. An important source is from the navigation in the Caspian Sea. Although, this may not be considered as a point source of pollution, but it can be assumed to be as a non-point source one.

Fig. 1 shows the map prepared during this study and indicates the different activities around the small part of Siah Keshim Wetland (by Anzali Watland).

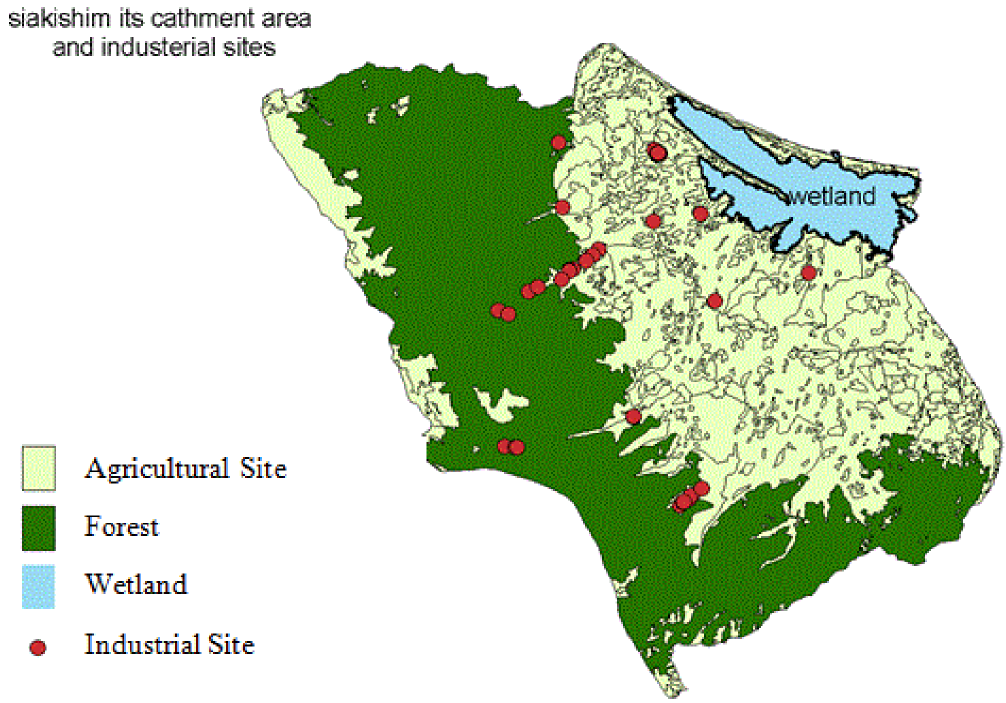


*Figure 1: Different activities around Siah Keshim Wetland.*

### *3.2. Analysis of River and Wetland Water Quality*

Variation of 10 important parameters including pH, DO, N- $NO_2$, N- $NO_3$, N- $NH_4$, TN, Dissolved phosphate, TP, COD and BOD in the Rivers and Siah Keshim Wetland as a small part of the region are shown in Fig. 2. It can be seen that pH in the Wetland is lower than in the rivers. This means that there is a high probability that anaerobic conditions and eutrophication can happen in some parts of the region. DO is in the suitable range because of turbulence in the rivers but it is lower in the summers that has high probability for eutriphication to happen in some parts. High variability of N is due to agricultural activities and fertilizer runoff. High amount of ammonia means that there is a chance of anaerobic condition and eutrophication in some parts (considering the relation between $NH_4$ and pH). Therefore control on non-point sources especially fertilizer runoff, fish conservation pools, and municipal wastewater discharge is necessary.

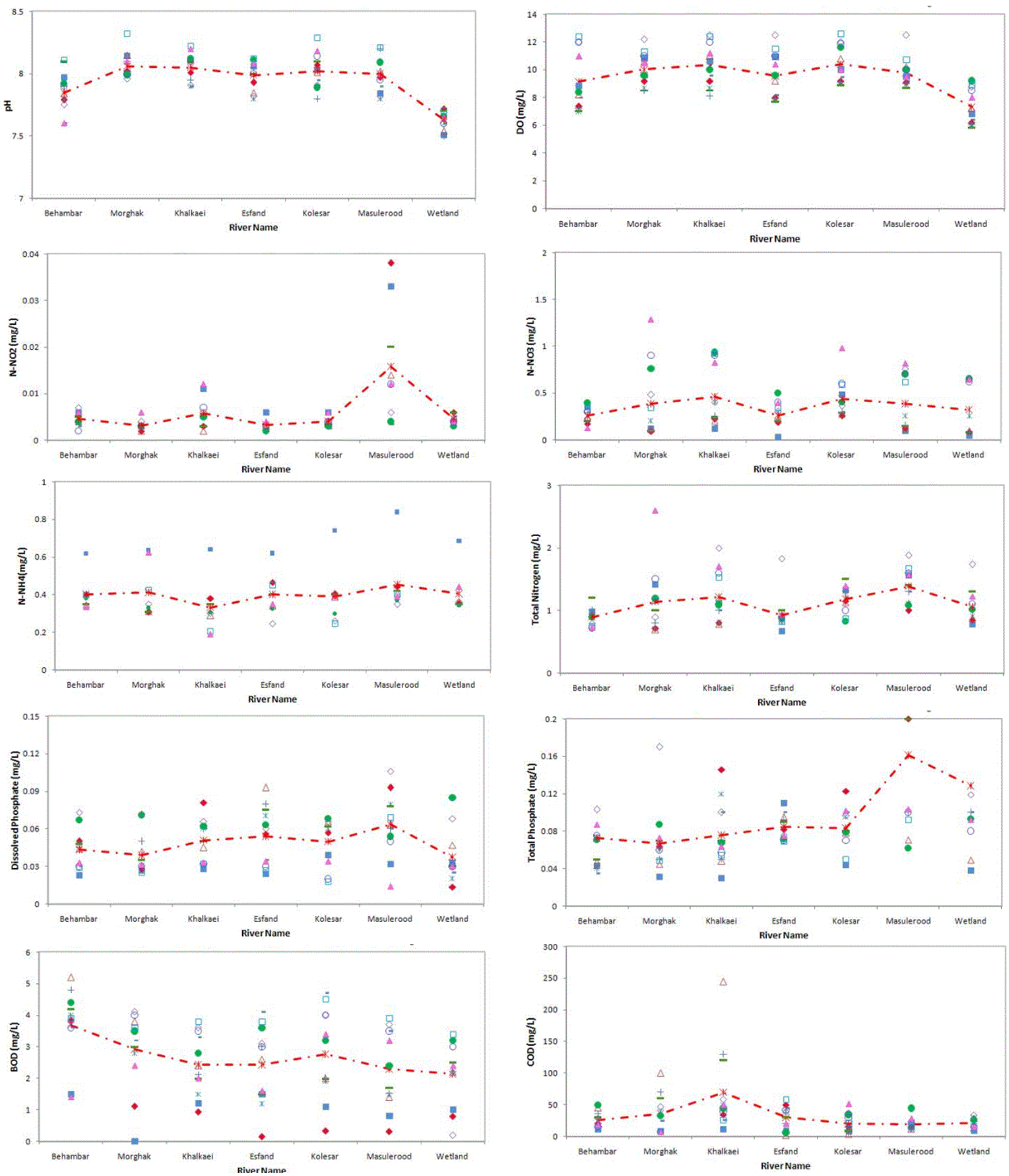


*Figure 2: Variation of the important water quality parameters in the rivers and Siah Keshim Wetland.*

According to the results, the amount of phosphate is 4 times higher than the permitted standard value on some days [5] and urgent control on non-point sources, municipal wastewater discharge and etc. is necessary. The ratio of N:P was higher than the standard value in some rivers [5] and indicates high risk of eutrophication. The amount of BOD is higher near the cities. The high ratio of BOD:COD indicates the pollutants are mostly biodegradable. Other water quality results are summarized in Table 1.

TABLE 1: SUMMARY OF OTHER WATER QUALITY RESULTS

| Parameter | Result |
|---|---|
| TS | • High amount of TS causes sedimentation and increases risk of eutrophication. |
| Heavy metals | • It was in the standard range as there was limited amount of industries located in the Siah Keshim (Ni, Cu, Pb, Fe, Zn & Cr)<br>• In the study of Vesali Naseh et al. [12] in 2012 the results of the study showed that total concentration of metals in the sediment samples were found to be in this order Fe>As>Cr>Zn>Ni>V>Pb>Cd and Anzali wetland was threatened by pollutants related to rivers entering it.<br>• The highest concentrations of heavy metals were measured in the muscle and liver of pikes collected from Anzali and Pirbazar stations. Comparison of the levels of three metals in fish tissues with international standards showed that Pb concentration was significantly higher in Anzali and Pirbazar fish than the permissible limit determined by Water Health Organization [10]. |
| EC | • Higher amounts of EC in Esfand river (indicates that the agricultural wastes are discharged) |
| Sulfate | • Was high in some parts of the Wetland<br>• Indication of anaerobic conditions |
| E-Coli | • Because of municipal and restaurant wastewater discharge to the river, the amount of E-Coli was high that must be considered |

## 4. CONCLUSION

The main sources of pollution that entered into Anzali Wetland can be summarized as follows:

- Polluted rivers with sanitary and industrial wastewater;
- Direct discharge of municipal wastewater produced in coastal cities;
- Direct discharge of industrial wastewater without or with insufficient treatment.

The Department of Environment controls the conditions especially industries by pressing to treat their wastewater but unfortunately the life of the ecosystem is yet in danger. A major research program is currently being undertaken, which has involved the establishment of 35 monitoring stations throughout the wetland to measure a variety of parameters, including changes in the water level, water quality and physico-chemical characteristics.

The National Fisheries Organization has conducted numerous immunological and hydrological studies [7]. This organization has put a great emphasis on the development of sustainable fisheries such as:

- Control on fishing by marine guards for example; beach seining is the only allowed fishing system for licensed cooperatives to catch bony fishes other than kilka;
- Establishment of Iranian Fisheries Research and Training Organization to give technical and scientific supports for fisheries;
- Monitoring fishing methods to prevent over fishing and damage to fish stocks;

- Allocation of funds researches on identification and conservation of fish stocks and preservation of sturgeons (Because of their importance, fishing sturgeons, caviar-producing species).

It is also important to mention that the Technical Cooperation Project for Anzali Wetland Ecological Management Project (Phase 2) Started in April 2014 and will last for five years. Prior to the phase 2 Project, JICA conducted the phase 1 project with related expertise organizations, such as DOE, Guilan Province DOE [14]. Use of SWOT analysis can help to estimate better the weaknesses, strengths, threats and opportunities, and to develop the tourism industry [15] and other activities in the region.

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# Developing a Comprehensive Approach for the Determination of Environmental Water Requirements of Wetlands

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### *Abstract*

Allocation of Environmental Water Requirements (EWR) for rivers and wetlands is a key task in sustainable water resources management of large river basins. Particularly in closed basins located in semi-arid environments where the hydrology is altered by water extraction for consumptive uses it is crucial to determine and allocate the amount of water needed to conserve natural ecosystems. The Urmia Basin is a large agricultural region in the north-west of Iran having diverse ecosystems including several wetlands. Urmia Lake, a large saline lake, and its surrounding wetlands, including Yadegarlu, Dorgeh Sangi, Kanibarazan, and Gharah Gheshlagh, provide important seasonal habitats for many species of migrating birds. During the last two decades Urmia Lake has been continuously desiccated due to drought as well as overexploitation of water for irrigated agriculture. The surrounding wetlands of Urmia Lake have been also threatened by the limited water inflows. In July 2014, the Iranian government established a 10-year program to restore Urmia Lake. In accordance with the lake restoration program, it is planned to determine the amount of EWR of its surrounding wetlands and allocate this water demand from upstream rivers. Taking in to account upstream rivers, wetlands, and Urmia Lake as an entire connected system it is essential that wetland's EWR are determined using an integrated framework to ensure sustainability of the three sub-systems. This study aims at developing a comprehensive approach for determining EWR of Yadegarlu, Dorgeh Sangi, Kanibarazan, and Gharah Gheshlagh wetlands considering their ecological functions and socioeconomic services.

***Keywords: Environmental Water Requirements, Wetland, Comprehensive Approach***

## 1. Introduction

Urmia Lake (UL) in the northwestern of Iran is one of the largest permanent hypersaline lakes in the world [1]. The lake and its associated wetlands support a variety of salt tolerant plant species and serve as exceptional habitats for many migratory birds. However, decrease of the lake area by around 88% in the past decades [2] has led to a considerable decline in such functions.

While the disaster of Urmia Lake desiccation has only become apparent relatively recently, ecological degradation in the lake and its dependent ecosystems such as wetlands has been taking place for the past two decades. Years of drought and over-use of water caused the lake surrounding the wetlands to dry, the lakes and aquatic biota to disconnect, the community to suffer substantial stress, and native species to be at risk of being lost [3].

To ensure a sustainable future for the basin, it is critical to determine the environmental water requirements (EWR) of the basin natural ecosystems. The Iranian Government has allocated more than $500 million in funding to support the UL Restoration Program (ULRP) and actions outlined in a 10 years plan for the region. One of the key projects defined to improve overall health of the basin ecosystems relates to determining and allocating sufficient environmental flows for the rivers, wetlands and Urmia Lake itself [4]. Besides the conservation and environmental significance, the culture and wellbeing of adjacent rural areas are also directly depends on the health of these ecosystems specially wetlands.

Consequently, it is crucial to establish a proper approach for the determination of the wetlands Environmental Water Requirements and to impose constraints on the developed river systems.

Allocation of environmental water for ecosystems has historically focused on rivers [5]. Later, environmental water allocation for wetlands was incorporated into the flow allocation process for the river system (e.g. the Murrumbidgee wetlands [6]). Unlike rivers, in wetlands there is not a direct relationship between water quantity and habitats quality. Thus, the determination and allocation of a wetland EWR is different from that of a river. Principal components for a wetland's water regime include the quantity of water, and the timing, duration and frequency of inundation [7].

There is no single best method or approach to determine the wetland EWR [8]. In general, there are two various approach for determining EWR of wetlands including hydrology-driven and ecology-driven approaches. The main assumption of hydrology-driven approaches is that the wetland biota is adapted to the historic water regime. Thus, hydrology-driven methods aim at the description and restoration of the pre-disturbance water regime of the wetland. On the contrary, ecology-driven approaches focus on the determination of required water regimes for the existing or preferred biota, and the provision of that regimes. Ecology-driven approaches has a higher level of defensibility for decisions regarding environmental water allocations compared to the hydrology-driven approaches [9].

In this study a comprehensive ecology-driven approach for determining environmental water requirements of a wetland was developed using the aspects of previously-used, peer reviewed methods that were best suited to this application, tailored to suit the data, tools and resources available for wetlands in Urmia Basin. The method involves setting suitable management objectives and outcomes that are linked to the overall management aim of maintaining a healthy, productive and resilient wetland in the basin. Then, a procedure was defined to determine the required amount of water allocation to an upstream river in which environmental needs of the river, wetland and Urmia Lake have all been incorporated.

## 2. STUDY AREA

The wetlands under study are located in the south of Urmia Lake (Fig. 1), where upstream rivers are draining before feeding the lake. Urmia Lake and its southern satellite wetlands, including Yadegarlou, DorgehSangi, KaniBrazan and GharahGeshlagh, are parts of an entire ecosystem (Table 1, Fig. 2). The ecological dependency between the lake and its surrounding wetlands is a key feature and should be considered in determining EWR of wetlands. With increasing salinity of Urmia Lake water and decrease in mass of Arteria due to its severe desiccation, the southern wetlands are of increasing importance as feeding habitat for species like flamingos and waders.

The southern coast of UL has a semi-arid climate with cold winters and mild summers. Average evaporation of the region is about 3 to 4 times of precipitation.

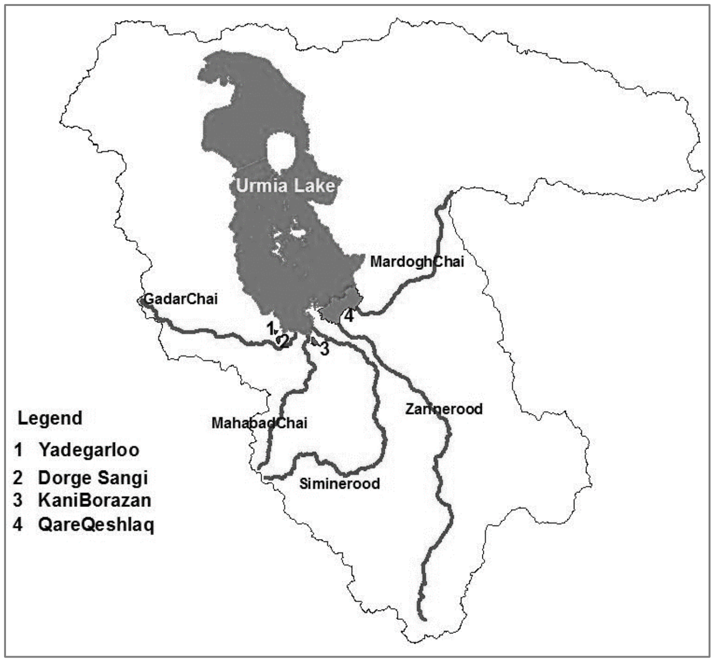


*Figure 1: Urmia Basin, Urmia Lake and the rivers and wetlands under study.*

TABLE 1: SUMMARY OF INFORMATION OF WETLANDS IN THE SOUTHERN PART OF URMIA LAKE.

| Wetland | Province | Area (ha) | Elevation (MSL) | Wetness frequency | Water quality | Importance |
|---|---|---|---|---|---|---|
| Gharah Gheshlagh | East Azarbaijan | 22,000 | 1,278 | Seasonal | Brakish | IBA |
| Kanibarazan | West Azarbaijan | 690 | 1,275 | Permanent | Brakish | - |
| Yadegarlu | West Azarbaijan | 250 | 1,240 | Dry | Brakish | Ramsar site |
| Dorgeh Sangi | West Azarbaijan | 735 | 1,288 | Permanent | Brakish | Ramsar site |

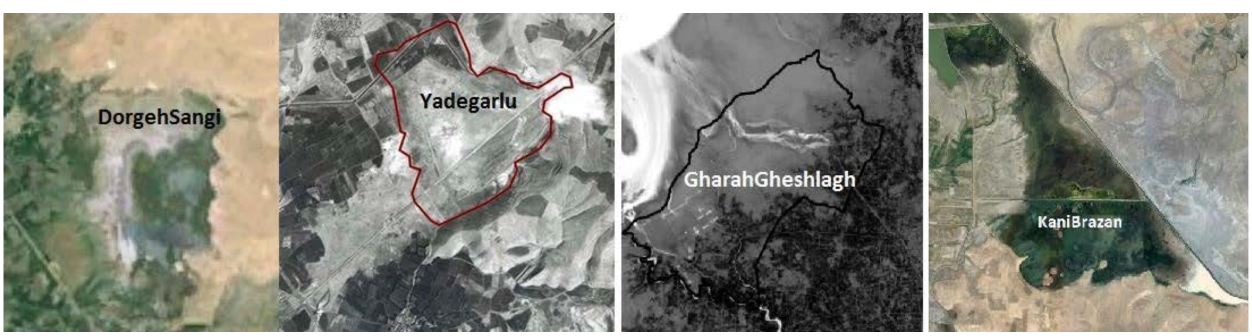


*Figure 2: Satellite images of the wetlands under study.*

## *2.1. Yadegarlou Wetland*

Yadegarlou Wetland is located within the administrative boundary of MohammadYar town near Yadegarlou and Gol rural areas. It was designated as a Ramsar site in 1975. Yadegarlou used to be a shallow (with a maximum depth of 1 m) closed seasonal eutrophic wetland with fresh-brackish water. It had a surface area of maximum of 250 ha, with the 260 ha pasturelands at its west side which is used for grazing. The wetland was fed by the excess flows from the Gadar River through the traditional irrigation canals and return flows from irrigated farms and pasturelands. Construction of the Hassanlou drain in the 1990s, resulted in its complete desiccation [10]. Only occasional water supply to the wetland or a heavy rainfall allows the wetland to receive water for quite a short period. Based on historical information, the wetland used to support breeding habitat for several important bird species like flamingos, ducks, and grebes.

### *2.2. DorgehSangi*

DorgehSangi is located in West Azarbaijan province, near DorgehSangi village. The wetland is a generally flat area grasped within the natural elevations with its deepest point measured about 1.5 m. The elevation of the wetland area is around 1,289-87 m above mean sea level. The total area of the wetland is about 735 ha including the wet part with a maximum area of 490 ha and the grazing marshes at the west (245 ha) which has already been converted to irrigation farm. Dorgeh Sangi wetland is a closed brackish water body in which inflows are balanced with only evaporation (6.5 $Mm^3$/yr). It is basically recharged by flows from Gadar River through traditional irrigation canals. Direct precipitation over the wetland and its relatively small catchment area, ground water seepages, and flows from several small springs at the toe of the southern rock hills are other sources of recharge. The total volume of diverted flow (in an average hydrological condition) into the wetland through the irrigation canals is around 3 $Mm^3$/yr, while the total annual ground water flow towards the wetland is only 35,000 $m^3$/yr.

There is a large pastureland area at the west part of the wetland which is used for producing fodder and grazing for the domestic animals of the owner villages. The pastures are irrigated (flooding methods) during late March through May.

### *2.3. KaniBrazan*

KaniBrazan is located at the downstream part of the Mahabad and Simineh rivers (Fig. 1). The wetland is located at the northern toe of Gahradagh mountain and extends northwards over flat coastal territories of Urmia Lake. Closer to the mountain's toe, the wetland is deeper and slightly undulating. Towards the north, the topography is very flat and creates a very shallow (generally <0.5 meter deep) wetland.

In addition to the surface runoffs from its small catchment area, the Kanibrazan wetland used to be mainly dependent on water resources from Gharadagh spring and excess irrigation waters from the upstream irrigated areas in Mahabad Plain to the south and west of the wetland, as well as flows from Miandouab Plain (Simineh roud river basin) to the east of the wetland. With the seasonal nature of these flows, the wetland used to be of seasonal regime with wet periods during spring and early summer and dry period during late summer and early autumn. The construction of dikes as well as a drainage system of the Mahabad Irrigation Network in 1978 has divided Kanibrazan into two parts from east to the west. The dike has no culvert and hydraulically disconnects the two parts of the wetland. Since then, the wetland has started to receive more regular flows from the Mahabad drain particularly during the irrigation season. As a result, the seasonal wetland changed into one with more or less permanent wetland in the south and a seasonal wetland feeding by Mahabad River in the north [10].

The wetland water quality is brackish and some parts of the wetland become eutrophic in dry seasons. Human use of the wetland area is limited. The shallower part of the wetland is occasionally used for grazing.

### 2.4. GharahGheshlagh

GharahGheshlagh wetland is located within the administrative boundary of Bonab city in the province of Eest Azerbaijan. It is the largest wetland at the southern Urmia Lake having an area about 22,000 ha. The main water resources of GharahGheshlagh wetland are inflows from Zarrineh and Mardogh rivers, surface runoffs and ground water discharges. A significant part of the wetland vegetation occurs in the southern and eastern parts which is mainly influenced by the rivers inflow. The wetland also supports diverse species of migratory birds and was declared as an Important Bird and Biodiversity Area (IBA).

Recently a channel has been constructed to connect Zarrineh to Simineh River to prevent evaporation losses between the rivers and Urmia Lake and to supply more water for the lake. However, this will lead to a reduction in the wetland inflows from its dominant water resource, Zarrineh River.

## 3. METHODS

### 3.1. Determining Environmental Water Requirements of Wetland

After the review of contemporary methods and frameworks, a comprehensive approach (Fig. 3) was developed to determine the EWR of wetlands surrounding Urmia Lake. It is a 12 step process in which hydrologic, ecologic, water quality and socio-economic aspects of wetland conservation are included.

#### 3.1.1. Characterizing wetland in terms of ecology and hydrology

The first step consists of describing the main ecological and hydrological characteristics of a wetland. Ecological status of a wetland can be acquired from existing data about its flora and fauna. It is also important to have quantified ecological data of species availability such as number of migratory birds which may correlates with the wetland water regime.

Hydrological condition can be defined using the water level records of the wetland, times series of water inflows from hydrometric stations, rainfall and evaporation data from meteorological stations, outflows from wetlands. It should be noted that in the absence of sufficient field data, satellite-driven data can be used. In this study to achieve the accurate bathymetry data of Yadegarlu and Gharah Gheshlagh wetlands we used Cartosat-1 imageries at spatial resolution of 2.5 m. Moreover, the seasonal variation of wetland area as well as the vegetation cover were analyzed using the Landsat 7& 8 data during a 15 years period. Then, these data are used to develop the water balance and assess its variation. It is required to assess the wetland hydrology at least under two scenarios: natural flow and altered flow. The former refers to the predevelopment water regime (in which the effect of dams as well as the water consumptions are omitted from the historical flow records), while the latter relates to the observed flows.

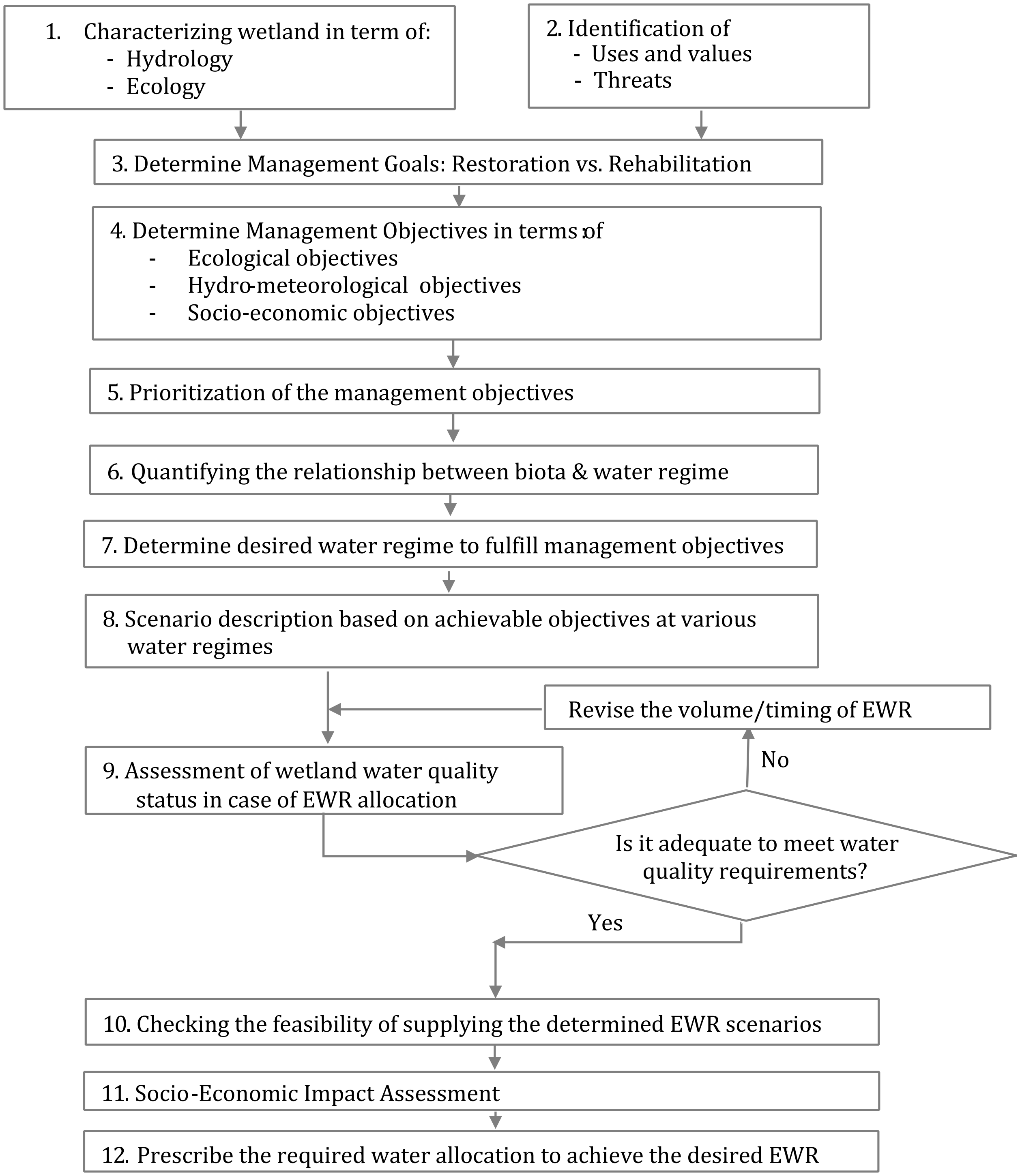


*Figure 3: Flowchart of a comprehensive approach for the determination of environmental water requirements of wetlands.*

By comparing these two flow records, alterations to the pre-disturbance water regime can be identified. Further analysis can be performed to assess variation of each term of the wetland water balance and to distinguish between anthropogenic and climate-induced impacts.

*3.1.2. Identification of uses, values and threats*

This step involves the identification of wetland functions, and uses as well as threats. Based on information collected in the previous step, environmental functions, conservation values, threats and uses are identified. Wetlands provide variety of functions including the regulation of water, transformation of nutrients, growth of living matter, dust control, and supporting rich biodiversity. Economically valuable fishes and endangered species are among ecological values of a wetland. Human uses may be related to recreation, the appreciation of water views, grazing of wetland and floodplains, hunting, fishing and bird watching and ecotourism. For example DorgehSangi and KaniBrazan are important bird watching sites and touristic attraction of these wetlands is a source of income for nearby villagers.

On the other hand, presence of an invasive species is an ecological threat. Water related threats may involve over-exploitation of water for agriculture, diversion of upstream rivers (the case of GharahGheshlagh) and degradation of the wetland water quality due to fertilizer and pesticides which exist in agricultural return flows. Over-fishing and physical barriers (e.g. roads in the middle of Yadegarlu and KaniBrazan) to migration of species are instances for human induced threats.

*3.1.3. Determine management goal*

The management goal is determined according to deviation of the wetland current condition form its natural status. It is commonly accepted that restoration to a pre-disturbance state may be an achievable goal in small wetlands, whereas for large wetlands affected by urban development, rehabilitation is a more suitable goal [11,12]. In our cases, partial restoration was considered as a management goal for Yadegarlu, which is currently dry, and rehabilitation for the remaining three wetlands.

*3.1.4. Determine management objectives*

Based on the management goal of the wetland and the identified functions and threats of the wetland (Step 2), specific management objectives should be determined. This may include ecological objective (e.g. objectives based on vegetation and water birds), hydro-meteorological objectives (e.g. providing water to keep soil moisture for dust control) and socio-economic objectives. Sometimes, objectives are defined so that the obligations associated with international conventions such as the Ramsar Convention (instructions for wise use of wetlands) are met or to exclude from the Montero list of damaged wetlands.

*3.1.5. Prioritization of the management objectives*

Once management objectives of wetlands are determined, it is crucial to prioritize them. Because it may not be possible to supply the adequate water to fulfill all objectives. Those objective related to human health and livelihood may have a higher priority over others. Setting priorities to the objectives help to define various scenarios in which different level of management objective can be achieved based on the amount of allocated water. This in turn facilitate the use of interactive methods which outperforms prescribed methods [13].

*3.1.6. Quantifying the relationship between biota and water regime*

In this step it is required to quantify the relationships between the wetland water regime and its indicator flora and fauna. Such relationships may be direct (i.e. relationship between the wetland water surface and number of migratory birds) or indirect (i.e. relationship between water regime requirements of vegetation used by water birds). Determining some thresholds in terms of its inflow/water surface, where suitability of habitat for significant flora or fauna are considerably influenced, will help in determining wetland EWR.

*3.1.7. Determining the desired water regime*

Based on the extracted relationships between hydrological regime and biota, the desired water regimes to achieve determined management objectives with different priorities are set. Components of desired water regime of wetlands may include volume and timing of annual flows as well as frequency and duration of drought and floods.  In this study water desired regime was proposed at monthly time span for normal, dry and wet years. Then, based on the frequency and duration of historical floods and droughts a proper flooding pattern was also suggested.

*3.1.8. Scenario description*

By combining the prioritized objectives and relevant water regime, several scenarios can be developed. Subsequently, models can be used to assess the impact of supplying various water regimes on the status of a wetland. Predicting the likely outcomes of various water supplies, assist decision makers to reach better trade-offs between different uses and values. We used SWAT, a basin-scale rainfall-runoff model developed by USDA [14], to simulate wetlands conditions under various scenarios.

*3.1.9. Assessment of wetland water quality*

One of the main concern about wetlands health relates to water quality. Although the aim of wetland EWR allocation is not meeting the water quality requirements by dilution strategy, water quality of the wetland under various EWR scenarios should be assessed. Then, the wetland water quality indicates whether it is required to revise the determined EWR to fulfill the water quality requirements or not. We used QUAL2K model to simulate water quality of upstream rivers discharging into wetlands.

*3.1.10. Checking the feasibility of supplying EWR*

It is possible that under post-development condition some EWR scenarios become infeasible for supply. This may be either due to limitation of inflows under new climate condition or structural limitations. Therefore, using the determined pattern of supplying EWR in the previous step, it is judged that whether it is possible to deliver the determined amount of water under current condition or not. Therefore, EWR scenarios are filtered and the remaining EWR scenarios are used for further evaluation.

*3.1.11. Socio-economic impact assessment*

The socio-economic challenges associated with supplying EWR of a wetland in over-allocated and overused basins are of high importance. To insure the successful implementation of the determined EWR, socio-economic impacts on the rural communities should be assessed. Furthermore, stakeholders should be informed about the benefits of supplying the wetland EWR and loosing environmental services in case of inadequate water supply to the wetland. This step aims at involvement of stakeholders in determining wetland EWR and to find cost-effective ways to enhance the supplying EWR scenarios. This step was undertaken with the aid of local Non-Governmental Organizations.

*3.1.12. Prescribing the required water allocation*

Sometimes the wetland EWR is determined in terms of the volume of stored water in the wetland. However, for water allocation trade-offs it should be expressed in terms of the required inflows at the appropriate time scale from relevant sources. This can be performed by the inverse water balance calculation. Moreover, the proportions of various water resources of the wetland including surface and groundwater discharges need to be calculated.

*3.2. Integrating Environmental Flows of Upstream River with EWR of Wetlands and Urmia Lake*

Once the amount and timing of water allocation for wetland EWR are determined, it should be considered in conjunction with the river environmental flows. When calculating environmental water allocation to the river, both environmental flow (EF) of the river itself and the downstream wetland EWR (WEWR), which is conveyed through river, should be considered. In some cases EF of the river may be sufficient for supplying the desired EWR of wetlands too. Nevertheless, that is not the case for most of the regulated rivers, particularly in arid regions where there is an intense competition for water. Therefore, supplementary water should be allocated to supply EWR of the downstream ecosystems.

In this study, as depicted in Fig. 1, some of the southern rivers of Urmia Lake reach directly to the lake, while others like Zarrineh and Mardogh Rivers are discharged into a wetland and then inflow to the lake. For the latter case the procedure of Fig. 4 should be followed to determine the appropriate water allocation to fulfill environmental objectives in rivers, wetlands and Urmia Lake. This requires trial and error, especially when water allocations are intended to be determined for several EWR scenarios.

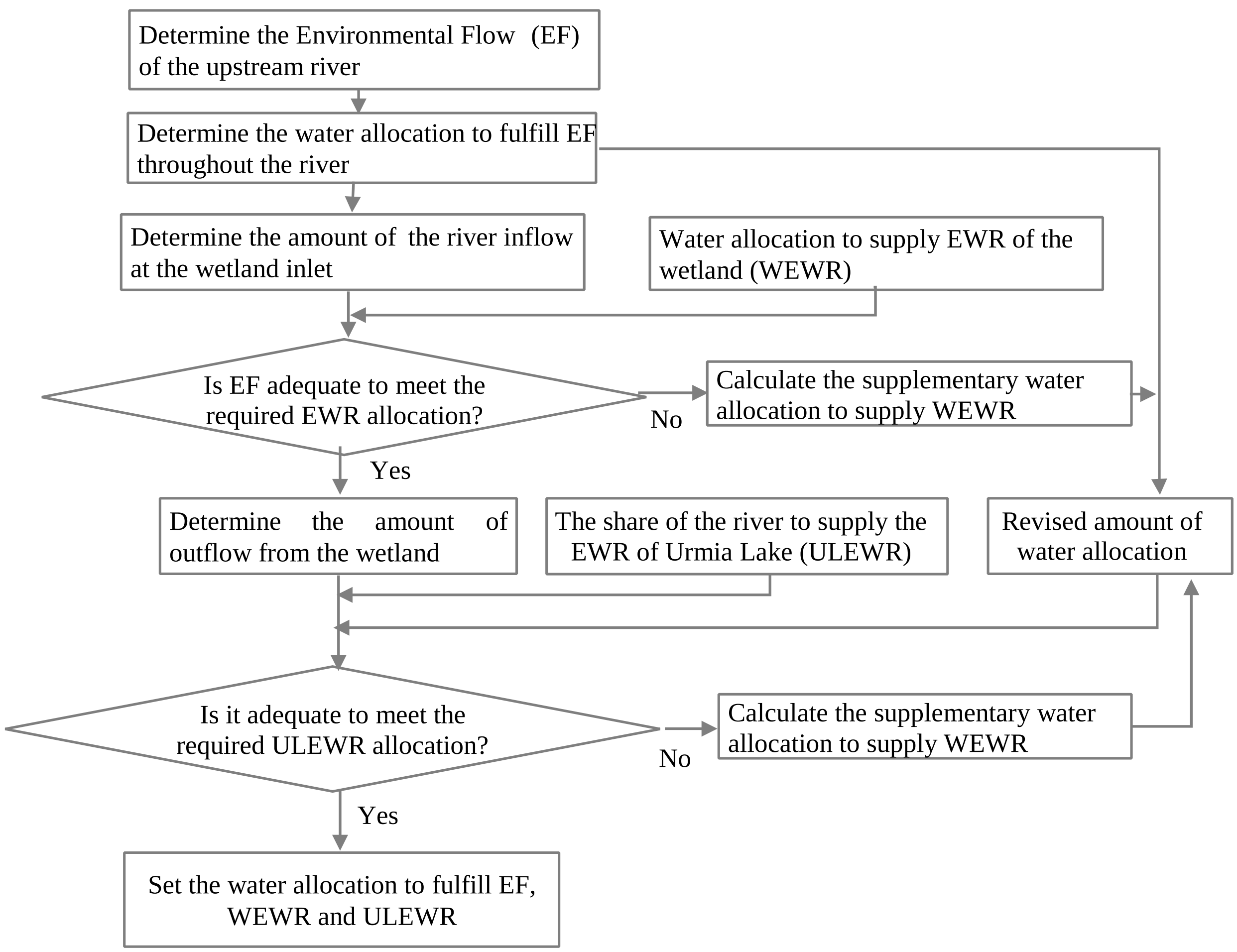


*Figure 4: Procedure for determining water allocation for the river environmental flow as well as the wetland and UL EWR.*

## 4. Results and Conclusion

This study addressed the issue of determining environmental water requirements of four wetlands located in the coastal area of Urmia Lake. A comprehensive ecological-driven approach is proposed to determine the EWR of wetlands considering the limitation of data. Then, through a procedure adequacy of water allocation for environmental flows of upstream rivers was assessed to simultaneously fulfill the EWR of the downstream wetland and Urmia Lake. Application of the proposed approach for the case of Urmia Basin as a large basin, is promising for integration of wetlands and the lake EWR into environmental water allocation at basin scale.


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# Ecological and Hydrological Constraints on Large-Scale Wetland Restorations in the Iraq Mesopotamian Al-Ahwar (Marshes) and the Florida Everglades: A Comparison

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### *Abstract*

Both the marshes of Iraq and the Florida Everglades have been significantly reduced in size due to upstream water storage and use for agriculture and cities and massive water drainage programs to convert these areas mainly to agriculture lands or provide access for oil exploration. Today <10% of the natural Iraq marshes remain, although governmental efforts are underway with limited budgets to restore water flows, recreate their natural hydrologic conditions, restore ecosystem structure and functions as well as create protected areas for the thousands of remaining endemic Marsh Dwellers. Together, the Federal U.S. government and the state of Florida have spent several billion dollars to restore the water supply and ecohydrology for the remaining 50% of the Everglades, which includes native Seminole Indian Reservations. Both governments face enormous social-economic and political difficulties regarding the future allocation of water for the marshes as the demand for water for agriculture and urban areas grows. This article compares and contrasts the past and current ecological conditions in the marshes, outlines the hydrologic issues facing these wetlands today as well as reviews some of the proposed solutions. Not surprisingly, regardless of a country's wealth or political system, both wetland ecosystems and their native flora and fauna face survival challenges due to human demands for water, land or resources coupled with anthropogenic pollution and salinity increases.

***Keywords: Mesopotamian Marshes, Everglades, Hydrology, Water Quality***

## 1. Introduction

Two of the great wetlands of the world, the Mesopotamian marshes (Al-Ahwar) of Iraq and Iran and the Everglades of the United States have both undergone massive drainage mainly for agricultural land development. In the Everglades case, additional wetlands were converted to urban areas due to a population explosion in Florida during the last century, while in Iraq oil exploration and drainage for movement of troops during a decade long war with Iran in the 1980s and 90s resulted in more than a 90% loss of marshes [1-3]. The Everglades today are only 50% of their original size. Amazingly, during the drainage and destruction of both wetlands they had indigenous populations living within the marshes for protection due to their earlier persecution by their respective governments over the past few centuries (Fig. 1). In both cases the marshes provided not only sustenance but also they were critical to the survival of thousands of Native Americans and over 500,000 marsh Arabs [4-7]. Fortunately, after much suffering at the hands of the military both native populations survived to see their governments set aside large portions of their wetlands as either Indian Reservations in the case of the Missaukee and Seminoles tribes in the Everglades in the 1920-50 period and in 2007 the Al-Hawizeh marsh in Iraq was named a Wetlands of International Importance “Ramsar Site”. By 2015 two additional wetland areas (Al-Hammar and Central) were included as Ramsar Sites in Iraq and in 2016 the Iraq marshes were named A World Heritage Natural Site, further protecting the native wetlands for the *Ma’dan* or native Marsh Dwellers. Given their somewhat parallel history of wetland destruction it is interesting to assess what impact this has had on their human ecology, ecosystem function, and restoration potential.


*Figure 1: A) upper left panel, Seminole Indian family in a village in the Everglades around 1900, B) upper right panel, Seminole Indian man in his wooden dugout canoe made from a cypress tree in the Everglades in the 1920 period, C) lower left panel, View of Marsh Dwellers in their village in the Mesopotamian marshes in 2004. Note the baking oven in the foreground and Mudhif (reed home) in the background, D) lower right panel, Marsh Dweller men poling among the common reeds in the Al-Hawizeh marsh in a Mashuf (wooden boat). (Seminole photos courtesy of Florida State archives and Iraq photos taken by Curtis Richardson.)*

## 2. A COMPARISON OF WETLAND ENVIRONMENTS

Notably, there are social-economic and political similarities between the marshes of Iraq and the Everglades and when coupled with the significant losses in ecological functioning in both wetlands due to drainage and reductions in water flow it becomes clear that regardless of a country's wealth or political system, wetlands face survival challenges due to human demands for water, land or resources. For example, both wetlands had endemic native tribes living within their borders for centuries that as mentioned earlier barely survived as a result of historical governmental persecution. These wetlands also provided habitat for rare and endemic plant and animal species, including massive winter bird populations that nearly faced extinction. A brief summary comparison of the similarities and key concerns facing both wetlands is outlined in Table 1. Both wetlands face severe hydrologic constraints as well as pollution problems and this will be covered in detail in section 3 along with review of the climate, geologic and ecological conditions that created each wetland type.

TABLE 1. A COMPARISON OF THE ECOLOGICAL, SOCIAL AND POLITICAL SIMILARITIES BETWEEN THE IRAQ MARSHES AND THE EVERGLADES WETLANDS OF FLORIDA BASED ON RESEARCH BY RICHARDSON ET AL. [1], RICHARDSON AND HUSSAIN [2] AND RICHARDSON [8].

| **Similarities Between the Everglades and Mesopotamian Al-Ahwar (Marshes)** |
|---|
| • Vast Wetland Area Dominates the Landscape<br>– Both have Wetland Areas in the RAMSAR Convention and are World Heritage Sites<br>• Endemic Native Tribes Survival Depends on Living in the Wetlands<br>• Major Bird and Mammal Habitat & Rare Species.<br>• Long-term Drainage History for Agriculture<br>• Increased Diking and Draining since 1950<br>• Presence of Invasive Plant and Animal Species<br>• Increasing Salinity & Decreased $H_2O$ Supply<br>• Oil Deposits found Beneath Wetlands<br>• Badly in Need of Hydrologic Restoration<br>• Political and Economic Constraints Control Restoration |

Both wetlands are driven by pulsed hydrology but are very different in terms of the delivery source (Table 2). The Everglades is a precipitation (PPT) driven system while the Mesopotamian marshes depend on spring snowmelt and river runoff. The Iraq marshes are surrounded by desert and have little rainfall and have very high evapotranspiration (ET) rates compared to the subtropical Everglades, where ET<PPT. Both are underlain by limestone substrates but the Everglades is an alkaline peat fen while Iraq's wetlands are marshes whose soils are mineral alluvium.

Both wetlands have alkaline pH surface waters and suffer major pollutant issues due to either P runoff from agricultural runoff in the case of the Everglades or salinity problems in the Iraq marshes due to high salinity in river runoff from agricultural lands coupled with high ET rates [8,9]. Interestingly, both systems suffer from mercury (Hg) trace metal contamination. Both wetlands are dominated by a single macrophyte species. In the case of the Everglades, *Cladium jamaicense* (sawgrass) covers vast areas of the higher portions of the landscape, along with dense blue-green cyanobacteria periphyton mats in the open water areas, while the Iraq marshes are dominated by *Phragmites australis (*common reed grass) with Diatoms in the water column. A detailed study of the vegetation and their responses to hydrologic changes and water pollution in the Everglades is summarized in a volume by Richardson [8], and a wonderful analysis of vegetation responses to re-flooding in the Mesopotamian marshes was produced in 2010 [10]. Finally, both wetlands have native populations living within the marshes but the economic differences are enormous as the Seminole and Miccosukee tribes both have thriving casino and recreational tourism businesses while the marsh dwellers of Iraq are very poor and survive on hunting and fishing in slowly recovering areas of the marshes [11].

TABLE 2. BRIEF COMPARISON OF THE KEY DIFFERENCES IN CLIMATE, GEOLOGIC AND ECOLOGICAL CONDITIONS IN THE IRAQ MARSHES AND THE FLORIDA EVERGLADES BASED ON RESEARCH BY RICHARDSON ET AL. [1], RICHARDSON AND HUSSAIN [2] AND RICHARDSON [8].

| Some Ecological Comparisons Between the Everglades and Mesopotamian Marsh Ecosystems | |
|---|---|
| ***Everglades Fen (Subtropical)*** | ***Mesopotamian Marshes (Arid)*** |
| • Hydrology (pulsed)<br>– Rainfall Driven: wet/dry season<br>– 132 cm yr. ET< PPT<br>• Bedrock: Karst Limestone<br>• Soils: Organic (Histosol)<br>• Water pH: 7.5-8.0<br>• Water Depth: 1-3 m in Wet Season<br>• Vegetation: *Cladium/Typha*/Cyanobacteria<br>• Pollutants: P, Hg, Na & S<br>• Tribal wetlands population: 4,000-5,000 | • Hydrology (pulsed)<br>– Spring Snow Melt<br>– 10-20 cm yr. Rainfall, ET > 250 cm yr.<br>• Bedrock: Calcareous Limestone<br>• Soils: Mineral Alluvium<br>• Water pH: 7.5-8.4<br>• Water Depth: 1-4 m in Wet Season<br>• Vegetation: *Phragmites*/Diatoms<br>• Pollutants: Na, Cd, Se, Hg, hydrocarbons<br>• Tribal marsh population: 50,000 to 100,000 |

## 3. MESOPOTAMIAN MARSHES

### *3.1. Background Ecology*

Iraq's Mesopotamian marshes are considered by many to be the "cradle of western civilization" and are frequently referred to as the Garden of Eden [5,6]. The word Mesopotamia means "between rivers," a reference to the Tigris and the Euphrates rivers that provide the major water supply to the marshes. During the Islamic Age the lakes and marshes were called Al-Bataih, "the lands covered with torrents" [12]. The marshlands are located in southeastern Iraq, but also are found across the border in Iran and are located between 31° 01' N 46° 14' E and 30° 34' N47° 47' E. These wetlands comprise three main areas, which are the Al-Hammar, the Central (Qurnah), and the Al-Hawizeh Marshes (Fig. 2). They were formed under ancient marine deposits following the postglacial transgression over the past 18,000 years as rising and falling sea levels changed the nature of the area from brackish lagoons to freshwater marshes [13]. The climate of the marshes is dominated by temperatures that can reach 50 °C in the summer, with virtually no rainfall (< 185 mm per year) and extremely high ET (> 2,000 mm per year) [12]. Water depths vary by season and can range from no standing water to depths nearing 4 m. The Mesopotamian marshes were once the largest wetlands in southwest Asia and covered > 15,000 km$^2$, an area nearly twice the size of the original Everglades. However, by the year 2000 less than 10% of the area remained as functioning marshes [1,14,15]. The only remaining marsh of any size was the northern portion of Al-Hawizeh (site 3, Fig. 2), which straddles the Iran-Iraq border. The Al-Hawizeh, called Hawr Al-Azim in its Iranian portion, together comprise the best remaining natural marsh in the region. The other two marshes, Central (also known as the Qurna marshes with the largest historical lakes (site 2 Fig. 2), and Al-Hammar with tidal influences (site 1 Fig. 2) were almost totally destroyed by drainage by 2000 (Fig. 3AB). This catastrophic environmental disaster was perpetrated in the marshlands of southern Iraq by Saddam Hussein's regime, especially from 1985 to 2000, resulting in the total collapse of the Central and Al-Hammar marshes. The remaining Al-Hawizeh was only 35% of its 1977 size of 3,076 km$^2$ by 2000 [1,2]. Thus, more than 75,000 Marsh Arabs were forced to flee Iraq and live in refugee camps in southern Iran for over 10 years until the end of the fall of Saddam's regime [6]. The refugees had mostly returned to Iraq by the end of 2005, but they found few viable marshes remaining (Fig. 3).

At the end of the two Gulf Wars several hundred thousand Marsh Dwellers were homeless with their settlements burned, livestock killed, fishing and date palm industries devastated, and most importantly their marsh home turned into mostly desert. The loss of these ecologically critical wetlands was of major concern because they were reported to be the former home of 300,000 to 500,000 indigenous Marsh Arabs [16,17]


*Figure 2: Regional map of Middle East showing the location of the three main areas of the Mesopotamian Marshes (1: Al-Hammar, 2: Central, and 3: Al-Hawizeh) of southern Iraq (colored dark green). The main water sources for the marshes are the Euphrates and Tigris Rivers.*

Thus, by 2005 both the marshes and the ancient *Ma'dan* culture were in jeopardy of becoming extinct. However, Alwash [18], in an informative book on the recent history of the *Ma'dan* and the impact of drainage on the Iraq marshes, suggested that the number of *Ma'dan* who actually lived and solely depended on the marshes for a living were probably closer to 50,000 to 100,000, but no census was done prior to the Gulf wars. She also wrote that the majority of *Ma'dan* by that time were actually farmers (*fellah*) who lived on the edge of the marshes but used them for hunting or fishing [18]. Today the Marsh Dweller population living in the marshes is estimated to be less than 100,000 [19]. The remainder is living in scattered villages throughout the desert or are refuges in the larger cities [11].

The marshes were also once famous for their biodiversity and cultural richness. They were the permanent habitat for millions of birds and a flyway for millions more migrating between Siberia and Africa [20,21]. More than 80 bird species were found in the marshes in the first complete census in the 1970s [21]. Populations of rare species like the marbled duck (*Marmaronetta marmarometta*, 40-60% of the world population), Basra Reed Warbler (*Acrocephalus griseldis*, more than 90% of the world population) were thought to be close to extinction [21] but were found in bird surveys in the mid-2000s [22], and more recently it was reported that they had extended their breeding range to the marshes and western part of Iraq [2,23]. Coastal fisheries in the Persian Gulf used the marshlands for spawning migrations, and they served as nursery grounds for penaeid shrimp (*Metapenaeus affinis*) and over 20 fish species.

*Figure 3: A) The left panel shows cattle feeding on desert plants in a portion of the drained southern Al-Hawizeh marsh in 2004. The Iranian dike cutting water flow from the Karkheh River into the marsh is seen on the horizon in the distant background, B) The right panel shows a view of the un-drained Al-Hawizeh (N 31, 38.583, E 47, 35.203) in Iraq with water buffalo feeding on common marsh reed grass.*

However, fish catches significantly decreased as a result of marsh drainage [20,24], but recent surveys indicate that key populations of fish were recovering in numbers in 2005 and 2006, although the sizes were small [25]. Of concern was the decrease of fish and macroinvertebrates from 2006 to 2007 due to reduced water levels, indicating that hydrologic conditions closely control recovering populations [25].

The marshlands also once served as a natural filter for waste and other pollutants in the Tigris and Euphrates Rivers, protecting the Persian Gulf that had become noticeably degraded along the coast of Kuwait [14,20,26]. In 2015, AlMaarofi [9] reported that ~ 45% of the annual water discharge of the Tigris and Euphrates Rivers was lost by 2002 and that the average water salinity of the two rivers in 2006 –2007 was nearly twice their historical level of 0.4 g/L (Fig. 4AB). Moreover, she reported that the Mesopotamian marshes increased in salinity from their historical level, 0.4 g/L, to 2.5 g/L during the 1980s and then declined to 1.1 g/L after re-flooding (Fig. 4C). The high salinity values found, especially during the re-flooding period, were from re-dissolution of salts that accumulated during the desiccation period, while the persistent increase relative to historical values was reported mainly due to increased salinity of the inflowing rivers and longer water residence in the marshes [9]. Her study also showed that water quality variables like dissolved oxygen, pH and nitrate show little change from historic values after re-flooding but increases in total dissolved solids, chloride and sulfate indicated that the marshes were impacted greatly by drainage and desiccation due to diking. Of further concern in the marshes is the amount of pesticides and trace metals like mercury and selenium, which can affect the food chain. Latif et al. in two recent studies [27,28] were able to measure both pesticides and mercury and found that pesticides like organochlorines were present in the marsh sediments, but were probably very low due to high summer temperatures (> 50 °C) and sunlight degradation over the > 10 years of marsh soil desiccation. Mercury (Hg) was however present and, like the selenium (Se) found in 2003 [1], could pose a toxicity problem to inhabitants who eat excessive amounts of fish. Finally, concerns about polycyclic aromatic hydrocarbons (PAHs) from petroleum spills have also been a concern in the marshes in southern Iraq but recent studies have shown only localized spill problems with overall levels in the sediments low with only slightly adverse biological effects levels reported [28]. Thus, according to Latif's survey PAHs are not the main pollutants of potential concern in the marshes at this time, except near oil spills.

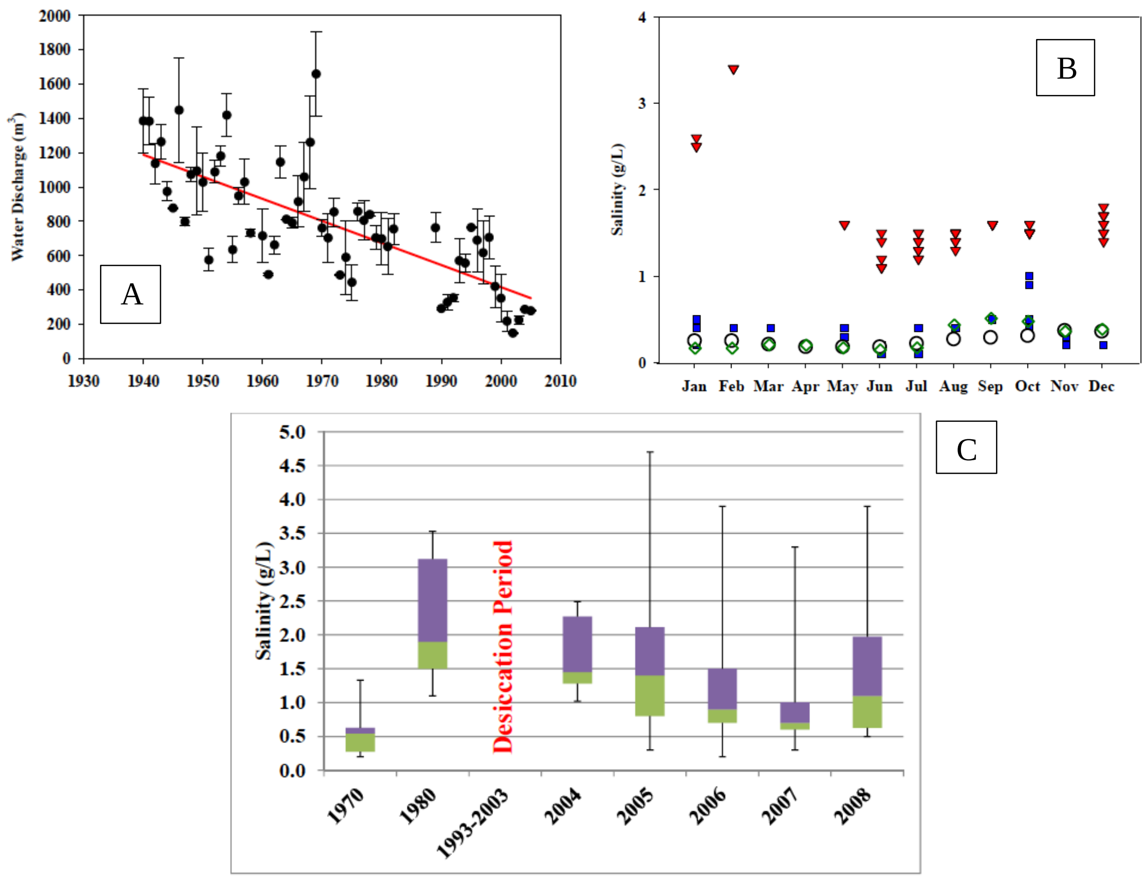


*Figure 4: A) The average water discharge (excluding flood years) of the Tigris and Euphrates River measured at Kut and Al-Nasiriya [9], B) Comparison of salinity of the Tigris and Euphrates Rivers pre-desiccation (1958-59 shown in blue and green) and after re-flooding (shown in red 2006-07) [9], C) Average salinity changes in the marshes of Iraq over the past 40 years [9].*

### *3.2. Hydrological Constraints*

The lack of water poses a serious threat to the survival of the marshes. A series of major international transboundary water diversions include the completion of the massive GAP water project in Turkey with 22 dams supplying irrigation water to 1.7 million ha of agriculture lands and the Tabqa dam project in Syria supplying water to 345,000 ha of irrigated land [29]. In addition a dam built by Iran to cut the Iranian water supply from the Karkheh River to the Iraqi portion of the Al-Hawizeh was completed by 2001 and has seriously reduced water flow into the marsh [29,30]. The Ataturk Dam built in 1998 can store more than the 30.7 billion cubic meters of water that flows from the Euphrates annually from Turkey into Iraq and can almost alone dry up the Euphrates [14]. Projected future demands on water for agriculture and people are enormous with estimates of Iraq water needs close to 95 billion $m^3$ by 2020 [31] (Table 3). These water use demand estimates are probably too high but do indicate that a goal to restore 10,000 $km^2$ of marshes requiring 20-30 billion $m^3$ of Iraq's available water is not possible after the diversion of water by dams in Turkey, Syria and Iran [29,30,32]. It is clear from these upstream water diversion projects and domestic use estimates that there will not be enough water to meet the projected needs for Iraq's population and agriculture, and thus the marshes will be in direct competition for water. This has been true especially during extensive drought years in 2008 and 2009 when the marshes suffered greatly from a lack of water [10,25]. Zhang and Abed [3] reported that the marshlands collectively, due to the construction of dams, intensive drainage schemes and drought, had by 2011 been reduced to 8,926 $km^2$ or 70% of their original size (Fig. 5). The marsh area losses were 46.7%, 76.9% and 30.5% for the Central, Al-Hawizeh and Al-Hammar, respectively. The magnitude and rate of wetland loss is astonishing and on an environmental genocide scale comparable to the draining of the Aral Sea and deforestation of the rainforests of Amazonia [14].

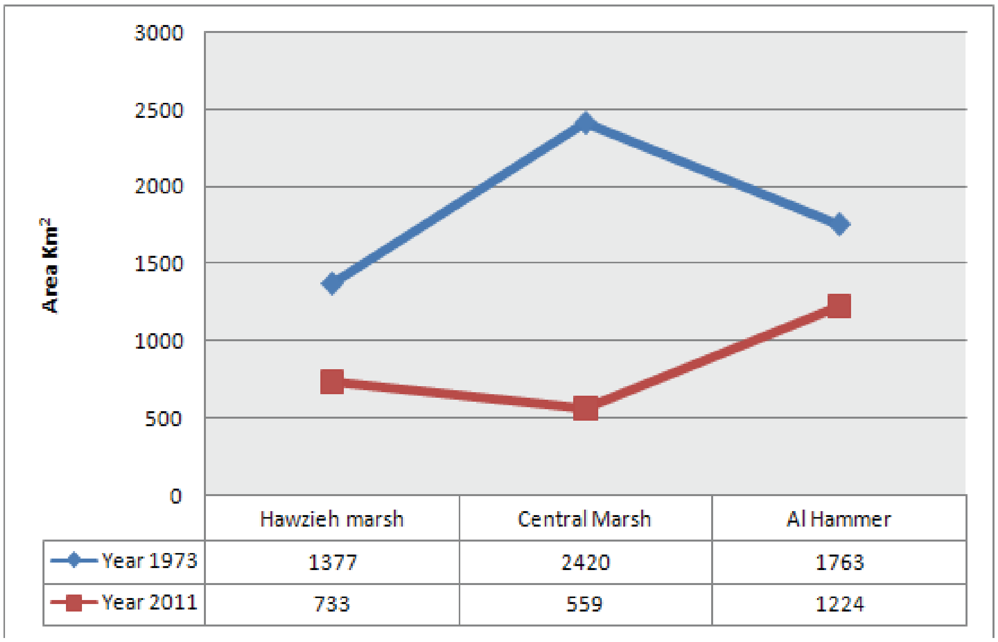


*Figure 5: Changes in the surface area of the Mesopotamian marshes in Iraq due to drainage and a loss of water from the Tigris, Euphrates as well as drought. The 1973 period represents pre-drainage conditions and the 2011 period reflects the area after re-flooding and restoration of the marshes following the massive drainage that took place in the 1980-2000 period as well as 2008-2010 droughts [3].*

In 2003 the Iraqi regime was removed and a restoration program was started to restore the Mesopotamian marshes by re-flooding through both national and international efforts [31,33]. Five years later 58 % of the wetland was recovered [33], with the coverage of the Mesopotamian marshes reaching 4,950 $km^2$ by 2008 [12]. However, the coverage declined to 3,420 $km^2$ in 2009, largely resulting from the Ataturk dam significantly reducing river flow from Turkey along with a dramatic decrease of freshwater discharge from the Tigris and Euphrates [32]. The long-term effects of alterations in water flow on marsh vegetation from 2000 to 2012 are shown on Fig. 6 [32]. Handal and Hu's recent detailed estimate of water flows into the marshes and the response of vegetation showed three distinctive regimes of water flow over time: 2000-2003 with low water and reduced vegetation due to drainage effects, 2004-2008 with increased water inputs from local dam releases and expanding vegetation cover, and a significant reduction in flow and drop in vegetation cover in the 2009-2012 period due to extended droughts and dams restricting flows from the Tigris and Euphrates and Karkhah Rivers [32]. The construction of dams and years of drought by 2010 resulted in the marshes losing half of the area they covered in 2008 after nearly five years of re-flooding. The long-term vegetation changes estimated for each of the three marshes corresponded closely to changing water patterns (Fig. 6). Currently, only 10% of the historical marshland area remains. A ground view of natural Al-Hawizeh marsh in Iraq compared to the drained areas of the marsh provides a realistic picture of the magnitude of the restoration effort that will be required to sustain these wetlands in the future (Fig. 3AB).

TABLE 3. INFLOW (BCM) AND WATER QUALITY IN THE TIGRIS AND EUPHRATES BASINS [31].

| | **Turkey-Syria borders (Euphrates)** | | **Iraq–Syria borders (Euphrates)** | | **Iraq – Turkey borders (Tigris)** | |
|---|---|---|---|---|---|---|
| | *Before Construction* | *After Construction[1]* | *Before Construction* | *After Construction[1]* | *Before Construction* | *After Construction[1]* |
| **Avg. Annual Inflow (BCM)** | 32 | 14.2 | 30.4 | 8.5 | 19.4 | 9.2 |
| **Water Quality (Dissolved salts) ppm** | 250 | 500 | 457 | 1,250-1,350 | 250 | 375 |

[1] predicted

- Total water available to Iraq after dam completion in Turkey and Syria is 48 billion $m^3$ (BCM).
- Total estimated water needs for Iraq in 2020 is 95 BCM.
- A deficit of 47 BCM, is expected.
- Restoring about 10,000 $km^2$ of the marshes would require 20-30 BCM of water, about 50% of Iraq's available water

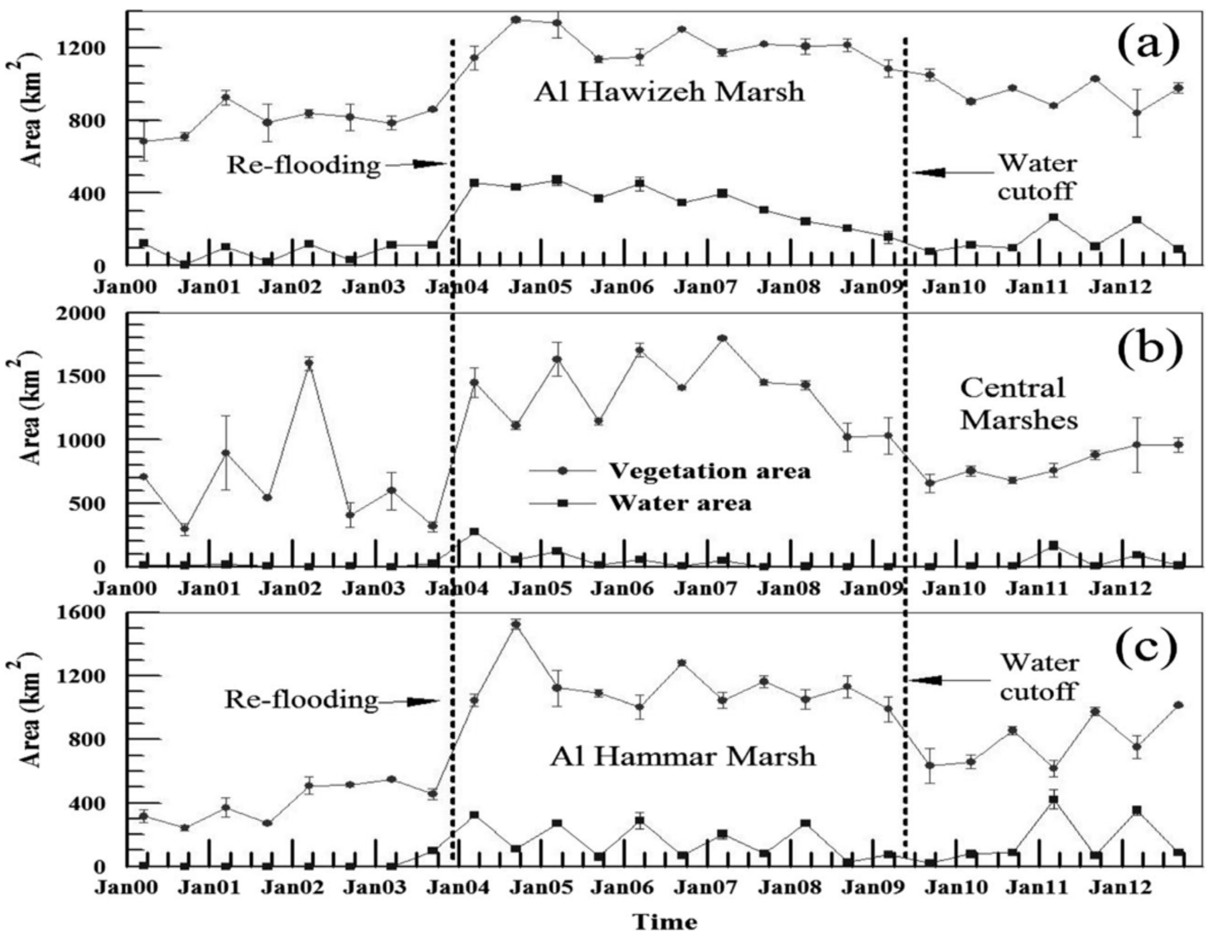


*Figure 6: Corresponding vegetation changes to variations in water supplied to the three main marshes of Iraq (a) Al-Hawizeh, (b) Central marshes, (c) Al-Hammar. The major changes in vegetation are found before and after re-flooding (2004) and when water was cut off by dams and/or increased drought as found during the 2009-2010 period. (Figure from [32]).*

### 3.3. *Water Restoration*

In 2014 a Ramsar report indicated that the Al-Hawizeh Marsh, the only remaining natural area left of the Mesopotamian marshes is "facing a complex range of site-specific, basin-wide and national threats, many of which have been well documented by studies and projects in the past decade [29]. The main threat is the decreasing input of water, primarily due to the construction of upstream water control structures in the river basin that feeds the marsh, and to declining rainfall. In addition, there are emerging threats, including from oil production around and within the marsh itself. These threats are compounded by the insufficient communication and cooperation between the different national government ministries, and between the national ministries and governorate departments [34]. There also appears to be insufficient communication between the ministries and companies involved in oil production and with the Centre for the Restoration of Iraqi Marshes and Wetlands, (CRIM) and the Ministry of Water Resources (MoWR), who are responsible for the conservation and wise use of the Al-Hawizeh Marsh Ramsar Site under the "Convention on Wetlands" [34].

However, even with the multitude of economic and political problems facing Iraq, restoration of the Mesopotamian marshes is now underway. Release of water when it is available goes to former wetland areas, resulting in the return of native plants and animals, including rare and endangered species. Plans are now underway by the Eden Again Project in conjunction with the Iraqi government [18,35] to try to restore as much as 80% of the marshes. Al-Ansari et al. [12] report that 75% of the area covered by the marshes can be restored if 3,263, 5,495 and 4,128 $\times$ $10^6$ $m^3$ of water is supplied for the Al-Hammar, Al-Hawizeh, and Central marshes, respectively. Some say even this goal is way too high given the multiple demands on the water supply and the lower revised volume of remaining water projected to help restore the marshes. Nevertheless, the current recovery is remarkable, considering that re-flooding occurred only about ten years ago and extensive droughts have occurred. While some areas are experiencing reduced recovery due to salinity and toxicity problems, many locations seem to be recovering well, especially close to canals. The major unknowns are (a) whether the Marsh Arab culture can ever become established again in the restored marshes in any significant way, (b) how Iraq's multiple water use issues and competition for water with Turkey, Syria, and Iran will affect the future water supplies needed for marsh restoration, and (c) whether or not landscape connectivity of the marshes can be re-established to maintain species diversity. What is evident is that there is not a sufficient supply of water to fully restore all the marshes, and thus a series of marshes with connected habitats of sufficient size to maintain a functioning wetland landscape needs to be established. Clearly, the long-term future of the former "Garden of Eden" depends on the willingness of the Iraqi government to commit sufficient water for marsh restoration and sustain vital areas designated as Ramsar sites like the Al-Hawizeh and the recently (2013) dedicated Mesopotamia Marshland National Park, which is a unique wetlands complex rich in wildlife located in southern Iraq, North of the Euphrates River and West of the Tigris and Glory River.

## 4. EVERGLADES WETLAND

### 4.1. *Background Ecology*

Historically, the Everglades extended from just south of Lake Okeechobee, now the Everglades Agricultural Area (EAA), to Florida Bay (26°57'N to 24°53'N) where the Everglades National Park (ENP) is found (Fig. 7). The current longitudinal width of the Everglades, although greatly narrowed by coastal development, ranges from 81°37'W to 80°13'W. The Everglades, originally called Pa-hay-okee ("grassy lake") by the Native Americans, is today a 700,000 ha subtropical alkaline fen whose origin dates to around 5,000 BP when the rate of sea level rise slowed and peat began to accumulate in the shallow embayment of south Florida [8,36-39]. Before drainage, the "Glades" as they are called by the local Floridians were an almost impenetrable wall of sawgrass "plains" and reptile-infested waters according to the early Spanish and American explorers [40]. Starting in earnest around 1900 efforts to drain the Everglades and create agricultural land were underway but progress was slow [37]. Shortly after World War II the Federal government developed plans to virtually drain the entire Everglades. The Everglades was saved from total destruction by Marjory Stoneman Douglas's seminal 1947 book *The Everglades: River of Grass,* which also helped establish the Everglades National Park in that year, thus preventing the Glades from being totally drained, although approximately 50% of it was developed by the start of the 21st century. Thirty percent of the original 1,036,000-ha Everglades was converted to agricultural and urban development, and 350,000 ha of the original area put under state of Florida ownership as Water Conservation Areas (WCAs) 1, 2 and 3 for "flood protection, water supply, and allied purposes of navigation and fish and wildlife protection" as mandated by the 1948 U.S. Congressional Flood Control Act (Fig. 7). The remaining 565,000 ha comprise the ENP. The Everglades Park in 1976 was designated as a World Heritage Site and an International Biosphere Reserve. It is home to more than 70 endangered species and is the largest sub-tropical wetlands in the United States [8].

The ENP is also the largest federally owned peatland in the lower 48 states and is the only subtropical wetland ecosystem in the U.S. that is listed under the Ramsar Convention and as a Wetlands of International Importance. Because of its size, floral and faunal diversity, geological history and hydrological importance both as a freshwater deterrent preventing sea water intrusions on the Florida coastal landscape and by providing the drinking water supply for millions of people in South Florida, the Everglades are considered by many ecologists and conservationists to be the "sentinel wetland ecosystem" for testing the American government's resolve to restore and maintain vast wetland areas under ever increasing urban land development pressures, agricultural irrigation demands as well as eutrophication problems. As a result of these increasing water demands the Everglade is under highly regulated and ever changing water management regimes, which greatly alter the plant communities in the Glades [8,41,42].

The Everglades, with its mosaic of wetland communities, is often referred to as a marsh or swamp; however, it is correctly identified as a patterned fen peatland or mire by wetland ecologists [8,43-45]. The overall wetland complex is dominated by peat-based soils that historically formed under natural peatland hydrodynamics not present in many areas today due to extensive canal and dike systems (> 2,000 km). The classification of the Everglades as a fen or alkaline mire is important when one considers how different marshes and swamps are from mires in terms of their hydrologic controls, biogeochemistry, rates of peat accretion, plant and animal communities, and successional and geomorphologic development (Table 2). The hydrological differences alone would greatly manifest themselves in any attempt to restore native communities and animal habitats with the wrong hydrologic model. Unfortunately, the terms "Everglades mire" or "peatland" by themselves do not reveal the vital and multifaceted hydrologic connections and nutrient sources that historically existed between the Everglades and surface water runoff coming from Lake Okeechobee via the Kissimmee River (Fig. 7) the close connections of groundwater and surface waters in the region due to the karst limestone underlying the wetlands, and most importantly the seasonal influence of rainfall and occasional hurricanes all of which influence vegetation patterns [8,45,46].

The subtropical climate of south Florida has hot humid summers, mild winters, and a distinct wet season with 80% of the rainfall falling from mid-May through October [47]. Harvey and McCormick [48] report that 81% of the pre-drainage water budget for the Everglades was from rainfall, with 8% coming from Lake Okeechobee overflow, 10% from marginal runoff, and only 1% coming from groundwater. The Everglades has more in common with tropical climates in that a wet/dry season is probably more important to vegetation composition than winter/summer differences in temperature. Daily temperatures average above 27 °C from April through October in the northern part of the Everglades and from March to November in the south, but freezing temperatures do occasionally occur. The key component of climate controlling vegetation patterns and succession is the amount of precipitation. A 110-year weighted average analysis of annual rainfall over south Florida (1895 to 2005) shows distinct drought and heavy rainfall periods when compared to the long-term average annual rainfall of 132 cm per year. Evapotranspiration is also an extremely important component of the Everglades. It has been estimated that 70 to 100% of rainfall exits the Everglades in this way [8]. Evapotranspiration was also recently found to be the most important driver of hydrologic flushing times in the southern ENP. In a recent study, Sandoval et al. [42] reported that when ET was less than inflow rates even after new restoration efforts it resulted in longer flushing times for water in the southern ENP. These weather patterns, when combined with effects of dikes and canal drainage, have resulted in severe drying and flooding of portions of the Everglades with a resultant shift in plant communities. While annual rainfall is the main driver of hydrology, hurricanes (sustained winds of 120 km $hr^{-1}$) are also an important reoccurring event ($\simeq$ every 3 years) in south Florida. Thus, extreme hydrologic events like hurricanes and droughts have also had significant effects on the water budgets for south Florida and the Everglades.

The Everglades is a P-limited ecosystem, which originally survived on nutrients primarily from rainfall, limited surface flow, and recycling within the system, especially after fire [8,49]. In this P-limited system, plants and algal species evolved that can survive under total phosphorous (TP) water concentrations as low as 5–10 μg/L [50,51]. The exception to communities evolving under low P concentrations were tree-covered islands and the vegetation around alligator holes [49,52] as well as plant communities adjacent to Lake Okeechobee with its high historical TP concentrations > 30 $\mu g \cdot L^{-1}$ [8]. Another factor maintaining P limitations in the Everglades, unlike northern mires or the Iraq marshes, is the nitrogen-fixing blue-green algae community, or periphyton, found in open-water sloughs. Because of the periphyton community's high rates of nitrogen-fixation, Everglades soils are exceptionally high in nitrogen (2–4% by weight) [53]; thus, very high N:P ratios (>100) exist, further driving the system to severe P limitations [51]. While multiple studies have identified P as the primary driver of *Typha* (cattail) invasions, there is no question that the cutting of canals deep into the limestone bedrock and the diking and creation of water impoundments in the northern Everglades, which began in earnest in the 1950s changed the water hardness (e.g., $CaCO_3$) and in turn community plant structure [54]. The canal expansion also increased marl deposition and increased calcareous periphyton abundance as early as the 1920s according to paleo-ecological studies by Cooper et al. [55] and Waters et al. [54]. This increase in calcareous periphyton before agricultural expansion and creation of impoundments in areas like WCA-2 (Fig. 7) suggest canal-derived calcium inputs and to some extent early drainage followed by deeper water retention played an important role in initiating plant, algal and microbial community changes [8,45,54].

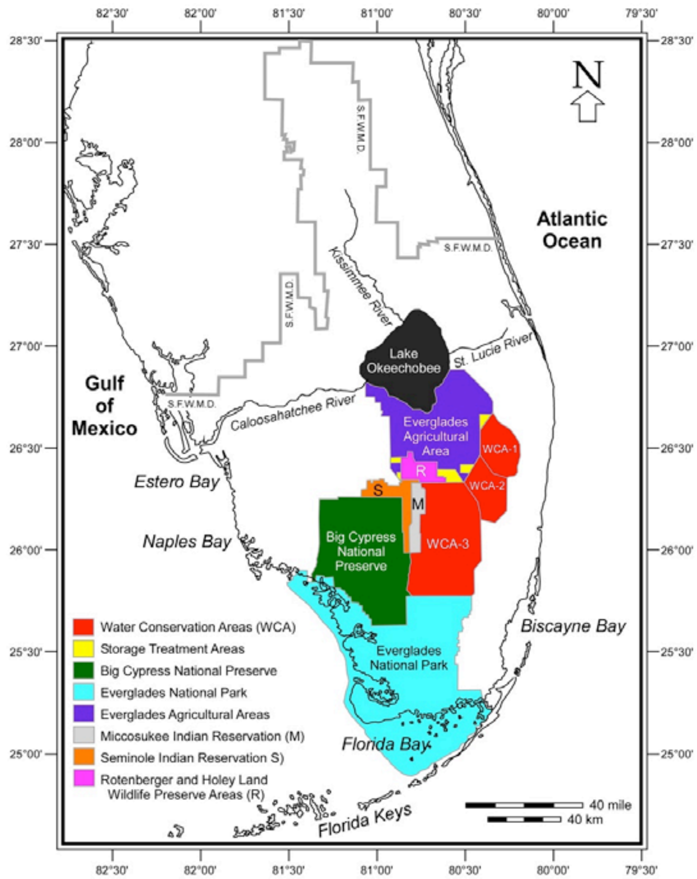


*Figure 7: A Map of the current boundaries of the South Florida Water Management District (SFWMD) that shows the Kissimmee River, Lake Okeechobee and Everglades land use complex. The Everglades is now divided into the state owned Water Conservation Areas (WCAs), Storage Treatment Areas (STAs), the Everglades National Park (ENP) and Everglades Agricultural Area (EAA). The surrounding areas are the Big Cypress National Preserve, Florida Bay and developed crop and urban land, a large part of which was former Everglades. Major water canals and, importantly, two Indian Reservations are also a part of the current Everglades. (From: [47]).*

Succession in the Everglades is influenced mostly by disturbance to the hydrology and, in turn, fire frequency and intensity (Fig. 8) [56]. Plant communities are found along an elevation gradient that translates directly into a hydrologic gradient, which controls fire intensity and frequency. The gradual build-up of marl soil or peat via accretion (1-2 mm/yr, [53]) results in the gradual increase in elevation, which changes the hydroperiod for the species. Ponds are the wettest sites, and soil accretion eventually allows them to develop into wet prairie communities, then willow (*Salix* spp.) heads and even sawgrass (*Cladium jamaicense*) if not severely burned. Frequent light fires have little effect on this successional sequence (Figs. 8 and 9). Severe fires burn the peat soil and lower the sites, which results in a reversal of this sequence and moves the communities back to wetter habitats. The lack of water due to drought or drainage allows for the invasion of upland macrophytes, scrub, and hardwood species. Alligator activity also acts to change the hydrology and nutrient status of areas and can result in pond development and maintenance [57,58]. More recent studies have demonstrated the importance of tree islands in the Everglades and revealed that they are phosphorus "hot spots" on the landscape, i.e., they act as a reservoir of P on the landscape due to the transfer of P from low concentration surrounding areas by roosting birds and predators [52,59,60]. The storage and release of high P concentrations from the tree islands have important implications for the ecological successional patterns of the Everglades that are not well understood. What is known is that the southern tail ends of tree islands are often areas of higher productivity due to the release of P and that burning of tree islands also releases large amounts of P to downstream areas [52]. The successional dynamics of the Everglades is thus mainly controlled by the interaction of climatic patterns (droughts and rainfall) and human alterations on hydroperiod, which in turn influences fire frequency and the degree of fire intensity as well as the transfer and release of P on the landscape.

The main difficulty for ecologists is in separating the influence of primary climate-driven factors like rainfall, hydroperiod, and fire from the secondary human-driven factors of drainage and flooding, nutrient additions, site disturbance, and exotic species invasions. Moreover, the influence of anthropogenic inputs of nutrients and water varies greatly in each portion of the Everglades, depending on proximity to canal input structures, mode of delivery (i.e., point or non-point source) and whether water delivery is seasonally pulsed or continuously released. Importantly, drainage canals and a massive water control system developed in the past 100 years have resulted in regulated hydroperiods (i.e., the number of days that the Everglades ecosystem has standing water at or near the surface) and altered hydropatterns (the distribution of water within the wetland), which in turn have changed fire frequency patterns and fire intensity (Fig. 8). Thus, climate alone is no longer the lone dominant factor controlling plant community succession since altered drainage patterns are so overriding throughout the Everglades [8].

Some may argue that phosphorus (P) is the main factor controlling the plant communities of the Everglades, but when one examines the amount of area impacted by P enrichment, it is not the case. While P enrichment can have a great impact on plant community structure, the actual area of the Everglades that is affected by P enrichment is not extensive. In fact, P impacts less area than that by invading exotic species. Qian and Richardson [61] found, for example, that WCA-1, WCA-3, and the ENP have 81, 91, and 94 percent of their area with soil P concentrations less than 500 $mg \cdot kg^{-1}$, a soil concentration maintaining the native species and preventing cattails from invading [62]. Levels above this indicate enrichment beyond historic levels [63-65]. Further supporting this view of the limited impact of P on the entire Everglades was the finding of Bruland et al. [63], who reported only 263 ha (0.11%) of WCA-3A displayed soils above 500 $mg \cdot kg^{-1}$.

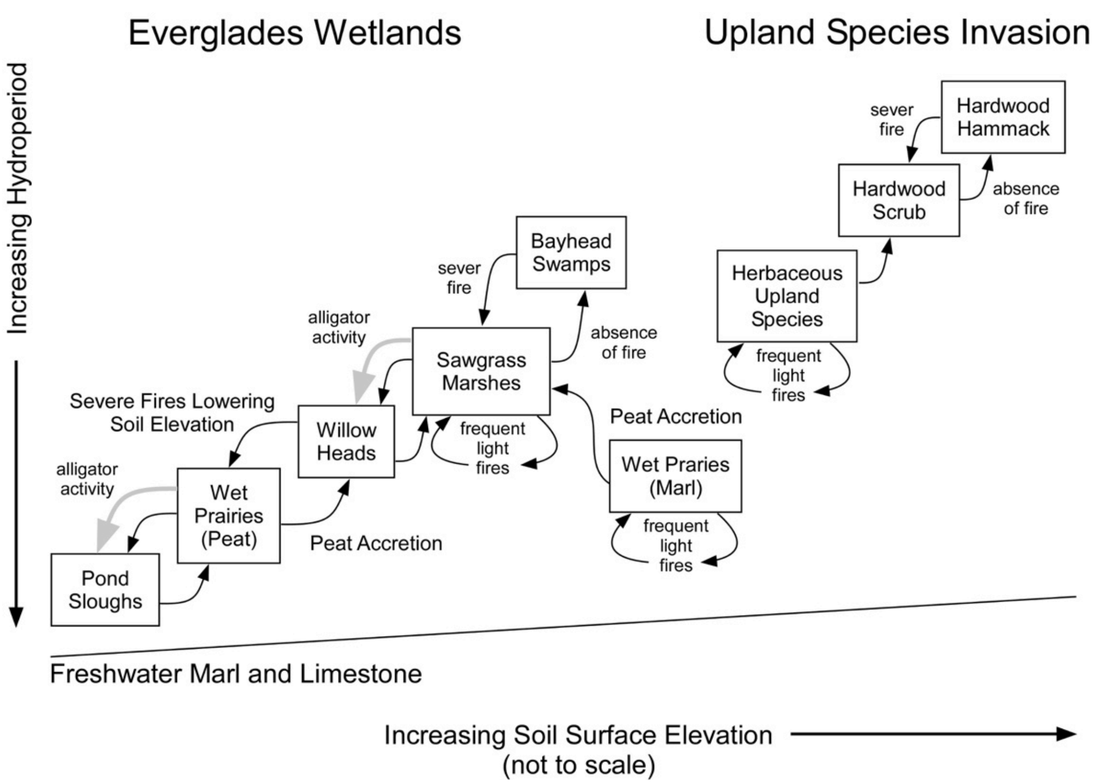


*Figure 8: Historic successional patterns in the Everglades showing the major plant communities and the importance of hydroperiod and fire interactions to develop the complex mosaic of vegetation found in the Everglades prior to major drainage. Modified from [8].*

*Figure 9: A) left panel, Aerial view of tree islands, sloughs, ponds, and grass plains in the southern Everglades during wet season. Note the surrounding sloughs (open water areas) and sawgrass stands (brown areas) with ponds (small circular deep water areas) scattered throughout. Deeper ponds are often created by fire and maintained by alligator activity [8], B) right panel, Ground view of a slough in the foreground transitioning into wet prairie and sawgrass stands near the tree islands in background (Photo: Richardson 2015).*

However, agricultural runoff from the Everglades Agricultural Area (EAA) and Lake Okeechobee (Fig. 7) did significantly change the nutrient inputs and balance in the Everglades after the 1970s because both contributed water with much higher concentrations of N and P than is typically found in rainfall and historic runoff in the Everglades [8,64,65]. Reddy et al. [66] estimated that phosphate loading in South Florida resulted in 400,000 metric tons of P being stored in the surface sediments and flocculent of lakes, rivers and soils of the Everglades and Lake Okeechobee. Nineteen percent of this total is stored in the Everglades itself with 35% in a non-reactive form and 65% is a reactive state. A proportion (10-25%) of this phosphate leaks from the system each year [66], causing major eutrophication problems.

The average TP concentration in water leaving the EAA farmland in the early 1990s was 150 μg $L^{-1}$ P, which was reduced to 115 μg $L^{-1}$ P in the canals and edges of WCA-1 [8]. However, by the time surface waters reached the structures above the ENP, concentrations were 10 μg $L^{-1}$ P or lower. The dumping of agricultural wastewater into the WCAs and using them as a sink for excess nutrients only accomplished this reduction. The result was thousands of hectares of cattail-dominated areas of the northern Everglades with high TP levels in vegetation, soils, and surface waters [8,67]. Thus, the control of cattail expansion and community shifts now depends on best management practices (BMP) in the federally mandated regulatory P-reduction program. The major hope for reducing TP loads into the Everglades is the use of Storm water Treatment Areas (STAs) to treat EAA, upstream and Lake Okeechobee waters prior to their release (Fig. 7). To date, 6 STAs covering over 16,564 ha have been built, the earliest in operation since 1994–95 (Figs. 7 and 10). More area has been added to the STAs by expanding their footprint and the areas now are in excess of 23,000 ha as of 2016.

In terms of TP reductions, both the BMPs and the STAs have resulted in a significant decrease of P to the Everglades. However, EAA outflow TP concentrations continue to remain too high, and while STA reductions are increasing they have not consistently reached the state of Florida mandated low safe threshold concentration of 10-15 μg $L^{-1}$ TP that had been hoped for by many scientists. While P mass loadings are significantly reduced by more than 50% for the EAA, P concentrations remain too high for major improvements in the receiving waters. For example, in a 16 year study (1995 to 2011) Chen and co-authors [68] reported that the STAs did remove 1,500 metric tons of TP from 13.6 billion $m^3$ of storm water runoff from farmland and adjacent drainage basins. They found storm water inflows to the STAs had an annual TP concentration of 143 ± 62 μg P $L^{-1}$, and an annual phosphorus loading rate of 1.56 ± 0.91 g P $m^{-2}$. Unfortunately, many of the

STAs exceeded their TP loading threshold of approximately 1 g P $m^{-2}$ $yr^{-1}$ [69] and released annual TP concentrations of 41 ± 31 μg P $L^{-1}$, which is far in excess of the Everglades Forever Act national pollutant discharge elimination requirements [70]. Importantly, by 2016 nearly 2,000 metric tons of TP have been removed by the STAs, and in 2015 average outflows to the Everglades were 17 μg P $L^{-1}$ [71]. If the present trend continues and no additional STAs are built, the Everglades will continue to receive unacceptable concentrations and loads of TP for the foreseeable future. However, the recent purchase of thousands of ha of farmland south of Lake Okeechobee provides a real opportunity to provide further nutrient reductions to help meet the established USEPA criterion of 10 μg $L^{-1}$ P for the Everglades by expanding the size of the STAs and developing a series of reservoirs to help store water and remove pollutants [41,71]. This plan could have significant positive consequences for the native plant communities and ecosystem structure and function if TP is reduced and the hydrologic regime is properly restored.

### *4.2. Hydrological Constraints*

The role Lake Okeechobee played in supplying water to the Everglades was initially not well understood (Fig. 7). Historically, lake levels in excess of 6 m were measured in the lake in the 1850s and as late as the early 1900s, and it was reported that when lake levels exceeded 6 m, water would spill over the soil bank on the southern part of the lake into the Everglades [45,47].

*Figure 10: Aerial view of storm water treatment areas (STAs) and pumping stations next to agricultural sugarcane fields. The remaining natural Everglades are located to the left of the diked road and power lines. The STAs are used to reduce nutrient loadings and organic floc into the Glades (photo courtesy of the SFWMD).*

Today the lake is 176,265 ha in size with an average depth of 3 m due to diking and water regulations. The pre-drainage shallow elevation gradient of 1.6–3.2 cm $km^{-1}$ coupled with deep overlying peat and dense native sawgrass allowed for storage of water during wet periods, slow water flow averaging 0.25 cm $s^{-1}$, and a gradual release of excess water during dry periods [72]. The importance of surface and ground water interactions in the Everglades was not really appreciated until the USGS report by Parker et al. [46] detailed studies on surface and groundwater flows and storage. Parker clearly showed for the first time the complexities of the hydrologic system that controlled the Everglades and that the extensive canal and dike system installed since the early 1900s had significantly altered water storage, surface and groundwater interactions, flow of water, and water depths throughout the Everglades. A more recent analysis by McVoy and co-authors [45] suggest that pre-drainage flow was much faster, water depths greater, and the patterned peatlands had less area of sawgrass plains and more sloughs. They also suggested a much greater role for Lake Okeechobee.

The difficulty of managing the hydrology of the Everglades starts with Lake Okeechobee, originally a primary source of Everglade water. Prior to 1930, Lake Okeechobee expanded and contracted depending on rainfall and inflows. After construction on the Hoover Dike was begun on the lake's southern borders in 1938 and completed all around the lake by 1960, water was confined and lake levels and outflows were totally regulated under a series of guidelines and a prescribed regulation schedule. The large littoral and marsh areas that extended north, south, and west of the lake were cut off from water by the dike, thus removing a large nutrient sink for the lake's excess nutrients. The main human-induced threats to the ecological health of Lake Okeechobee are now deemed to be excess nutrient loadings, especially P, altered hydroperiod, and invasion of exotic species [8,73]. Today outflow is highly regulated, as is the lake level under the current WS/E (water supply/environmental) schedules [74]. However, hurricane events and droughts have often greatly altered these schedules, and in 2016 there was great controversy over the increased pulsed releases of high P-laden water into the estuaries that caused severe eutrophication problems. Thus, maintaining water levels and standard release schedules are very difficult for Lake Okeechobee water managers, further complicating downstream Everglades water regimes. Further information on the WS/E schedule and regulations, the multitude of SFWMD temporary deviation release schedules, and guidelines for pulsed releases for each zone in the lake to the Everglades can be found at the SFWMD web site (http://www.sfwmd.gov/portal/page/portal/xrepository/sfwmd_repository_pdf/adaptive_protocol_2002final_0.pdf).

It has been estimated that the undisturbed Central Glades had approximately $1.49 \times 10^6$ $m^3$ of water, of which approximately half or $814 \times 10^6$ $m^3$ exited the Everglades to the Lower East Coast (LEC) yearly (Fig. 11). The historical total discharge for the LEC to the Atlantic was estimated to be $1{,}987 \times 10^6$ $m^3$ per year. By 1994 the annual Everglades water budget was highly regulated, and LEC flows dramatically doubled to $4{,}579 \times 10^6$ $m^3$ as freshwater water was being transported to the Atlantic Ocean via a complex series of canals and pumping stations at the expense of flows into the ENP (Fig. 11). Importantly, water inputs into the ENP were less than half of historic inputs and dramatic alterations to water flow were needed to save the WCAs and ENP from total destruction.

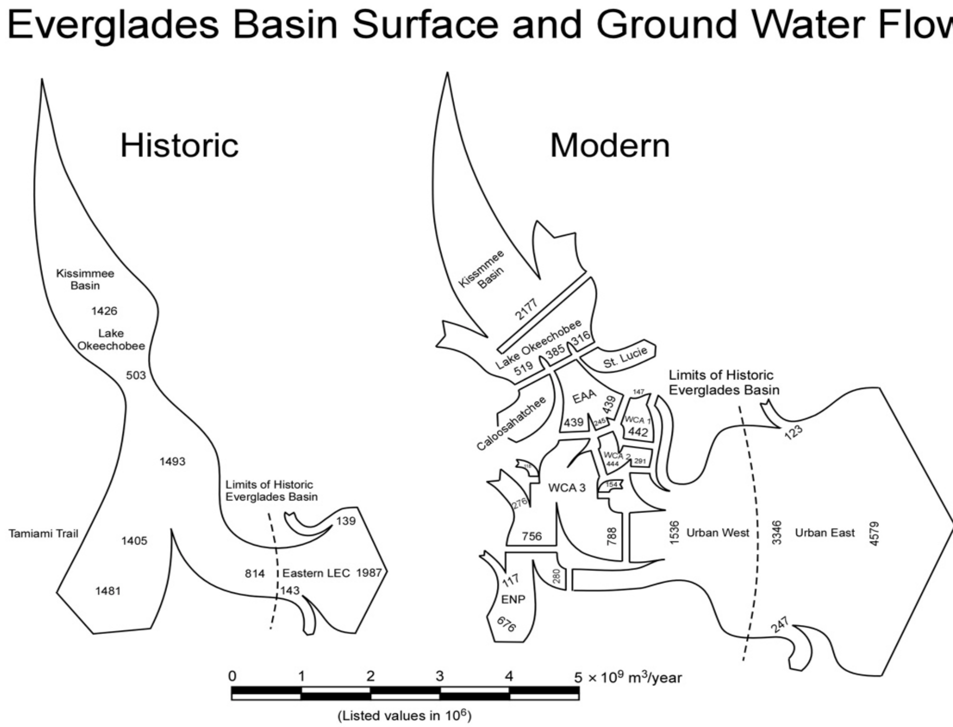


*Figure 11: Minard-type graphic of the historic (before 1880) and modern (1994) average annual water flows (based on 1993 SFWMD LEC Report data by Larsen, in [8], prior to newly established USACE release guidelines and structure discussed below and shown in Fig. 12). The line widths are proportional to the volume of the water flows. Values are given as $10^6$ $m^3$ per year.*

### *4.3. Water Restoration*

The implementation of the US Army Corps of engineers (USAEC) 1948 plan, more recent South Florida Water Districts Management District (SFWMD) plans (1990, 1992, 2006) and the Federal Governments Comprehensive Everglades Restoration Plans (CERP 1999) has resulted in a complex and often conflicting array of seasonally and annually revised (often revised during the year due to hurricane or drought conditions, etc.) water schedules for Lake Okeechobee, the WCAs and the ENP. By 2000 the Central and Southern Florida (C&SF) Project had over 1,000 miles (1,609 km) of canals, 720 miles (1,158 km) of levees, and approximately 200 water control structure that cover 16 counties and an area of over 18,000 square miles (6,948 $km^2$) from Orlando to the Florida Reefs. The Everglades alone had gone from 20 to 70 pump stations by 1996. As of 2015, a total of 106,852 hectares of land needed (64%) to implement CERP were acquired to provide space for new water reservoirs, STAs and new water flow structures [71].

The CERP plan a joint state and federal effort was designed to restore more natural flow to the Everglades complex, and increase water volume to the ENP without drowning tree islands in the northern and central WCAs [75]. Highlights of the plan, when implemented, proposed flows and allocations that would result in a 20% reduction per year of Lower East Coast (LEC) losses to the Atlantic Ocean, from $4{,}578 \times 10^6$ $m^3$ to $3{,}641 \times 10^6$ $m^3$ and $442 \times 10^6$ $m^3$ of new environmental water allocated to the ENP. Flows of $2{,}025 \times 10^6$ $m^3$ per year into Lake Okeechobee were projected to be near 1994 levels, but outflows to the Caloosahatchee were doubled from $519 \times 10^6$ $m^3$ to $1,029 \times 10^6$ $m^3$ per year. EAA water from the lake in the amount of $203 \times 10^6$ $m^3$ per year was also planned for additions to the WCAs. Almost immediately the plan was under attack from environmentalists and scientists who were concerned that too little water was being allocated to the ENP, although under the plan more water is allocated than in the past [75]. Another key concern was that moving extra water to the park would come at the expense of the central Everglades ecology. These areas would have to bear the increased flow, which in all likelihood would damage the tree island habitats [8] and lead to a loss of key species. Leading the objections were the Miccosukee tribe, who have over 100,000 ha of holdings in the central Everglades and view the tree islands as key to their hunting and ceremonies. The Miccosukee also worried that the extra water would be laden with excess nutrients [75].

With an emphasis on delivering more water to the ENP to more closely mimic historic conditions, the USACE devised a modified water delivery plan (MWD) for the Everglades National Park. The plans are outlined in detail on the USACE web site (http://www.saj.usace.army.mil/Missions/Environmental/Ecosystem-Restoration/) along with development schedules for new projects to the existing Central and Southern Florida (C&SF) Project to aid the central Everglades as well These projects were required to enable water deliveries for the restoration of more natural hydrologic conditions in the ENP. These improvements are to enable the re-establishment of the historic Shark River Slough flow-way from WCA-3A through WCA-3B to ENP (Fig. 12). However, of major concern in the delivery of water to the ENP is the loss of endangered species habitat for the Cape Sable Seaside Sparrow (*Ammodramus maritimus mirabilis*), Everglades snail kite (*Rostrhamus sociabilis plumbeus*) and wood stork (*Mycteria americana*). Despite all the management guidelines and the recent alterations to the system, questions still remain on whether water delivery schedules will be adequate to maintain ecosystem integrity of the ENP and maintain populations of the endangered species due to dramatic variations in yearly water availability.

An assessment of the water allocated through the input structures to the WCAs and the ENP provides us with insight into how water deliveries to the ENP have changed over time, how closely mandated regulation schedules have been followed, the effects of extreme climatic events on delivery schedules, and whether water deliveries can meet restoration needs on an annual basis (Fig. 12). As noted earlier, the ENP originally received as much water as the LEC, more than $1,400 \times 10^6$ $m^3$ per year (Fig. 11). An analysis of the 27-year record prior to the current regulations showed that flows varied greatly from year to year; moreover, flows only exceeded ($1,233 \times 10^6$ $m^3$) once from 1978 until 1992 [8]. Flows to the ENP were the lowest in 1989 ($0.8 \times 10^6$ $m^3$) due to the extensive drought that year. Surface water was not present and as a result extensive fire burned throughout the ENP. Thus, the ENP was kept exceptionally dry during some periods due to the lack of water and then drowned in wet years even though a mandated water delivery schedule was in place. Since 2002, the ENP has been receiving water under a new alternative water schedule plan where deliveries should average closer to $979 \times 10^6$ $m^3$ per year. However, flows in 2003 were near $810 \times 10^6$ $m^3$ and in 2005 reached $1,566 \times 10^6$ $m^3$. In 2006, an exceedingly dry rainfall year, the park received only $573 \times 10^6$ $m^3$. Thus, the shifts in water delivery have been less dramatic under the new schedule now in place than earlier delivery schedules, but year-to -year variations in rainfall still highly influence release volumes due to a lack of upstream water storage reservoirs. Currently, water continues to be pumped to the ocean and estuaries, and this pumping will continue until enough planned water reservoir projects are completed [71].

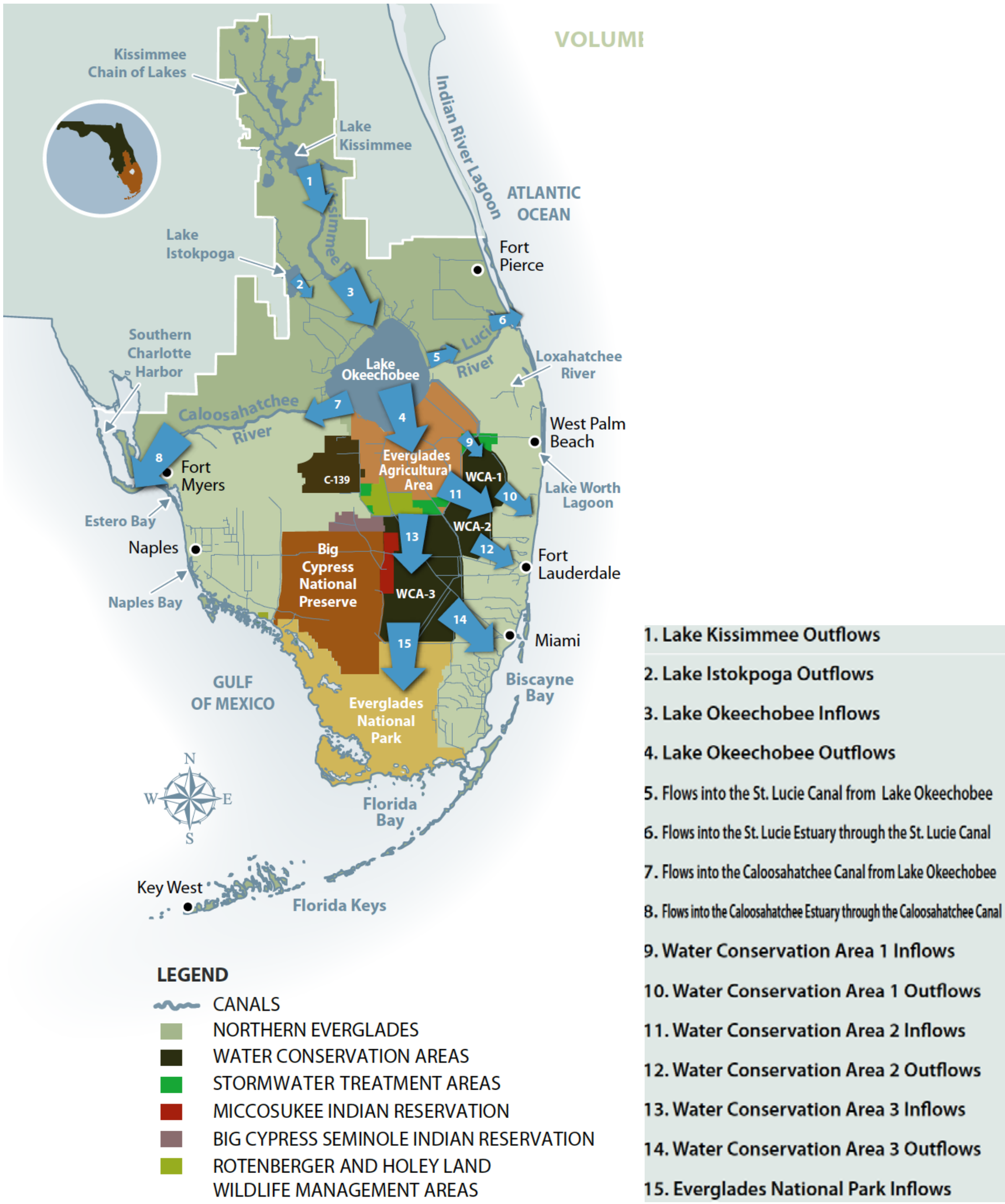


*Figure 12: A 2015 map depicting the current areas under water control by the SFWMD and the USACE. Fifteen inflows and outflows are shown which totally control the water flow in the Florida water conservation areas (WCAs), and the Federal Everglades National Park (ENP) as well as the Indian reservations [71]. The actual flow values are shown in Table 4 below.*

A comparison of the regulated surface water flows for key water bodies that comprise the water supply for the Everglades in 2015 compared to historic average flow from 1972 to 2015 shows in more detail the variation in the inputs and outputs compared to long-term averages at each structure. The differences in flow at each station across the 2013 to 2015 period are due to the USACE and SFWMD regulation schedules and in part to a severe El Niño effect, which resulted in a severe drought in portions of lower Florida during 2015 (Fig. 12, [71]). Inflows and outflows in the northern part of the landscape were well above the historical average in 2015. Nevertheless, overall flows ($1,252\times10^6$ $m^3$) into the ENP were nearly 60% lower than in 2014, but close to historic averages. However, both 2014 and 2013 flows contributed around 60% more water into the ENP than the historic average. Overall total 2015 flows were lower than 2014 except for outflows from Lake Kissimmee and Lake Istokpoga, and inflows to Lake Okeechobee and WCA-3 (Table 4). Fortunately, in recent years the inflows into the ENP have not come close to the record maximum or minimum flows into the ENP (Table 4). Importantly, recent increased flow of freshwater from new restoration efforts during the dry season in the southern Everglades (ENP) resulted in an increase in ions, especially N and P particularly during the dry season, but at coastal sites increased inputs of fresh water decreased the inputs of brackish water from groundwater and Florida Bay resulting in a diminution of Na, Cl and N and P concentrations flowing back into the wetlands from the Gulf [42]. This is important since this area of Florida faces severe sea level rise issues [71,76].

TABLE 4. A COMPARISON OF HISTORICAL WATER FLOWS INTO AND OUT OF LAKE OKEECHOBEE AND OUTFLOWS TO THE WCAS AND ENP. FLOWS THROUGH THE ST. LUCIE AND CALOOSAHATCHEE FLOW INTO THE ATLANTIC OCEAN AND ESTERO BAY ESTUARY AND INTO THE GULF OF MEXICO, RESPECTIVELY. (FLOWS UNITS ARE CUBIC METERS OF WATER $\times 10^6$)

| Lake, Impoundment, or Canal | Historical Mean Flow | 2015 Flow | Percent of Historical Mean | 2014 Flow | 2013 Flow | Historical Maximum Flow | Historical Minimum Flow |
|---|---|---|---|---|---|---|---|
| 1. Lake Kissimmee Outflow | 883.8 | 1443.9 | 163% | 944.3 | 542.7 | 2683.2 | 20.0 |
| 2.Lake Istokpoga Outflow | 274.7 | 550.4 | 200% | 393.9 | 346.6 | 786.8 | 32.8 |
| 3. Lake Okeechobee Inflow | 2597.8 | 3493.0 | 134% | 3324.6 | 2590.3 | 6051.3 | 465.9 |
| 4. Lake Okeechobee Outflow | 1774.0 | 2384.8 | 134% | 3117.8 | 1285.3 | 4907.9 | 217.8 |
| 5. St. Lucie (C-44 Canal) Inflow at S-308 | 313.1 | 159.4 | 51% | 548.5 | 128.3 | 1378.0 | 5.0 |
| 6. St. Lucie (C-44 Canal) Outflow at S-80 | 594.6 | 232.2 | 39% | 833.6 | 188.7 | 1471.3 | 0.0 |
| 7. Caloosahatchee River (C-43 Canal) Inflow at S-77 | 653.8 | 710.4 | 109% | 1511.8 | 618.0 | 2683.8 | 52.2 |
| 8. Caloosahatchee River (C-43 Canal) Outflow at S-79 | 1522.3 | 1522.3 | 100% | 3110.3 | 1403.7 | 4459.7 | 107.2 |
| 9. Water Conservation Area 1 Inflow | 578.7 | 302.6 | 52% | 469.1 | 449.0 | 1612.8 | 188.3 |
| 10. Water Conservation Area 1 Outflow | 538.4 | 244.3 | 45% | 581.2 | 597.0 | 1768.1 | 18.3 |
| 11. Water Conservation Area 2 Inflow | 794.8 | 1016.4 | 128% | 1330.2 | 1324.0 | 2164.4 | 139.7 |
| 12. Water Conservation Area 2 Outflow | 796.2 | 999.2 | 126% | 1190.8 | 1157.0 | 2132.9 | 115.4 |
| 13. Water Conservation Area 3A Inflow | 1447.9 | 1618.8 | 112% | 1539.8 | 1630.0 | 2685.5 | 485.0 |
| 14. Water Conservation Area 3A Outflow | 1239.7 | 961.1 | 78% | 1791.7 | 1511.0 | 3183.8 | 303.4 |
| 15. Everglades National Park Inflow | 1220.5 | 1252.4 | 103% | 1962.4 | 1846.5 | 3501.2 | 204.0 |

In summary it still appears that lower amounts of water will be delivered to the ENP in drought years due to human and agricultural water allocations. These shifts in allocations are of major concern and the USACE has developed under its adaptive management plan a new series of alternative model runs to more closely mimic historic flows if possible Thus, the plans are in place to modify and update the modified water deliveries to sustain the ENP, and WCAs but whether the water is available each year to meet these guidelines is still controlled to a large degree by climatic conditions and upstream agriculture and urban demands on allocations of water.

## 5. Conclusion

The social, economic and ecological constraints on sustaining both the Everglades and the marshes of Iraq have many parallels. They have both suffered under extensive water drainage, loss of habitat for rare and endangered species, degradation of native plant communities, increased pollution problems as well as increased salinity issues, all of which have harmed the native tribes who depend on these wetlands for their livelihood. An adequate yearly supply of clean water is the key to sustaining both these unique wetland ecosystems and the native tribal cultures that inhabitant these lands. The Marsh Dwellers of Iraq and the Seminoles of Florida share a cultural heritage and a spirit of wetlands. Their way of life is closely tied to the waters and the survival of these historic lands. However, compared to the Seminoles who have a lucrative tourism, gambling and cattle business along with government tribal rights and funding the Marsh Dwellers are suffering in abject poverty due to a lack of government support and an almost total loss of their fishing, hunting and tourist livelihood. To restore both complex wetland systems will require the correct timing and volumes releases of good quality water with delivery systems that mimic where possible their historic flow regimes. . Specifically, a restoration of their wetland plant and animal communities will depend on the creation of both hydroperiod and hydropatterns conducive to sustaining key species within each wetland ecosystem.

In the case of the Mesopotamian marshes the major unknowns are how Iraq's multiple use water issues and competition for water with Turkey, Syria, and Iran will affect the future water supplies needed for marsh restoration, whether the Marsh Dweller culture can ever become established again in the restored marshes in any significant way, and whether or not landscape connectivity of the marshes can be re-established to maintain species diversity. What is evident is that there is not a sufficient supply of water to fully restore all the marshes, and thus a series of marshes with connected habitats of sufficient size to maintain a functioning wetland landscape needs to be established. However, even with the multitude of water issues facing the Mesopotamian marshes, restoration is now underway. Release of water when it is available goes to selected wetland areas resulting in the return of native plants and animals, including rare and endangered species. Moreover, Ramsar sites like the Al-Hawizeh and the recently dedicated Mesopotamia Marshland National Park, as well as the 2016 designation of the marshes as a World Heritage Site suggest a better future for the marshes.

In the future the Everglades will be maintained mostly as a managed peatland system with water pumped to the wetlands on a USACE and SFWMD regulated schedule from Lake Okeechobee, the STAs and surrounding lands, a schedule that must also meet multiple water needs from agriculture and urban cities. With only 50% of the original Everglades remaining and hundreds of control structures in place some say this is the only choice available to sustain what is left of the Everglades. Ecologists have argued that we have the opportunity with adaptive management to test alternative water delivery schedules and peatland restoration techniques to restore key components of the former Everglades. Like the Iraq marshes, the wetland plant and animal communities will depend on the creation of both alternative water delivery schedules and peatland restoration techniques to restore key components of the former Everglades.

Like the Iraq marshes the wetland plant and animal communities will depend on the creation of both hydroperiod and hydropatterns conducive to sustaining key species within each wetland ecosystem. However, the peatlands of the Everglades were not formed with the same hydrodynamics as the river dominated Iraq marshes so water delivery has to be restored to a system more akin to the original broad scale seasonal overflow pattern from Lake Okeechobee [8, 45]. In fact McVoy et al. [45], in an excellent review of pre-drainage Everglades hydrologic conditions, suggests Lake Okeechobee outflows into the Everglades occurred in most years and throughout the year, thus keeping higher water depths in many locations with faster water flows, which created a patterned peatland of ridges and sloughs. He further states "water flows, depths, floc transport, and ultimately landscape pattern are all closely intertwining with slough vegetation types, suggesting a strong landscape sensitivity to pre-drainage hydrologic conditions. Sheet flow--the uniform and unimpeded distribution of flow velocities across all sloughs--appears to be key to preserving the habitats created by ridge and slough patterning. Post-drainage losses of pattern in areas of altered hydrology confirm this linkage." Fortunately, some of this larger-scale restoration work based on alternate flow regimes and delivery system effects on the peatlands is being considered or tested [71]. For example, STAs projects now remove nutrients to the ombrogenous (rainfall driven and nutrient poor) interior portion of WCA-1, and by not allowing eutrophic surface water flows into the interior region the normal succession stages of marsh-fen-bog development can continue. Finally, a major continuing problem for water managers in the future will be trying to balance conditions to maintain peatlands conditions for the central Everglades habitats while being pressured continuously to alter hydrologic levels and flows for survival of endangered species at specific locations in the ENP or for human water needs. By not maintaining the variety of specific hydrologic, nutrient, and fire conditions that shaped the diversity of Everglades habitats, endangered species arguments will continue to mount and ecosystem management will become more and more manipulated to the detriment of natural community structure and diversity.

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# Integrating Ecosystem Services into the DPSIR Framework for Sustainable Wetland Management

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## *Abstract*

Wetlands are important regions for human activities. However, the resources they offer are under pressure from a variety of factors, and their natural performance is threatened by short-sighted planning policies. One endeavor to decrease the development impacts on wetlands is the implementation of wise use management. As wetland areas are dynamic and vulnerable systems that are affected by both social and economic conditions, it is critical to comprehend the relationship between socio-economic conditions and the environment to use appropriate strategies. Recently, great attention has been paid to wise use of wetlands, which is the sustainable utilization of wetlands in a way that is compatible with the wetlands ecosystem conservation strategies and statements. This paper presents an innovative, reliable approach for wise use of wetlands, using the analysis of changes in land use during 40 years as a major driver of change, Driving force-Pressure-State-Impact-Response (DPSIR) framework has been implemented to find the most important criteria by using a combination of Entropy-Analytic Network Analysis (ANP) and a diverse range of local actors. DPSIR model has been applied for the wise use of wetlands based on sustainable livelihood. A set of criteria was identified based on ecosystem services of wetland. Then, these sets were placed in each part of DPSIR framework while the linkage amongst them was determined. Final criteria were selected using the multi-criteria evaluation techniques and interviewing the experts and different local communities living in the wetland area. Sustainable livelihood strategies were determined to be considered in policy making. As the case study, the Hawr-Al-Azim wetland in Iran has been considered. According to the findings, the integration of social, economic and environmental criteria within DPSIR framework by using multi-criteria evaluation techniques has provided a holistic approach for integrated wise use of wetland; and this method can be employed effectively as an analytical tool for policy making in the context of sustainable wise use of wetlands in Iran.

***Keywords: Wetland Ecosystems, DPSIR, Sustainable Livelihood, Ecosystem Services, ANP Technique***

## 1. INTRODUCTION

The RAMSAR Convention has identified wetlands as areas of marsh, fen, peatland or water with a great production and economic benefits [1]. Wetlands need the environmental policies to improve on the “wise use” front, which in Ramsar’s definition of wise use means “the maintenance of ecological characteristics, achieved through the implementation of ecosystem approaches, within the context of sustainable development” [2]. Wetlands provide valuable services such as: improving the quality of water, protection of biodiversity and habitats, recreation, nutrition, soil and sediment regulation, disturbance and natural hazard regulation, cultural values and food production. The wetland ecosystem services are the necessary parts of the livelihood strategy of the communities that are dependent on the wetland. The sustainability introduces the ways to have the wise use of wetland ecosystems in terms of social, economic and ecological. [3].

However, wetland ecosystems are amongst the most threatened ecosystems because of the widespread destruction caused by human activities [4]. The greatest threat to the wetlands is the development related to conversion of ecosystems, leading to large-scale losses of habitats and services [5]. Progressive changes in land-use arising from the industrial, agricultural and constructed developments are the main issue in wetlands [6,7]. Despite the national policies and international agreements the wetlands are going to be lost and destroyed due to some other threats such as: the hydrological disturbances and pollutions. [8].

Most of the wetland communities are extensively depended on the resources for their livelihood. Any changes in the quantity and quality of wetland’s resources or the access to the resources, will affect people’s livelihood, especially the poor people [9]. Sustainable management of natural resources with the participation of communities are a common strategy to improve the resource management and empowerment of local communities based on the concepts of participative management, local ecological knowledge and understanding of local institutions. [10]. A sustainable livelihood is a systematic and comparative perspective that relates those issues identifying with the poverty reduction, sustainability and empowerment processes [11].The turning point of a sustainable life is related to its application in different areas, position of uncertainty and its potential as a participatory and consultative process for fertilization of ideas and strategies amongst the diverse beneficial people [12]. Sustainable livelihood attitudes have the required flexibility to be able to use them in adaptive responses and also as entry points to policies. Living is permanent when it can be adapted with pressures and shocks and can be improved, strengthen and maintain its capabilities and assets, provide the life opportunities for the next generation and be aware of not to weaken the basis of natural resources [13].

Application of ecosystem services approaches to improve social linkages has been made in some researches [14-16]. Comprehensive analyses of the complex issues of the wetland using DPSIR (Drivers- Pressure- State- Impact- Response) framework to linking wetland ecosystem services to livelihood capitals resulted from the key strategies for sustainable planning to improve the wise use of the wetland [17] and contribute to human well-being [18]. Without monitoring pressures on wetlands, it is difficult to have a suitable plan for conservation [19].

According to the diversity of goods and services provided by wetland and divergent livelihood objectives between users of the wetland which resulted from a discrepancy in access to resources and various forms of capitals, intensity of use of the wetland resources strategies is interestingly different amongst the beneficial people [20-22]. Therefore, a more holistic approach is needed to systematically explore the links between socio-economic drivers and ecological impacts on the wetland [23]. Using DPSIR framework, this study links ecological characteristics of wetland due to ecosystem services, with the socio-economic part. As an indicator-based environmental reporting approach, the DPSIR framework aims to describe environmental problems by identifying the cause-effect relationships between the environment and various socio-economic activities. This study has been designed with a new look to the participation of local people to develop a policy for local authorities and official institutions for the management of wetland. Integrated assessment framework for mutual relations of wetlands - livelihood is made from five elements [12]. These are:

1. Wetlands as a system for the mutual relations of ecological – livelihood role
2. Communication with areas of environmental vulnerability
3. Livelihood strategies
4. Institutions and freedom
5. Outputs of human welfare

This paper has two main objectives. First, the paper aims to analyze the threats and main challenges to wise use of the Hawr Al-Azim wetland through comprehensive overview and analysis of the current situation based on ecosystem services and changes in land-use. The second objective is to determine some exclusive strategies that should be formulated for this wetland with regard to ecosystem services and the livelihood of the local people.

## 2. Description of Study Area

Hawr Al-Azim Wetland is one of the international wetlands registered on UNESCO's Natural Heritage List. It is part of a single hydrological system and forms one of the largest permanent freshwater wetlands in Lower Mesopotamia, being located between N 30° 58´- 31° 50´ and E 47° 55´- 47° 20´ [24]. This wetland is situated in the North Azadegan Plain, 80 km southwest of Ahvaz city, near the border between Iran and Iraq (Fig. 1). This wetland is one of the biggest wetlands in Khuzestan province. About one-third of the wetland is in Iran, and the rest belongs to Iraq [25].

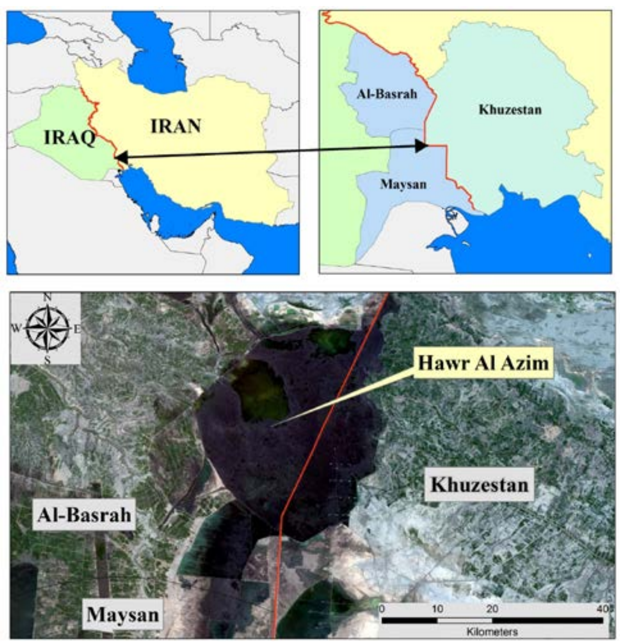


*Figure 1: Location of Hawr Al-Azim wetland.*

Hawr Al-Azim and Hawr Al-Hawizeh (Iraqi part) are parts of a single hydrological system and form one of the longest freshwater wetlands in Lower Mesopotamia and represent the remaining fraction of the former dramatically over the past 30 years [25]. Hawr Al-Azim is the only remaining wetland of the great marshlands of the Middle East and is extremely rich in terms of biodiversity. Before the war, people financed their families by using this wetland and also its water. People had jobs such as: raising buffalo, fishing, hunting birds, mat weaving, straw and agriculture, and they lived close to the yielding trees of the area. But by the beginning of the war, people were forced to migrate to other parts of the country, except those who still had a hard time living with the straw and fishing. There are many issues in this wetland such as: the sewage inflow and increasing water pollution, the war effects, the reduction of the environmental flow requirement due to upstream dams, extensive construction activities, and the sugarcane and petroleum industries that are exposed to risk.

Due to some man-made projects such as upstream dam projects combined with the wastewater from industries and sugarcane crops, the Hawr Al-Azim wetland, which connects to Hawr Al-Hawizeh in Iraq, is under the threat of water pollution and construction of dams on the Karkheh River which feeds it and some petroleum industry developments. Increased irrigation and loss of spring flooding due to the dams add to the salinity of the water. Concentrations of fertilizer, pesticides and human and chemical waste are steadily rising. Due to the lack of providing the environmental flow requirements, the wetland is now faced with water shortage. The activities of the petroleum company in this area have led to widespread destruction of the ecosystem due to road making, non-compliance with the agreed width of the roads, disposal of the residues from well drilling, and sewage discharge into the wetland. As a result of these activities, water connection is not established between the different parts of the wetland.

The destruction of this wetland and the people residing there increased rapidly after the war. According to the United Nations Environmental Programme, the Hawr Al-Azim wetland has transformed from one of the biggest marshes in the Middle East to a barren wasteland with a soil that is too salty to sustain any plants [26]. The situation has continued to worsen since 2000 with increased salinity and widespread desertification. However, plantation effluent combined with dam construction and lower rainfall threatens a devastating ecological crisis in the wetland. The discharge of sugarcane waters with high salinity into a freshwater wetland would eventually lead to the failure of the ecosystem. Drying of the wetland has increased the number of dust storms. And it has led the province to face dust and storms about 21 times more than the standard. Since the war, the natural sources have faced a threat. Water shortage caused by the construction of dams on the rivers leading to the wetland has made a significant damage to its ecosystem.

Based on these descriptions, we have to be cognizant of the many difficulties involved and approach them in a very careful and scientific way. These issues require consideration at an early stage in relief and recovery operations. Furthermore, the assessment has revealed the critical need to build institutional capacities for environmental management in this wetland. In the Iraqi part (Hawr Al-Hawizeh), some efforts have been made and some re-habilitation projects for marshes have been defined by UNEP [27]. In Hawr Al-Azim (Iranian part), there is a lack of an integrated plan. Unless urgent action is taken to reserve the trend, the entire wetland in Iran will be gone during the next decade.

## 3. METHODS AND DATA PROCESSING

The relevant literature and reports were reviewed to analyze the status, threats and main challenges to the wise use of Hawr Al-Azim wetland. For the presentation of ecosystem services of Hawr Al-Azim, the scheme developed by the Millennium Ecosystem Assessment [28] was followed. Analysis of the current situation was investigated based on the assessments of change in land-use. The DPSIR analysis framework was utilized to comprehensively analyze the complex issues of the wetland use.

For the assessment of change in land-use, data from Landsat TM with 30*30 meters resolution for the years 1973, 1992, 2000, 2010 and 2014 were obtained. The reason for choosing different years in different decades was to investigate patterns related to policies and plans. These were used to find changes in the land-cover using ERDAS 8.3 software. Satellite data were geo-coded and projected onto an RSO grid. The image was initially classified using unsupervised classification. It is used as a guide in selecting sites for the supervised classification process. Initial land cover categories were identified using the maximum likelihood method followed by a post-classification process. Other material and the reference data used in this study were topographical maps (Scale

1:50,000) and land use maps obtained from Department of Environment (Scale 1:25,000). These maps were used for geometric correction of the satellite images and for some ground truth information. They were used as preliminary abstractions of land-use information and they were found to be useful in image interpretations. Recent land-cover and land-use maps, as well as ground information, were also employed for the purpose of supervised classification and classification accuracy assessment. All data were integrated in GIS and land-use change analyses have been carried out using algorithms developed in GIS environment [29].

In this study, in order to prioritize the assessments for sustainable management of the wetland to improve the wise use with regard to the influential role of institutions, especially local institutions, the framework of the DPSIR was used. Effective indicators in the wise use of the wetland were defined with a careful study of the available information and using the model parameters used in previous studies and with regard to the role of wetlands in providing livelihoods. So both the exploitation of the wetland resources and long-term protection of the wetland and its resources should be considered. For analyzing the DPSIR framework of the wetland, the key stakeholders and local and official authorities in the exploitation of wetland resources were identified. After identifying the involved beneficial people, the official and unofficial institutes were identified with the breakdown of the local, social and governmental or political institutions, based on the major activities in the Hawr Al-Azim wetland. In the next step, the criteria affecting the wise use of the wetland were placed in a framework of DPSIR model [30]. After determining the indexes of the DPSIR model, the most important part of this study was the screening of the indicators that are most relevant to either formal or informal institutions. So eventually, the indicators with the most institutional relations were set to determine the priorities. To determine these indicators, a framework management was developed through a participatory process involving stakeholders from different disciplines. Due to the high number of chosen indicators, multi-criteria evaluation techniques were applied. Indicators were prioritized by using ANP (Analytic Network Process) and considering the internal relations. Based on pairwise comparison and ANP techniques, the indicators with priority were determined based on the final weights of criteria using a limited matrix. An appreciation scale ranging between 1 and 9 [31] was used to represent equal to extreme importance of paired criteria. The results of the expert survey were converted into a matrix. The matrix was created by putting the list of criteria on the left and the top of the matrix. When one criterion is compared to itself, the evaluation scale should be 1, representing equally preferred criteria. The geometric mean value for each cell was computed. Analytic network process was used to calculate super matrix, weighted matrix and the limited matrix. Accordingly the priority of the indicators was specified to set the priority for the policy of the sustainable wise use of Hawr Al-Azim wetland.

## 4. RESULTS

### *4.1 Ecosystem Services Provided by Hawr Al-Azim*

Hawr Al-Azim wetland has a variety of values which arose from its ecological, economic, social, and water cognitive features and functions. Services and values of Hawr Al-Azim wetland are specified in Table 1 according to a division of MEA.

TABLE 1: MAIN ECOSYSTEM SERVICES PROVIDED BY HAWR-AL-AZIM

| | Wetland ecosystem services in Hawr Al-Azim Wetland |
|---|---|
| **Provisioning Services** | Supply of forage for livestock<br>Building local materials to cover rural structures<br>Reed to prepare the mat and cover the roofs of residential units<br>Safeguard the livelihoods of indigenous peoples to hunt waterfowl<br>Providing food, especially wheat, rice, and barley<br>To lay the groundwork for handicrafts<br>Small shrubs for heating costs<br>Supply of water for agriculture<br>Drinking water for human and livestock<br>Supply of medicinal plants |
| **Regulatory Services** | Hydrological sustainability<br>Control desertification and dust storms<br>Stability of coastline and sides of the river<br>Retention of nutrients and sediments<br>Setting the local climate<br>Water Purification<br>Carbon storage |
| **Cultural Services** | Cultural heritage<br>Job creation, especially for people living in wetland<br>Research and Education<br>Recreation and Ecotourism development<br>Water activities and sports<br>Picnics, excursions, and tours<br>Observation of nature and watching bird |
| **Support Services** | Vegetation cover for grazing<br>Animal habitats for certain stages of their life cycle<br>Animals Habitat in vulnerable stages of their life cycle or shelter during adverse conditions<br>Habitat for native and migratory birds<br>Providing proper grounds for living of farmed and wild fishes<br>Protection of important contribution of a particular species population that supports variety of species<br>Diversity conservation of ecological area<br>Supporting threatened species or threatened ecological communities |

Hawr Al-Azim wetland delivers a wide range of ecosystem services. In provision services, this wetland has the critical situation to provide a suitable habitat for aquatic migratory birds and fishes. This area serves as an important habitat for wildlife, raising livestock such as buffalo, waterfowl, boar and fish that are used by local people. Also, it has some significant economic benefits such as supplying water for agriculture and providing food, especially wheat, rice and barley. In regulatory service, Hawr Al-Azim wetland helps the regular humidity and rainfall and controls dust storms and desertification and helps to filter out the waste and water pollutants from the aquatic ecosystem.

In cultural services, beyond its environmental importance, this marshland has been home to ancient human communities for more than five millennia. They have evolved a unique subsistence lifestyle that is firmly rooted in their aquatic environment. The people lived in some settlements located on the edge of the marshes. They developed a unique way of life fastened to their environment, fishing, hunting and planting rice, barley and wheat and building the reed houses [32]. This area has the potential to become a tourism destination and contains many socio-economic advantages that are critical to the existence and well-being of the local communities.

### *4.2. Land-Use Change Analysis*

Comprehensive analysis of Landsat imagery from 1973-2014 enabled a quantified assessment. The results of changes have led to a better understanding of some critical changes on the wetland. Table 2 shows the results of changes in mainland use/cover of Hawr Al-Azim during the past 40 years.

TABLE 2: LANDUSE CHANGE ANALYSIS ACCORDING TO CHANGES IN MAIN LAND USE/COVER OF WETLAND

| Land use/cover | Land use change analysis | | | | |
|---|---|---|---|---|---|
| | 1973 | 1992 | 2000 | 2010 | 2014 |
| Farmland & rangeland | 21,322.08 | 10,397.88 | 23,441.86 | 21,822.07 | 60,096.33 |
| Bare land | 76,934.52 | 120,144.10 | 219,849.19 | 142,222.70 | 113,610.96 |
| Marsh land | 227,816.64 | 125,841.30 | 84,106.70 | 142,917.01 | 121,946.31 |
| Water body | 36,285.12 | 105,147.20 | 34,109.46 | 54,545.43 | 65,877.03 |

Based on these results, marshlands are under threat and bare lands will increase if the current policies for management of the wetland continue. The worth condition of the wetland was 2000 and after that, some projects by UNEP helped to improve the ecosystem. Again during current years the development of petroleum mining increased and again, the wetland experienced some critical threats. Changes in land use are expected to continue to be a major driver of changes in the provision of ecosystem services. Comparison of the results in the two Iranian and Iraqi parts is shown in Table 3 and in Fig. 2. The results emphasize that the Iranian part is under a lot more pressure. When we consider that only one-third of the wetland belongs to Iran, decreasing water body and increasing bare lands is very critical to loss of wetlands.

TABLE 3: THE RESULTS OF LAND USE CHANGE ANALYSIS COMPARISON BETWEEN THE CHANGES IN IRANIAN AND IRAQI PARTS

| Land use/cover | Land use change analysis | | | | | |
|---|---|---|---|---|---|---|
| | | 1973 | 1992 | 2000 | 2010 | 2014 |
| Farmland & rangeland | Iran | 8,728.20 | 3,429.72 | 12,163.93 | 12,570.79 | 20,035.89 |
| | Iraq | 12,593.88 | 6,968.16 | 11,277.93 | 9,251.28 | 40,060.44 |
| Bare land | Iran | 36,221.04 | 20,985.12 | 61,589.02 | 29,794.63 | 33,309.63 |
| | Iraq | 40,713.48 | 99,159.03 | 15,8260.2 | 112,428.1 | 80,301.33 |
| Marsh land | Iran | 62,867.52 | 34,544.79 | 35,445.45 | 48,171.87 | 38,193.39 |
| | Iraq | 16,4949.1 | 91,296.54 | 48,661.25 | 94,745.14 | 83,752.92 |
| Water body | Iran | 8,957.52 | 57,285.09 | 7,023.20 | 25,684.32 | 24,705.81 |
| | Iraq | 27,327.6 | 47,862.18 | 27,086.26 | 28,861.11 | 41,171.22 |

The results show that unless urgent action is taken to reverse the trend, the entire wetland will disappear in the near future. The situation of wetland in 2000 is with increased salinity, widespread desertification, and upstream dams.

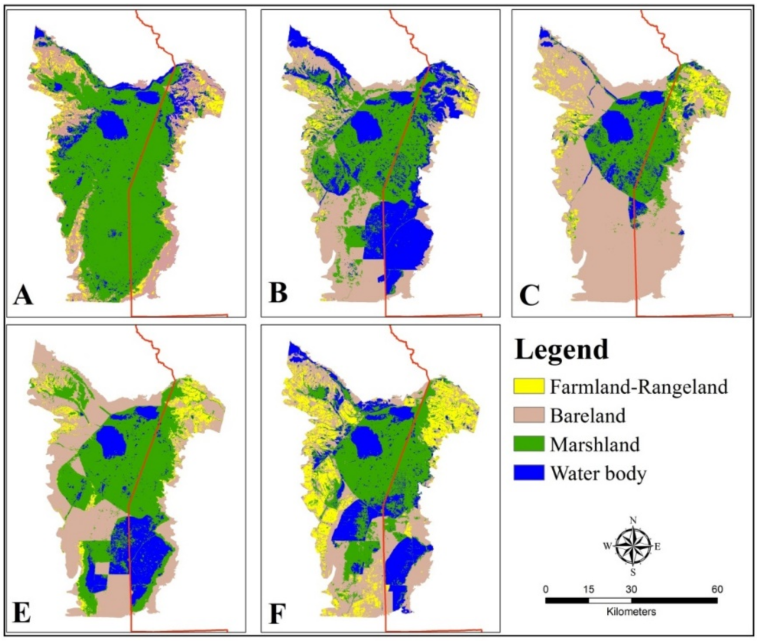


*Figure 2: Land use change in Hawr Al-Azim wetland (1973-2014)*

### *4.3. Integrated Assessment Using DPSIR Framework for Wise Use of Wetland*

For the DPSIR analysis, problems mentioned by stakeholders, and local and official authorities fell into different categories. The results identified the major stakeholders of Hawr Al-Azim Wetland. They are local people, provincial governors and governors, Khuzestan Province's Department of Environmental Protection (considering the legal obligations, this administration is in charge of protecting the wetland ecosystem), Organization of Khuzestan Water and Electricity (one of the main tasks of the Ministry of Energy and consequently the regional water companies is quantity-quality maintaining of domestic water supplies), Khuzestan Department of Fisheries, Khuzestan Department of Natural Resources, Agriculture Organization of Khuzestan, Cultural Heritage and Tourism Organization of Khuzestan, Department of Roads and Transportation of Khuzestan province, the sugarcane companies (regarding to the number of units of sugarcane which shed their drainage water into the wetland and change the salinity of the water; entry of drainage water from these projects to the wetland has always been a posed and debatable problem amongst the experts; it causes many changes in biodiversity and the ecosystem), petroleum industry (with regard to the transmission of petroleum products and events that have already occurred), the villages' council, and NGOs. The DPSIR framework analysis is summarized in Fig. 3.

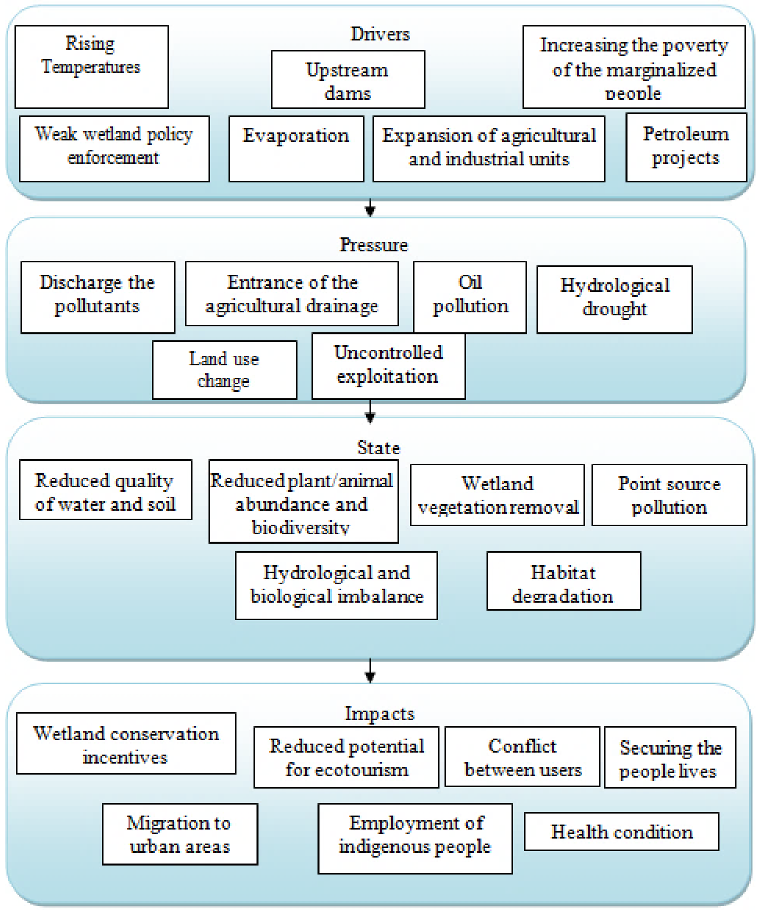


*Figure 3: DPSIR analysis of Hawr- Al- Azim wetland, based on stakeholders' opinion.*

Based on several workshops and stakeholders opinions, 27 indicators were specified; 8 indicators as drivers, 6 pressure indicators, 6 state indicators and 7 impact indicators in the framework of the DPSIR model. The drivers are divided into two categories: natural and human. In the natural driver sector, rising temperature and evaporation were considered as the main drivers, Human drivers were the increasing poverty of the marginalized people of the wetland, weak wetland policy enforcement, petroleum projects, expansion of agricultural and industrial units, upstream dams, and irrigation developments. The results mentioned that drivers that had made some pressure on the wetland are drought, influx of agricultural drainage from sugarcane units; discharge of waste and pollutants into the wetland, uncontrolled exploitation of the wetland resources, land-use change, and oil pollution.

State indicators were wetland vegetation removal, reduced quality of water and soil, reduction in the diversity of plant and animal species, habitat degradation, hydrological and biological imbalances, and point source pollution were defined in this category. In the impact category, indicators included safeguarding the livelihood of indigenous people, wetland conservation incentives, the conflict between uses, reduced potential for tourism and ecotourism, health conditions, the level of employment of indigenous people, and migration to urban areas were considered.

Based on the results, in the opinion of indigenous respondents, indicators of increasing poverty, uncontrolled exploitation, hydrologic drought, reducing biodiversity and abundance of plant and animal species, biological and hydrological imbalances, habitat degradation, status of tourism industry and ecotourism and safeguarding the livelihood of indigenous people have the most institutional connection and were chosen to enter the next stages of the study.

Objectives, policies and executive programs of the government organizations as secondary beneficiaries of the wetland have some critical positive and negative impacts on the indicators of wise use improvement in the DPSIR model. The most important indicators in terms of connection with formal institutions were weak wetland policy enforcements, development of industrial and farming sections, land use changes, petroleum projects, waste discharge into the wetland, habitat degradation, hydrological and biological imbalances, conflict of uses, status of the tourism industry and ecotourism and health conditions.

### *4.4. ANP Analysis to Find the Most Important Criteria*

The criteria values in the limited matrix showed the list of priorities. These results can also be arranged as the cumulative results. The first nine criteria covered 85% of priority results; the remaining 15% were excluded as negligible because of very small values. So, only the most important criteria, with more than 5% effect, were considered and those are the first eight criteria. Based on these results, the most important criteria are summarized in Table 4.

TABLE 4: THE RESULTS OF PRIORITY ASSESSMENT USING ANP

| DPSIR Framework | Criteria | Value |
|---|---|---|
| **Drivers** | 1. Increasing the poverty of the marginalized people | *0.233* |
| | 2. The weak policy enforcement | *0.136* |
| | 3. Petroleum projects | *0.093* |
| | 4. The expansion of industrial and agricultural sectors | *0.012* |
| **Pressures** | 1. Land use/cover changes | *0.112* |
| | 2. Hydrologic drought (reduction of wetlands' water) | *0.053* |
| | 3. Waste discharge into the wetland | *0.041* |
| **State** | 1. Reducing diversity of plant and animal species | *0.051* |
| | 2. Hydrological and biological imbalance | *0.051* |
| | 3. Habitat degradation | *0.045* |
| **Impact** | 1. Safeguarding the livelihoods of indigenous peoples | *0.055* |
| | 2. Conflict between users | 0.033 |
| | 3. Health status | 0.02 |
| | 4. Tourism industry and ecotourism status | 0.065 |
| **Impact** | 1. Safeguarding the livelihoods of indigenous peoples | *0.055* |
| | 2. Conflict between users | 0.033 |
| | 3. Health status | 0.02 |
| | 4. Tourism industry and ecotourism status | 0.065 |

According to the achievements, in the driver category the priorities were increasing the poverty of the marginalized people, weak wetland policy enforcement, and petroleum projects. In the pressure category, land use/cover changes and hydrologic drought were found to have the most priority. In the state category, reducing the diversity of plant and animal species and hydrological and biological imbalances were found to have the most priority for response. In the impact category, the tourism and ecotourism status and safeguarding the livelihood of indigenous people had the most priority.

According to the preference of the indicators, responses as the main policies were developed to respond to each of the indicators to promote the wise use of the wetland. The main responses and strategies for sustainable management of Hawr Al-Azim Wetland were identified as follows:

1. Improved policy coordination
2. Assessment and control the impacts of development projects especially oil mining on wetland
3. land use regulations and enforcement
4. Integrated water management
5. Sustainable harvesting regimes

6. Improved wastewater treatment, point, and mobile source controls
7. Participatory resource management, capacity building
8. Monitoring, mapping and research of Hawr Al-Azim Wetland.

## 5. CONCLUSION

The proposed indicators based on the DPSIR-ANP model were able to introduce the most important policies for the wise use management of the wetlands. With regard to the quantity indicators for each of the monitored wetlands, comprehensive management in the future should be possible. Local institutions of indigenous people have an impact on their livelihood decisions and should be empowered in order to maintain ecosystems and their services. In addition, the priority indicators can be a great help to assess the performance goals of wetland comprehensive management plans. Priority indicators can make the decision makers, planners and directors at provincial and local levels aware of the invested time, energy and funds due to the changes in the conditions of wetland and indigenous people that are dependent on it.

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**U.S.-Iran Symposium on Wetlands**

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# How to Save the Dying Lake Urmia?

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### *Abstract*

This paper explains the changes in Lake Urmia in the course of desiccation period and proposes a realistic method for saving this international protected wetland. A large amount of salt and mineral sedimentation on the bed of the lake has made irreversible geomorphologic changes that neutralize the efforts for its restoration. The change has converted the lake into a flat playa with very little slope from the edges to the deepest parts, causing a rapid spreading of water over the vast surface of the lake. This phenomenon has facilitated rapid evaporation of water from the lake surface, leaving behind hundreds of thousands of hectares of salt desert which is considered as a large zone of salt and sand storms. Under current conditions, it looks impossible to increase the volume to surface area ratio using conventional methods to reduce the evaporation. Therefore I believe reducing the lake surface area and collecting the inflowing water to smaller parts could help save considerable areas of the Lake Urmia.

## 1. INTRODUCTION

The water crisis in Iran and its disastrous effect on Lake Urmia is leading to a catastrophe much beyond an environmental crisis. Climate change combined with excessive consumption of underground and surface water is showing its unpleasant effect with drying of the 20$^{th}$ largest saline lake in the world, with severe socio-economic and health effects on people living in West and East Azerbaijan.

Urmia Lake is home of *Artemia urmiana,* coexisting with a parthenogenetic population for millions of years [1]. It is a unique wetland for thousands of migrating and local birds, listed in the Ramsar Sites (Convention of Wetlands of International Importance) and known as a UNESCO Biosphere Reserve. The islands in the lake hosted many birds for wintering and breeding, many mammals, including Iranian yellow Deer (*Dama dama mesopotamica* and *Ovis orientalis gimelini*), and many species of reptiles and amphibians [2]. It used to attract tens of thousands of tourists annually for bird watching and to enjoy the health benefits of the saline ecosystem and healing mud with specific therapeutic effect on joint disorders. Production of *Artemia* used to exceed tens of thousands of tons annually and was considered a big source of income for people and local government [3].

Our latest studies show that the lake is facing the gravest situation in the past 100 years, approaching total desiccation, rivaling the Aral Sea disaster in Central Asia. According to the satellite and ground data collected, the lake has lost almost 99% of its water, leaving behind hundreds of thousands of hectares of salt fields which can fuel salt storms. The salt storms will destroy precious fertile soil and ruin the health of those living in the surrounding regions. According to many studies; the existing problem is partly due to climatic changes and drought that started about 20 years ago, but it is also attributable to human activity, ineffective regional water policies and wasteful usage of water resources in the agriculture sector. According to the estimates, over 6 billion tons of salt have settled on the bottom of the lake, most of that is already exposed to are and gradually being moved by wind [4]. Therefore, implementation of a wise and realistic restoration plan based on the quantities of water available for the Lake Urmia is the most essential step required to be considered.

## 2. Changes in Lake Geomorphology and its Negative Impact on Restoration Plans

Before the desiccation process began, the surface area of the Lake Urmia was about 5,500 km$^2$, deepest area was about 16 m and the average depth was about 6 m. Total water volume was about 33 BCM and the average water salinity was 160 parts per thousand (ppt) [4]. The lake desiccation started in 1995 and the reduction in inflow and increased evaporation resulted in saturation of lake water with salt within 6 years. Salt sedimentation began from 2006, and added to the bottom sediments layer by layer. The water level decreased by 8 m during past 20 years, currently the water depth at the deepest area of the lake is less than 2 m, proving that sediment thickness is almost 6 m in these areas. The salt sediments are seen over an area of 3,500 km$^2$, combined with the river sediments in north wing. Sedimentation of huge amounts of salt and other minerals has converted the lake into a very flat and shallow playa with the rate of slope at about 20 cm in 10 km. Due to this fact, inflowing water spreads over a very large area, increasing the evaporation surface but at the same time the water holding capacity of the lake has decreased largely. Calculations prove that due to the significant change in the lake morphology, the evaporation capacity per unit volume of water in the lake has doubled. Therefore restoration of the entire lake using conventional methods seems to be impossible.

Satellite images confirm our field studies and our conclusion on increased surface area ratio compared to the water volume (Figs. 1, 2, 3).

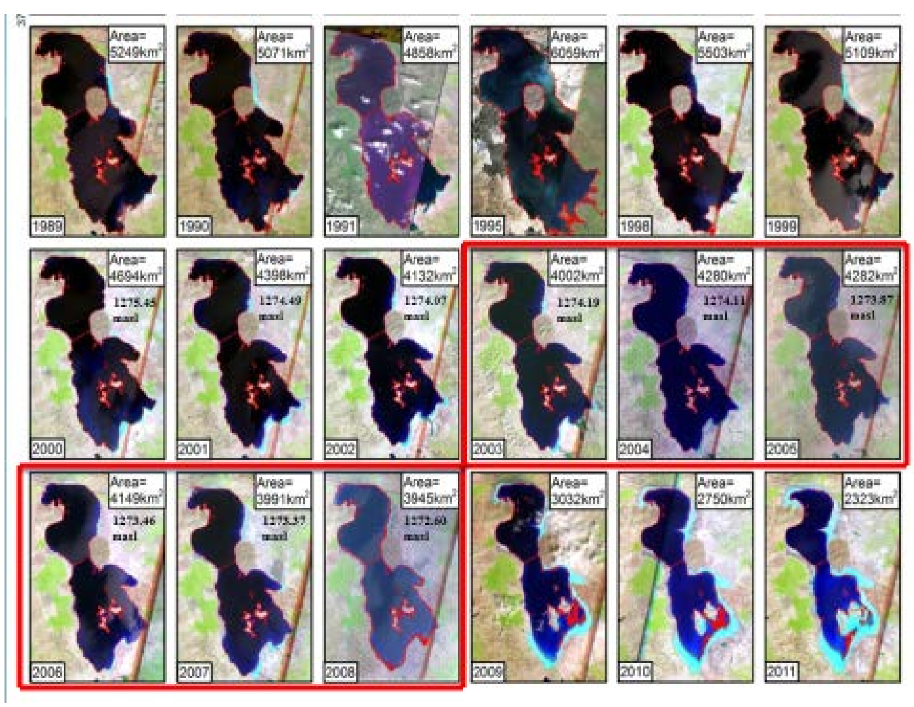


*Figure 1: Satellite images of Lake Urmia from 1989 until 2011.*

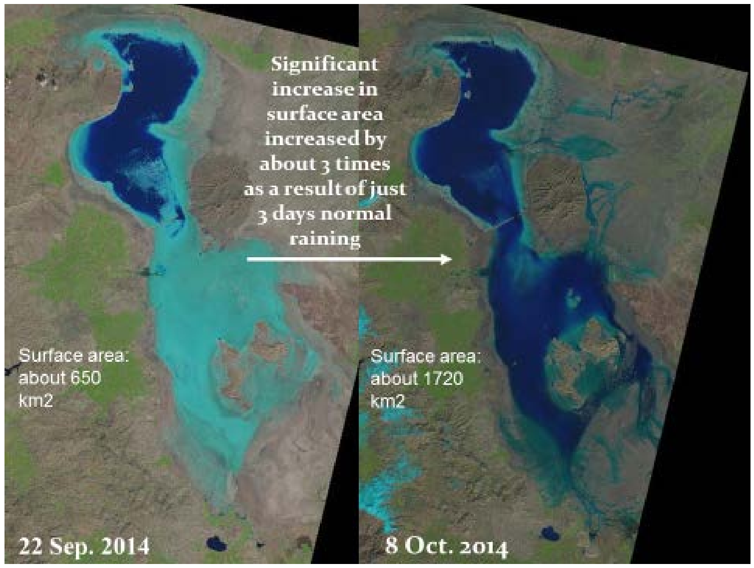


*Figure 2: The changes in the surface area of the Lake Urmia as a result of 3 days normal rain.*

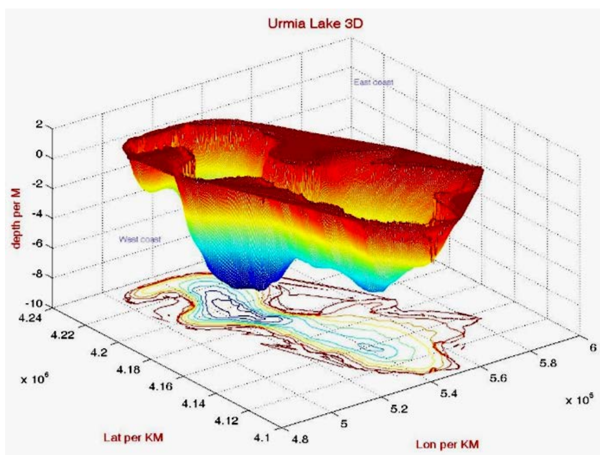


*Figure 3: Three dimensional figure of Lake Urmia showing deep areas in the lake [5].*

Comparison of the satellite images of Lake Urmia from 2003 until 2008 shows little change in surface area (only 67 $km^2$), whereas during this period the lake level reduced by 1.54 m and the lake lost over 10 BCM by evaporation (Fig. 1 and Fig. 4). Indeed the similar surface area misled the authorities and they did not notice this huge loss of water from the lake. On the other hand, the water level also has been another misleading factor, because the water level combined with the surface area was considered as a rough indicator of the lake's water volume.

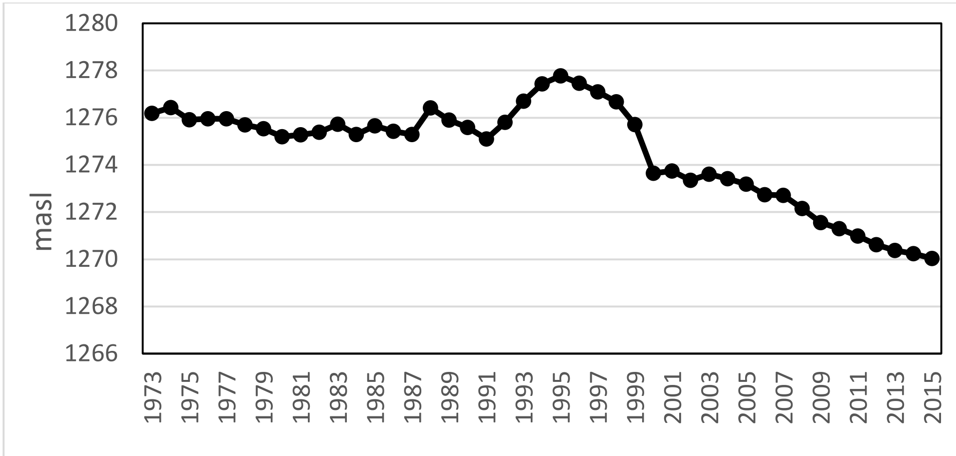


*Figure 4: Changes in water level of Lake Urmia from 1973 until 2015.*

Comparison of the satellite images of the Lake Urmia on 22 Sep 2014 and 8 Oct 2014 (at the interval of just 16 days) shows great change in the surface area which took place as a result of three days normal rain. Based on rough estimates 500 MCM of water made entry into the lake during this short period causing an increase in lake surface area by almost 3 times. This could happen only due to very flat bed and rapid spreading of the water in large area.

The three dimensional view of the lake in 2002 [5] shows that the deepest area of the lake was located at North wing (about 10 m) and the deepest part in South wing was about 8 m deep. Our recent depth measurements in the lake showed that the water depth at the deepest zone was not more than 2 m. This proves the extent of sedimentation of salt and other minerals and how it has caused uplift of the lake bed by few meters (Figs. 3, 5, 6). Uplifting of the bed has taken place gradually; every year one layer of sediment has been added mainly during the late spring and summer, during the period of maximum evaporation.

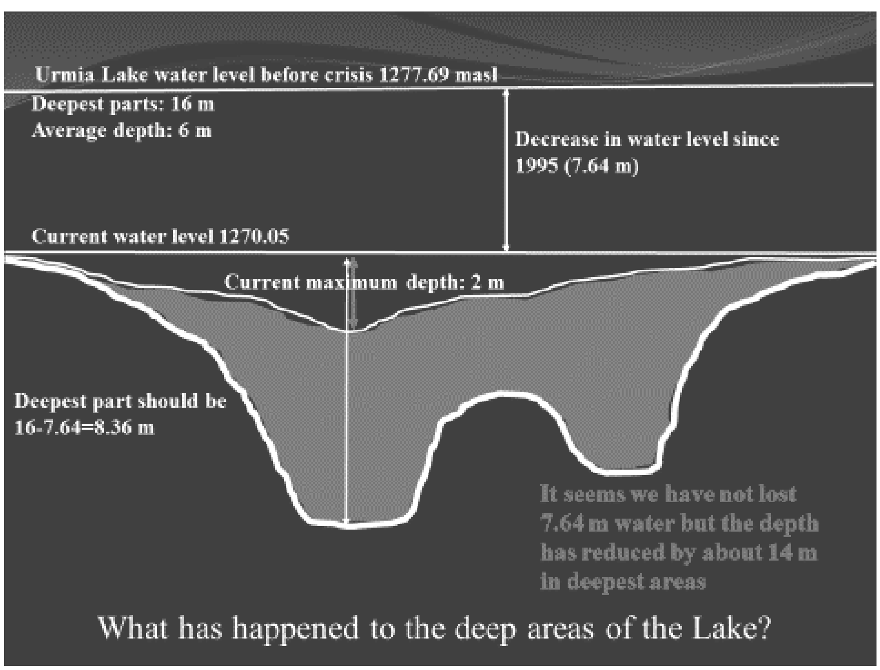


*Figure 5: The area of the lake bed filled with salt and other minerals shown in light grey.*

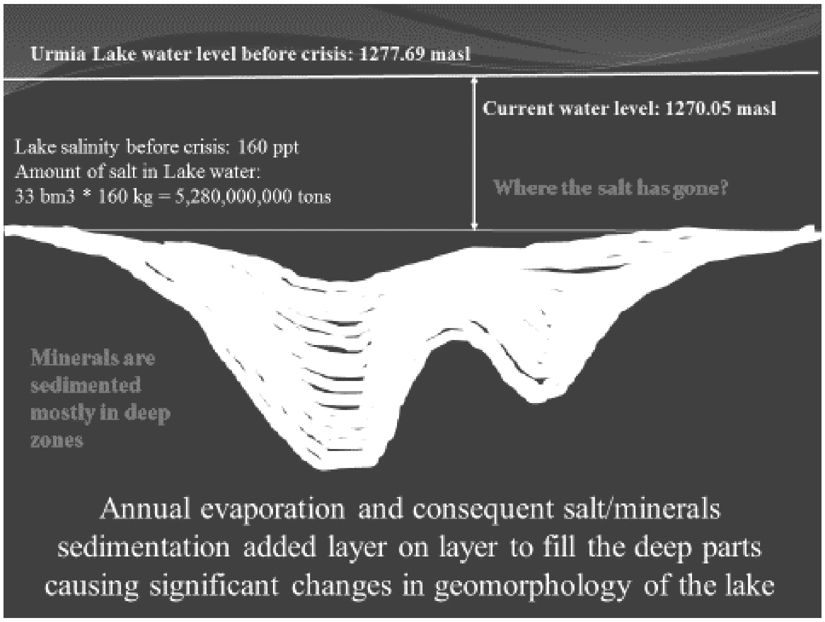


*Figure 6: Layer by layer sedimentation of salt and other minerals filling the lake bed.*

## 3. Results of Recent Field Excursions and Sampling

Eighteen sampling stations were selected to measure the depth and collect water samples for chemical analysis. The depth measurements were compared with changes in the water level during the last 5 months. It was observed that water level decreased by 55 cm from 20th May until 13 Oct, whereas the water depth decreased by one m during the same time, indicating that 45 cm of sediments was added to the lake bottom (Figs. 7, 8). Water salinity was highly different at different parts of the lake during this period due to inflow of fresh water through rivers ranging from 100 to 485 ppt. But the salinity was always over 400 ppt in deep areas of the lake (areas with more than one meter depth).

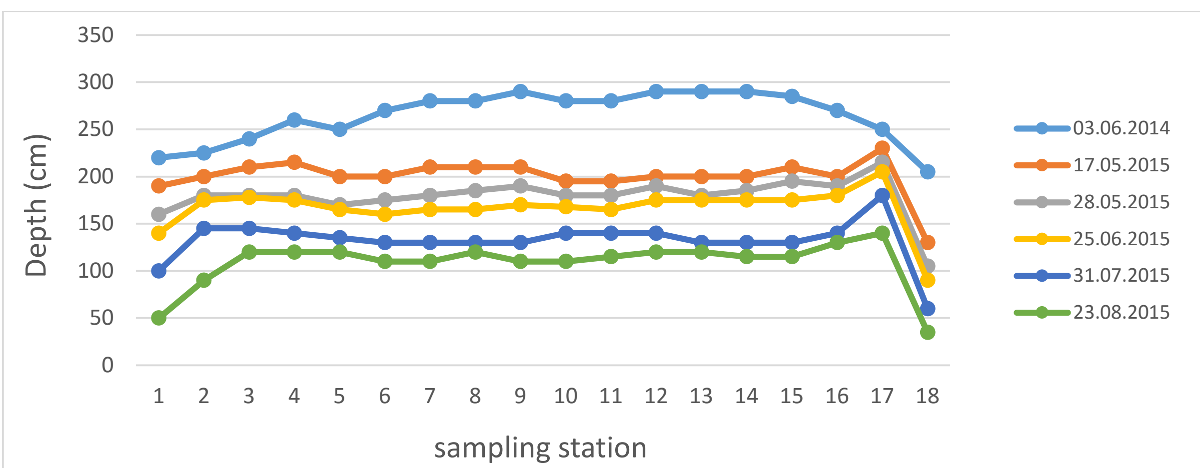


*Figure 7: Depth variations in sampling stations.*

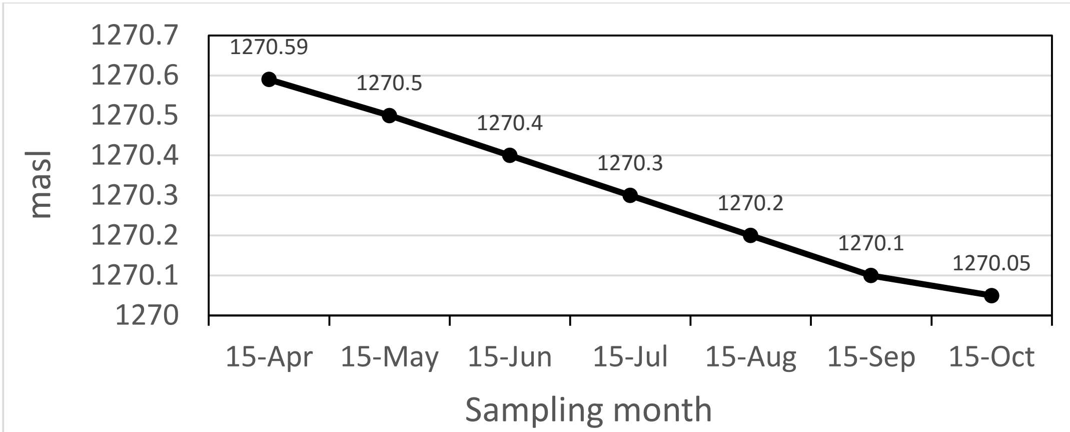


*Figure 8: Water level changes from 15 April up to 15 October 2015.*

## 4. Why Can We Not Restore Lake Urmia as It Was Before?

We cannot restore the whole lake because the lake geomorphology has changed, it is converted into a flat and shallow playa and its water holding capacity has reduced significantly. We do not have enough water to fill the whole lake, as the drying process has shown that evaporation is always higher than because if it could be restored with annual inflow of 2.5 BCM of water it would have never dried. Based on the satellite images, the Lake Urmia was at ecological level from 2002 to 2004. At ecological level the lake should contain about 15 BCM water and the area is about 4,000 km$^2$. If the lake was at ecological level containing 15 BCM of water and there was an annual average inflow of 2,440 MCM of water until 2012 (Fig. 9) and if it went on drying during the same period, how we can expect to restore a dry and flat Lake Urmia with the same amount of water. It is very obvious that if the dried Lake Urmia could be restored with annual inflow of 2.5 BCM of water, the lake containing about 15 BCM of water and receiving an average of annually 2.4 BCM of water, would have never dried up.

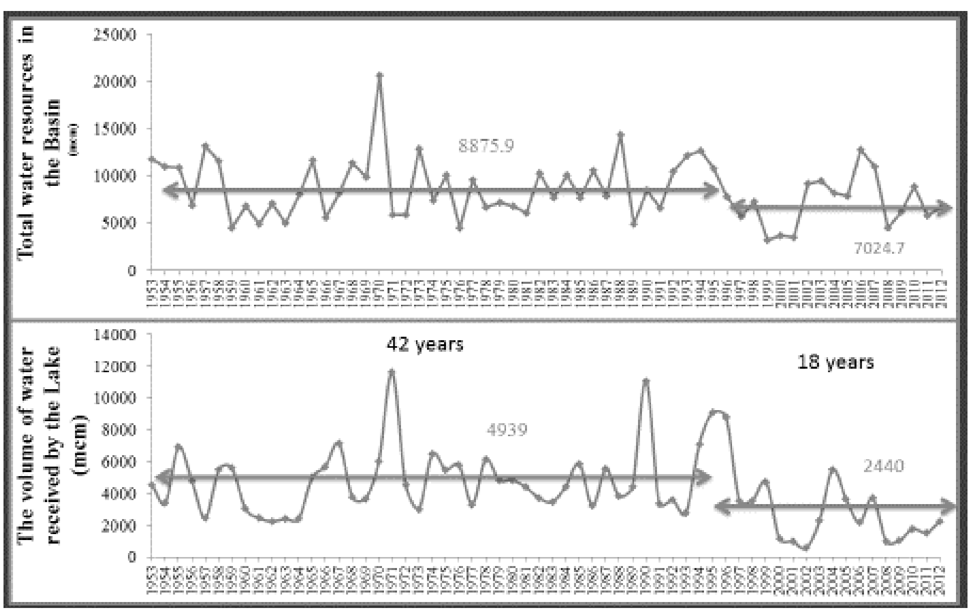


*Figure 9: Total water resources in the Lake Urmia basin and the annual average water inflow of surface water to the Lake from 1953 until 2012.*

In order to return the Lake Urmia to ecological level within next 10 years (from 1,270.1 to 1,274.1 masl), we need to increase the lake water level by 40 cm annually. That means we need to add water to uplift the lake level by 140 cm annually as surface evaporation equals 100 cm every year (Fig. 10). How much water will be required to increase the level by 140 cm every year? How far will the inflowing water spread over if we add such quantity of water to the lake?

According to my calculations in order to increase the water level by 140 cm we will need 2,730 and over 3,500 MCM of water during first two years. The water quantity required in later years will increase to a much bigger size, but the lake cannot accommodate the excess of due to changed geomorphology. This means restoration of Lake Urmia would not be possible unless we dissolve the deposited salts in order to increase the depth and its water holding capacity.

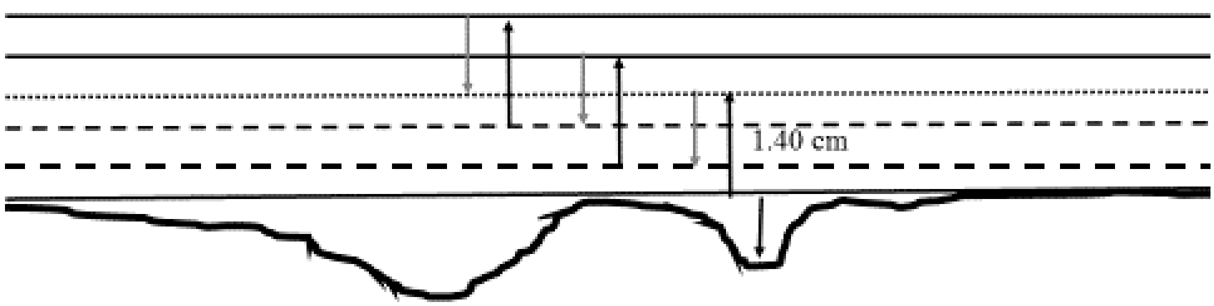


*Figure 10: Black arrows show uplifting and grey arrows show the subsequent reduction of the lake level after evaporation.*

## 5. Adaptive Phased Restoration and Phased Management of Lake Urmia

Phased restoration of the Aral Sea and phased management of the Great Salt Lake are two important and valuable experiences that provide lots of lessons for us. Dikes in Aral Sea have proved to have an essential role in saving parts of the Sea [6,7], and the causeways and dikes on Great Salt Lake are good examples of a sustainable phased management of a wetland with environmental and socio-economic importance [8]. We are spending a very critical period of water crisis and preservation of wetlands is becoming more and more difficult due to higher consumption of water in agriculture and industry. Many small and large lakes have been dried during last decade, including 25 wetlands in Iran. After the Aral Sea, Lake Urmia is the largest wetland facing almost total desiccation due to similar causes.

Lake Urmia is divided by a causeway into North and South arms and most of the inflowing surface water makes entry into the lake from the southern part. The causeway has an opening of about 1.5 km connecting the two arms, apparently allows sufficient mixing between the sides [9]. The slope of the Lake is from south to north, therefore inflowing water moves from the rivers terminal points towards the opening in the causeway to transfer the water to north. The deep areas are mostly filled with salt sediments and inflowing water spreads over a very large area in both north and south arms. This process shallowly fills about 3,000 km$^2$ of the lake with little water, which evaporates in less than 2 months during the summer. Only during this year from late spring until end of summer (within just four months), Lake Urmia lost one meter depth, (50 cm drop in water level and 50 cm uplifting of the bed due to salt sedimentation), leaving behind less than 2% of the water. The Urmia Lake is approaching total desiccation, and if this happens, the biggest natural protected wetland of Iran and the highest socio-economic potential of West Azerbaijan will turn into the biggest environmental-socio-economic disaster for the whole region.

In the current situation due to supersaturation of the lake with salt (over 480 ppt), the inflowing water cannot even mix properly with existing water in the lake and does not have enough energy to dissolve the sediment salts. The inflowing water can only dissolve the superficial salt layer in dried areas, whereas most of the salt has deposited in deep areas. Hence the inflowing water tends to spread over in large area of the lake, and is prone to immediate evaporation. Therefore it seems senseless to spend millions of dollars to transfer water without any concrete plan for its preservation in the lake. Continuation of this process will only contribute in wearied prolongation of the lake restoration period.

Therefore, we have no choice but to implement methods aiming at increasing the water volume to surface area. As the deep areas are already filled with salt and mineral sediments and the lake has turned into a shallow playa, the only remaining method to increase the volume/surface area ratio is to reduce the lake size by diking to allow preserving higher volumes of water in a smaller area. Based on this idea I propose partitioning of the Lake Urmia, initially dividing it into two separate north and south arms connected via a control gate and spillway under the bridge of the causeway (Fig. 11). Then we need to construct dikes to cut the areas in the south arm that exclusively act as buffer zone, facilitating rapid water evaporation. As a result we will have a south arm (1,700 $km^2$) and a north arm (1,300 $km^2$) with a total surface area of 3,000 $km^2$. Based on the potentials of the basin for water production and the volume that could be saved for Lake Urmia, we propose to set the average depth of the lake at 2 m, maintaining the water level at 1,272 m above sea level. Our studies prove that there is not much salt sediments in the south arm, therefore we believe that water salinity in the south will be suitable for *Artemia* and the migrating and local birds. The salinity of this portion could be adjusted at about 100-180 ppt via a control gate and spillway to support high density production of *Artemia* as natural feed for a number of birds especially flamingos. Based on my estimates about 100 tons of *Artemia* cysts and 1,000 tons of excess *Artemia* biomass could be produced in this region to support development of an *Artemia* industry to safely assure the needs of Iranian aquaculture industry for this strategic product and at the same time preparing the ground for recruitment of 1,000 persons. Nine major rivers terminate to the south arm which can fill the larger south wing within 3-4 years based on the inflowing water and rainfall. The south arm will remain connected to the north arm via a control gate and spillway located under the bridge of the causeway to allow water to flow over when south arm is filled. The north wing due to high concentration of salts may serve as a potential source for exploration of minerals in the benefit of the people living in the region.

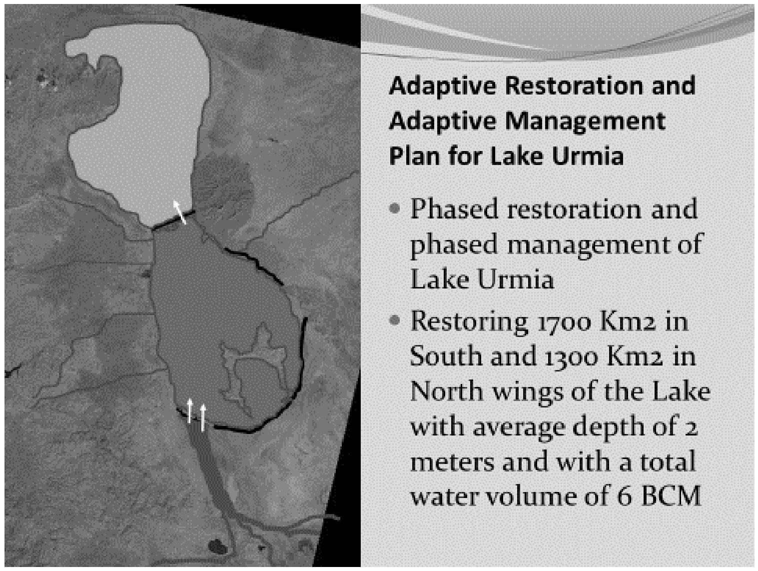


*Figure 11: Proposed diking method for partitioning and phased restoration/management of the Lake Urmia.*

## 6. Concluding Remarks to be Remembered while Planning to Save Urmia Lake

1. The geomorphology of the lake has changed and the lake bed is covered with over 6 billion tons of salt and other minerals which is as thick as five meters in previously deep areas.
2. The lake has converted into a vast playa with minimum water holding capacity and with increased potential for evaporation.
3. The water crisis is deepening in Iran including in the Urmia Lake basin each year, making it very uncertain that the water right of a lake could be guaranteed in the future.
4. Increased population density and need for food on one hand and maintaining the life and job of the farmers on the other, increases the uncertainties of saving enough water from agriculture sector for Lake Urmia.
5. The modern desiccation of the Aral Sea illustrated that the natural environment can easily and quickly be wrecked but that repairing it, if possible, is a long and arduous process.
6. Although Aral Sea was considered as a lost cause, it has now been unequivocally demonstrated that significant parts of it can be preserved and ecologically restored.
7. Fortunately the natural environment is amazingly resilient. Hence, we need to combine efforts to find possible methods although unconventional to help the nature to revive.
8. Do not keep lots of hope on saving the lake by transferring huge amounts of water from other ecosystems far away from the lake. Such actions usually need decades to complete and could face problems as a result of changes in governments and political situations.
9. Large-scale environmental restoration projects require careful monitoring and follow-up. This is necessary not only to make sure they are working as expected and to provide management feedback, but to learn new lessons that may improve the success of similar actions elsewhere.

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# Urmia Lake Restoration Program

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## *Abstract*

One of the most critical issues in Iran, which both people and authorities are faced, is drought of many watersheds and groundwater level reduction. In this paper, the drought procedure of the biggest picturesque lake in Iran, Urmia Lake, is explained. Based on academic researches three main reasons for Urmia Lake's crisis are improper development of the agricultural sector, improper water consumption pattern in potable, health and industrial sectors and last but not least climate change and continuing drought. Indeed, the renewable water use stands at 70%, which is significantly higher than the sustainable limit of the basin. Therefore, worsening condition of Urmia Lake from one side and the government's commitment to solve such national environmental crisis on the other side resulted in approving establishment of a program titled "Urmia Lake Restoration Program" which we are aiming to express and analyze in this paper. Ultimately, the essential strategies to save and restore Urmia Lake, all of which concentrate on significant decline in water consumption throughout the basin, are explained and measures taken till now are presented.

***Keywords: Drought, Renewable Water Use, Sustainable Limit, Urmia Lake Restoration Program***

## 1. INTRODUCTION

In the North-West of Iran, the basin of Urmia Lake, the country's largest in-land lake, covers an area of over 50,000 m$^2$; it is also a significant water ecosystem. Due to its unique natural and ecological characteristics, Lake Urmia is a protected area as a UNESCO Biosphere Reserve and a Ramsar Site. With all runoff flowing into the closed basin, perfect conditions are in place to assess and control various environmental elements. The average precipitation as well as the number of rainy days in the basin of Lake Urmia has significantly fallen (i.e. 18% which is equal to 68 mm) in recent years compared to that of previous time periods on record. Consequently, this trend has resulted in a drop in runoff and surface water inflow throughout the basin. Therefore the average runoff inflow to Lake Urmia has decreased by 50% (i.e. 2,500 MCM). The significant decline in the water level of the lake (Fig. 1 and 2) alongside renewable water resources (i.e. 21% which is equal to 1,850 MCM) reflects these terrible events. Presently, the renewable water use stands at 70%, which is significantly higher than the sustainable limit of the basin. Latest figures (June 2014) show a 50% drop in ecological water level and an 82% decline in Lake Urmia's water content [1].

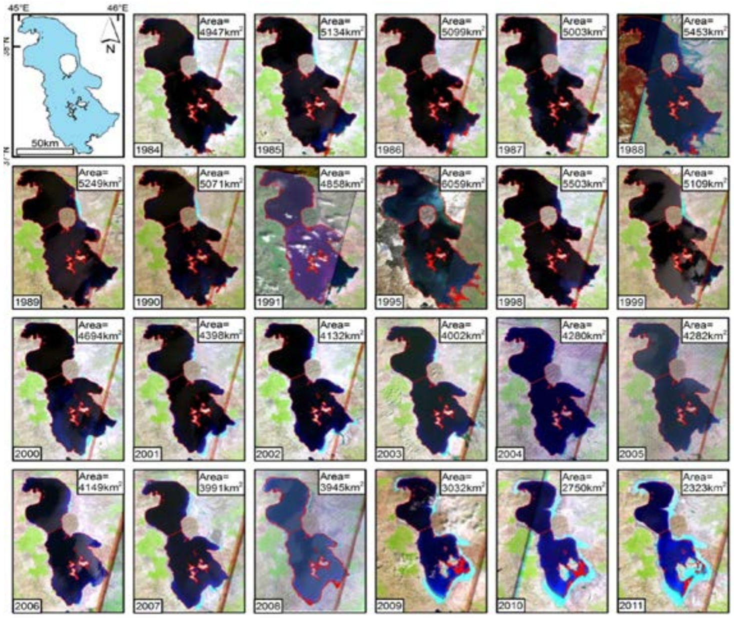


*Figure 1: Lake Urmia, Changes in Water Level (1984-2011).*

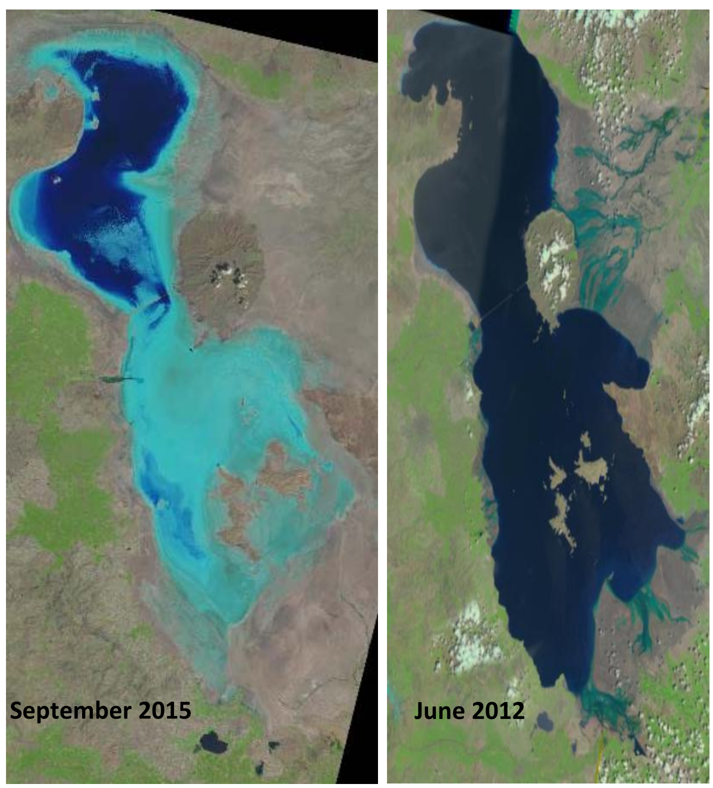


*Figure 2: Lake Urmia, Water Level Status in June 2012 Compared to September 2015.*

Present status of Urmia Lake is the result of unsustainable development in the catchment area for several decades and abnormal water withdrawal from the basin's renewable water. A complex of various natural and human factors such as executing various projects on water resources development, increasing development of the agricultural sector, changing the agricultural pattern and producing high water-consuming products on the basin area, low water productivity and lack of effective protection from the basin ecological and environmental resources, as well as, climate change and decreasing rate of precipitation and surface runoff all over the Urmia water basin have brought about such conditions for the largest inland lake in Iran. In other words, lack of enough water flow into the lake in the recent years has resulted in an intensive trend of decreasing water level and lowering of its water volume.

## 2. AN ANALYSIS OF WATER RESOURCES AND CONSUMPTIOIN STATUS IN THE LAKE URMIA BASIN

Currently, the water consumption in various sectors stands at 70% of the basin's renewable water resources, which is significantly higher than the amount of the stability limit of Lake Urmia. The agricultural sector is the largest consumer with a share of 89% of total renewable resources. Approximately 70% of renewable water resources are consumed in different sectors, with the agricultural sector using a minimum 60% of total renewable resources and 90% of total water use in the basin. While the admissible level of water withdrawal from renewable water resources stands between 20 to 40%.

In order to save and restore Lake Urmia, studies necessitate significant decline in water consumption throughout the basin, provision of environmental requirements of the lake as well as water transfer to Lake Urmia [2].

Iran's Ministry of Jihad-e-Agriculture along with Ministry of Energy are the government entities responsible for enforcement of the 40% water consumption decrease in the agricultural sector as a sustainable solution to address Lake Urmia crisis. The implementation of such measures leads to a 45% saving in renewable water resources. Releasing water storage of dams can remedy or to some extent address the critical status of the lake in the short-term. Implementation of various solutions to reduce consumption and transfer of water from Silveh and Zab basins and unconventional use requires a minimum of ten years for the restoration process of Lake Urmia to reach the ecological level [2].

## 3. URMIA LAKE RESTORATION PROGRAM (ULRP)

Worsening condition of Urmia Lake from one side and the government's commitment to solve such national environmental crisis on the other side resulted in approving establishment of a program titled "Urmia Lake Restoration Program." Following up such program establishment, Ministry of Energy undertook to hold various professional and technical sessions and workshops, as well as professional meetings on "executive strategies to save Urmia Lake" in Tehran University which resulted in the approval of 19 prioritized projects to solve the problem of Urmia Lake. The 19 projects were approved in the program of saving Urmia Lake in the meeting dated 8 October 2013, which was eventually discussed and approved in the cabinet on 9 October 2013 for which the Minister of Energy takes the responsibility to coordinate and lead the execution of the Urmia Lake Restoration Program [3].

Considering the critical environmental conditions relevant to drought of Urmia Lake and considerable decrease of water level and volume, as well as enhancing and focusing on the actions related to Urmia Lake restoration, the cabinet held a meeting on 22nd January 2014 to establish "National Committee of Urmia Lake Restoration Program" based on 138 principal of the constitutional law on which Dr. E. Kalantari, was elected and approved as the staff secretary and executor of the project. Following such approval, the program has formally started and approached the activities as follows:

- Better analysis of Urmia Lake crisis dimensions such as effective factors originating such crisis, as well as present and future conditions of the lake;

- Attracting participation and cooperation of all responsible and relevant organizations and authorities to benefit from their professional and expertise points of view;
- Benefiting from know-how and participatory contributions of university professors, professionals, experts and researchers internally and externally;
- Emphasizing on the participation of local authorities in numerous and concordant activities to fulfill the Urmia Lake Restoration Program objectives;
- Attempting to create the public and comprehensive determination and participation through informative mass media to restore Urmia Lake, to improve its present condition and to observe it as “a public challenge”;
- Compiling the road-map of Urmia lake restoration.

Urmia Lake Restoration Program established 6 professional committees, 20 various professional work-teams, carried out comparative studies (e.g. studied strategies already made on similar challenges in the world) and established regional councils to start its activities through professional, scientific and participatory approach to prepare a road-map and to execute a comprehensive strategy harmonized with Urmia lake restoration.

In 7 June 2014, Lake Urmia’s water level was about 1,270.6 m, which illustrated a balance decrease of 3.5 m compared with the lake ecologic balance. Considering the negative trend in the lake level and the urgent requirement of supplying water not only to stabilize the present situation, but also to increase the level and volume of the lake water, some urgent actions are necessary. Urmia Lake Restoration Program reached to the turning point that the strategy of increasing water inflow to the lake through decreasing water uses in the basin agricultural sector, as well as, minimizing the water losses through the water conveyance to the lake water body would be the pivotal activities to restore Urmia Lake. Therefore, approaching such trend plus the required coordination with the Ministry of Energy and the Ministry of Jihad-Agriculture, the staff has defined the required projects and presented them to be executed. It is noteworthy that international experiences, especially those related to Aral Sea restoration, reveal that using the internal basin water resources, as well as, doing the essential steps for increasing water productivity all over the basin, would be beneficial to achieve the revival of Urmia Lake. The suggested water resources that can supply water for restoring Urmia Lake are mentioned in Table 1. Moreover, in Table 1, more details about annual volume of water transfer to lake water body can be found.

TABLE 1: WATER SUPPLY POTENTIAL FOR LAKE URMIA [4]

| **Water Source** | **Description** | | **Annual Volume of Water Transfer to Lake Urmia’s Water Body (MCM)** |
|---|---|---|---|
| *Current Volume of Water Transfer to the Lake from Rivers* | *Net Water Inflow Volume to the Lake’s Water Body* | | *1,500* |
| *Water Resources Outside Basin* | *Water Transfer Project from Zab River* | | *600* |
| | *Water Transfer Project from Silveh River* | | *190* |
| *Unconventional Water Resources* | *Basin wastewater* | | *300* |
| *Reducing the Water Consumption in Agricultural Sector* | *Savings in Agricultural Water Use (40%)* | *From Surface Water Resources* | *970* |
| | | *From Ground Water Resources* | *370* |
| | *Releasing Water Storage of Dams* | | *First Year: 510*<br>*Second Year: 580*<br>*Third Year: 640* |
| *Reducing the Water Loss in the Lake’s Buffer Zone* | *Water Transfer to Lake’s Body of Water* | | *250* |

The other important point is that the lake restoration is a time-taking approach. Executing the required strategies to revive and restore the lake to its natural ecologic balance will take at least 10 years. The predicted schedule to restore Urmia Lake till 2024 is illustrated in Table 2.

TABLE 2: URMIA LAKE RESTORATION TIME SCHEDULE UP TO 2023 [4]

| | **Year** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** | **2021** | **2022** | **2023** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Status** | **Stabilizing Period** | | | **Urmia Lake Restoration Period** | | | | **Final Restoration** | | |
| **Water Supply (BCM)** | *Natural inflow of the rivers* | *1,500* | *1,500* | *1,500* | *1,500* | *1,500* | *1,550* | *1,600* | *1,650* | *1,700* | *1,800* |
| | *Water conveyance from Zab* | | | | | | *600* | *600* | *600* | *600* | *600* |
| | *Water conveyance from Silveh* | | | *190* | *190* | *190* | *190* | *190* | *90* | *90* | *90* |
| | *Water conveyance of Sewage* | | | | | *100* | *200* | *250* | *300* | *300* | *300* |
| | *Water conveyance to the lake water-body (decrease of losses)* | *150* | *200* | *250* | *250* | *250* | *250* | *250* | *250* | *250* | *250* |
| | *40% water saving in the agricultural sector (8% per year)* | | *227* | *450* | *800* | *1,070* | *1,340* | *1,340* | *1,340* | *1,340* | *1,340* |
| | *Water release from the dams* | *150* | *200* | *250* | | | | | | | |
| | *Total* | *1,800* | *2,127* | *2,640* | *2,740* | *3,110* | *4,130* | *4,230* | *4,230* | *4,280* | *4,380* |
| | *Evaporation (million m$^3$)* | *1,486* | *1,728* | *1,959* | *2,052* | *2,068* | *2,276* | *2,512* | *1,647* | *2,718* | *2,923* |
| | *Final restored volume (million m$^3$)* | *2,453* | *4,090* | *4,985* | *4,974* | *6,042* | *7,976* | *9,747* | *11,351* | *12,869* | *14,403* |
| | *Final restored level (km$^2$)* | *2,072* | *2,435* | *2,792* | *2,990* | *3,215* | *3,600* | *3,845* | *4,044* | *4,166* | *4,331* |

According to the program studies, the time-schedule for restoring the lake up to the year 2022 is illustrated in Table 3. It is noteworthy to make the required actions to supply more water for Urmia Lake to fulfill the planned objective. For decreasing the period of two years from the planned time-schedule of Urmia lake restoration up to the year 2024, actions to be carried out are as follows:

- More volume of water conveyance to the water body and further decrease of water losses;
- Increasing the volume of water conveyance from Silveh River to Urmia Lake;
- Decreasing the agricultural water consumption trend from 10% to 8% per year;
- Continues water releasing from the dams up to the year of 2019.

TABLE 3: URMIA LAKE SCHEDULE (UP TO THE YEAR 2022) [4]

| | Year | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|---|---|---|---|
| | **Status** | **Stabilizing Period** | | | **Urmia Lake Restoration Period** | | **Final Restoration** | | |
| **Water Supply (BCM)** | *Natural inflow of the rivers* | *1,500* | *1,500* | *1,500* | *1,500* | *1,500* | *1,550* | *1,600* | *1,700* |
| | *Water conveyance from Zab* | | | | | | *600* | *600* | *600* |
| | *Water conveyance from Silveh* | | | | | *350* | *350* | *350* | *350* |
| | *Water conveyance of Sewage* | | | | | *100* | *100* | *100* | *100* |
| | *Water conveyance to the lake water-body (decrease of losses)* | *150* | *250* | *300* | *350* | *350* | *400* | *400* | *400* |
| | *40% water saving in the agricultural sector (8% per year)* | | *280* | *540* | *800* | *1,060* | *1,340* | *1,340* | *1,340* |
| | *Water release from the dams* | *510* | *580* | *640* | *700* | *700* | | | |
| | *Total* | *2,160* | *2,610* | *2,980* | *3,350* | *4,060* | *4,440* | *4,540* | *4,690* |
| | *Evaporation (million m³)* | *1,527* | *1,727* | *1,928* | *2,092* | *2,292* | *2,492* | *2,687* | *2,805* |
| | *Final restored volume (million m³)* | *3,378* | *4,261* | *5,313* | *6,571* | *8,339* | *10,287* | *12,139* | *14,024* |
| | *Final restored level (km²)* | *2,529* | *2,823* | *6,063* | *3,356* | *3,648* | *3,935* | *3,935* | *4,285* |

On the whole, the program has defined its mission as "Urmia Lake Restoration" and its outlook in 2014 based on the performed professional and expertise studies, has chosen to reach to its ecologic balance. Following its mission, the program has established an operative plan to fulfill the outlook of Urmia lake restoration with 26 required strategies of which 18 are executive and 9 are study strategies. Fourteen strategies were approved in the meeting held by National Committee of saving Urmia lake on 29 April 2014, which was issued to the working group members in the latter ref. 18171 dated 18 May 2014 by the honorable first deputy of president; the other 12 strategies were discussed in the meeting held by the working group and approved on 29 June 2014. It was also suggested that proper strategies be studied by the staff and the relevant entities. Such strategies are as follows [3]:

1. The approved strategies in the meeting held on 29 April 2014 by the national committee of Saving Urmia Lake are as follows:
   A. Executive Strategies:
      i. Prohibition of any kind of additional withdrawal from the basin water resources and prevention of new development especially in the agricultural sector;
      ii. Preventing unpermitted withdrawal from the surface waters;
      iii. Stopping all the dam construction projects under study and under operation (except for shahid Madani and Cheragh-veis Dams), as well as downstream irrigation and Drainage projects in Urmia lake water basin and water reservoir and release in Shahid Madani Dam, exclusively for Urmia Lake);
      iv. Securing the required budget and enhancing water conveyance project from the Zab river to flow into the Urmia Lake Water Basin;
      v. Establishing and executing the comprehensive education plan, informing and awakening procedures, as well as, absorbing public and local communities participation to highlight the results of the present situation and the importance of Urmia Lake Restoration;

vi. Setting the affairs relevant to the Urmia lake water basin and installing smart and volumetric meter to control water withdrawal in line with increasing river water inflow into the Urmia Lake;
vii. Monitoring to decrease the agricultural sector water consumption:
    - Decreasing 40% ground and surface water rights, being purchased by the Ministry of Energy in two years;
    - Decreasing and performing the productivity increase plan on the 60% remained water in the agricultural sector by the Ministry of Jihad-Agriculture;
    - Supplying the required capital and technologies to increase the productivity of the remained water by the government;
viii. Conveying water to the islands and wetlands in the basin of Urmia Lake from Hasaan-lue Dam and re-opening the water inflow courses to the southern wetlands;
ix. Preparing the Urmia Lake water basin cadaster areas;
x. Executing the approved projects by the executive entities together with monitoring and supervising the project's execution by the Urmia Lake Restoration Program.

B. Feasibility study strategies:
i. Designing and settling the comprehensive management of decision support system of Urmia Lake water basin;
ii. Studying and analyzing the Shahid Kalantari access road on Urmia lake and presenting reforming strategies;
iii. Assessing and feasibility study on industrial productivity of Urmia lake minerals by considering environmental issues.

2. Approved strategies in the meeting dated 29 June 2014 by Urmia Lake Restoration Program:

A. Strategies to be done:
i. Water conveyance of the river to the lake water body;
ii. Exploring dust production centers for stabilization;
iii. Studying and executing ecologic protection project of Urmia Lake national park prioritizing its southern region;
iv. Performing the required coordination with the judiciary power to facilitate and enhance the execution of the law on the water-wells lacking permission, especially the ones effective on surface water;
v. Reconnaissance of the area limits effective on the main aquifers conveying water to the Urmia lake;
vi. Enhancing the execution of water conveyance from Silveh river at the vicinity of west Azerbaijan exclusively from Urmia Lake according to the allocation approval of the Ministry of Energy;
vii. Establishing Research Centre for the future of Urmia Lake by the Environment Protection Organization.

B. Study strategies:
i. Pathology of health, hygienic, social and environmental effects resulted from partial drying of Urmia lake, preparing the executing preventive project to decrease potential risky effects;
ii. Preparing a program for increasing employment and sustainability way of living by the relevant entities;
iii. Feasibility study of using modern technology appropriate with Urmia lake restoration;
iv. Studying the project of water conveyance from the Caspian sea to Urmia lake;
v. Reconnaissance of halo culture, sustainable use of saline soil and water resources suitable for the flora of the region around Urmia Lake.

3. Strategies proposed but not approved yet:

A. Stopping cultivation in shallow areas of Nowruz-Lu diversion dam and Zarrina-rud junction to Simineh-rud areas for 3 years and paying compensatory remunerations to the farmers
B. The Urmia Lake Restoration Program has already established relevant program along with the required coordination and meeting with the managers, and experts of the responsible authorities. This comprehensive program included the required projects, the executing entity of each project, the needed budget (the title of the existing budget, and assessment of the future required budget).

## 4. Measures Taken

Although it is the country's first real experience in terms of integrated management with the participation of 17 organizations, the results are significantly valuable and productive. The main actions that have had a profound impact on increasing the volume of water entering the lake are listed below:

- Stop all developed or under-developed dam projects, irrigation and drainage network construction, which could conserve 1,275 million cubic meter of lake's water right;
- Releasing 576 million cubic meter water from dams during two last years;
- Dredging rivers poured into the lake;
- Transferring 131 million cubic meter wastewater from the existed treatment plants;
- New sewage network construction (around 55% has been progressed);
- Controlling and decreasing water withdrawal from surface and groundwater resources has produced 90.3 million cubic meter water saving;
- Exploring dust production centers and stabilizing them (around 12,000 hectares);
- Improvement water productivity in irrigation network and agricultural section lead to 78 million cubic meter water saving.

Although these helpful actions have been already been taken, the present condition of Urmia Lake is not matched with the anticipations in the road map. Indeed, the recent lake level is 28 cm lower than predicted at this time, which revealed the obstacles in implementation.

## 5. Conclusion

Various studies have shown that the current crisis in Urmia Lake is due to improper development of the agricultural sector, climate change and continuing drought. The average rainfall in the region has decreased 18% (i.e. 68 mm) in recent years. Also, the amount of renewable water resources in the basin has declined 21% which is equal to 1,850 million cubic meters reduction. At present the use of renewable water resources in the basin is 70%, far higher than the regional stability level and needs to be reduced to 40% range. By applying a 40% reduction in agricultural water use, the use of renewable water resources would be decreased up to 45%, ultimately stability return to the basin and the lake will be restored as a long-term effect. Since water transfer projects are time-consuming while the current status of the lake is crucial, the advised urgent measure which should be taken in short-term to make the lake stable and recover it to the ecological condition are: reducing water losses in the Buffer zone, reduce water consumption in the agricultural sector and releases water from dams. Finally, by applying different restoration strategies such as reducing water consumption, transferring water from Silveh and Zab basin and unconventional water resources within the basin, the revitalization process will require a 10-year period time at least.

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# Investigating Human and Climate Impact on Parishan Wetland Water System Using System Dynamic Approach

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## *Abstract*

Parishan wetland has been selected by UNESCO as a biosphere reserve and was recorded as an international wetland in Ramsar Convention in 1986. This region is located (29°31'N 51°48'E) at 820 m above sea level in Kazeroon, Fars province, south west of Iran and was the largest freshwater lake in the country. Parishan Lake was extremely important for a wide variety of wintering waterfowl and also for breeding waterfowl, especially in wet years. It is fed by permanent springs and seasonal water sources, lies in an enclosed drainage basin in a broad valley and is brackish to saline, the salinity varying widely with the size of the lake. Unfortunately at the present time this important lake is endangered by climate change, drought and mismanagement of water consumption. A comprehensive record from Lake Parishan shows human impact on the lake and its catchment over the last several decades. This paper investigates the effect of groundwater extraction around Parishan wetland and climate change on water level of Parishan wetland using a system dynamics approach. A system dynamics model, Lake Parishan Water System Model (LP-WSM), was used to evaluate the hydrology of the basin. Increase in extraction from agricultural wells caused a decline in the groundwater table and a decrease in lake level at the same time. On the other hand, decrease in water lake level causes a decline in the groundwater table due to decrease in penetration while changes in temperature, evaporation from the wetland, and precipitation are effective climate factors playing an important role in decreasing lake water level in dry years. Finally, some recommendations are made to improve the situation.

***Keywords: Parishan Wetland, Drought, Climate, Water Management, System Dynamics***

## 1. INTRODUCTION

Historical literature indicates that the older civilizations have formed along the rivers and wetlands and various values of the wetlands have always improved the quality of natural environments. Nowadays, most of the people, particularly those living around the wetlands, are to some extent aware of the values and functions of the wetlands, and the role they play in sustaining the indigenous communities.

Despite being located in the semi-arid part of the country, the Fars Province is considered as one of the five first provinces of Iran regarding the extent of its wetlands. However, due to accelerating development programs and over-exploitation of the basic natural resources, along with occurrence of natural events such as climate change and prolonged droughts during recent decades has led to degradation of parts of these valuable habitats. Wetlands in many countries are facing similar crises; and considering their global functions, particularly from biodiversity point of view, their improvement requires an effective participation of the involved parties worldwide.

Parishan wetland in Fars Province is among the valuable and important ecosystems of Iran, which not only provides rich biodiversity but also provides significant socio-economical services to the local population. The wetland is part of the “Arjan-Parishan” protected area and is registered as an internationally important wetland in Ramsar Convention. It is considered by UNESCO as one of the biosphere reserves [1].

The Lake Parishan area has been subject to several different studies including geology and geophysics, climatology, water and land resources, fauna and flora, human population and rural economy etc. Also several dissertations deal with the ecological attributes of the lake which all together provide good information on the lake.

The earliest report on Lake Parishan is the material included in “A directory of wetlands in the Middle East, 1995”, compiled and edited by D. A. Scott [2]. The comprehensive studies were accomplished by Department of Environment (DOE) in Iran with the purpose of developing a plan for management of the Arjan and Parishan protected areas and to evaluate and promote its ecotourism capacities. During the dry years of the early 1970s, water levels were low, the lake was brackish to saline, marsh vegetation was confined to the western and eastern ends of the lake (near freshwater inflow), and there were large areas of bare salt flats in the south-west bay [3].

Parishan was an oligotrophic lake surrounded by eutrophic marshes. It also supported extensive beds of reeds and reedmace, as well as halophytic vegetation. Large areas of the semi-arid steppe around Lake Parishan have been converted to wheat fields. Nearby mountain sides are still covered with forests of oak, while the lower slopes are partially covered with steppic forest of almonds, hawthorn and hackberry. This site was used for subsistence fishing, reed-cutting, extensive grazing by domestic livestock before. In its catchment there were a few small settlements with orchards and gardens, some wheat cultivation and other crops.

In recent years, parts of Iran have experienced a severe and persistent drought [4]. Whilst drought is a natural and quite frequent phenomenon, the persistence of the current drought is unusual. This has had a cumulative impact on Iranian wetlands, exacerbated by increasingly unsustainable levels of water use in much of the country. Whilst the paper has worked intensively on the issues of water use and allocations to wetlands, ongoing declines in precipitation and increases in temperatures and evaporation have exacerbated the pressures on water resources available to wetlands [5]. Although a number of mitigatory actions have been taken, with no recovery towards normal precipitation levels, the risk has become a reality. The Lake Parishan demonstration site has been dried since 2009. This paper is the result of the simulation for water hydrology based on the climate, social and agricultural subsystems to predict the water level of the lake Parishan in recent decades. After LP-WSM model calibration, the future strategies can be made and compared based on the water behavior of the lake with an integrated assessment of system dynamic model.

## 2. MATERIAL AND METHODS

### *2.1. Location*

Lake Parishan is located 15 km west of Kazeroun town, in Fars Province (Fig.1). It is in a rather isolated depression in between the Shapour and Dalaki River catchments. Geographically its center is defined as 51.20 E and 29.30 N. It is about 820 meters above mean sea level [1].

## 2.2. Topography

The wetland is formed in a shallow depression stretched out at the toe of the northern foothills and extending several kilometers in the east-west direction. The entire bed of the wetland is flat with very slight slopes from all sides towards the central deeper part of the wetland close to the foothill.

The catchment area of the wetland includes in addition to the wetland, the high mountains in the north with altitudes of around 1,800 m above mean sea level, (locally called Sarbalesh) and low hills all along the southern boundaries. The flat bed of the wetland (at 820 m above mean sea level) extends southwest and fades out into the flat valley of Kazeroun.


*Figure 1: Map of Parishan wetland.*

## 2.3. Climatology

Lake Parishan is located in the semi-arid part of southern Zagros with hot and comparatively long summers, and temperate and comparatively short winters. It is influenced by four major air masses among which "Mediterranean fronts" are the most significant and are the source for the major part of the annual precipitations.

### 2.3.1. Precipitation

Precipitation in the area is usually in the form of rainfall and mainly occurs during winter and spring months. Summer is generally dry with very occasional low precipitation. Snow occurs very rarely and only on the top of the higher altitudes of the northern mountains, and lasts no more than a few days. Parishan climatology station has precipitation records since 1988. Average annual precipitation of the station is 450 mm and ranges between minimum of 200 mm. to maximum of 700 mm. In the Kazeroun station about 15 km east of Parishan, the average annual precipitation, recorded since 1957, is 470 mm and ranges between 130-900 mm.

Analysis of the annual precipitation indicates that with 75% probability (3 out of 4 years), the annual precipitation at Parishan is equal to or less than 600 mm. If according to the evidences the annual precipitation lower than 250 mm could be considered as dry year affecting the inflows into the lake, then 8 out of 22 years of data period (about 1/3 of the period), the area has faced drought. Worth to mention is that 3 out of the 8 dry years have successively occurred in the last 3 years ending in 2009/10.

The annual average number of days with precipitation is 30 and ranges between 11 and 55 days/year. Generally, most of the annual precipitation occurs in winter time followed by fall and spring months in a descending order. December and January are the months with maximum average monthly precipitation, and July is the month with absolutely no rainfall. Mean monthly precipitation is shown in Fig. 2.

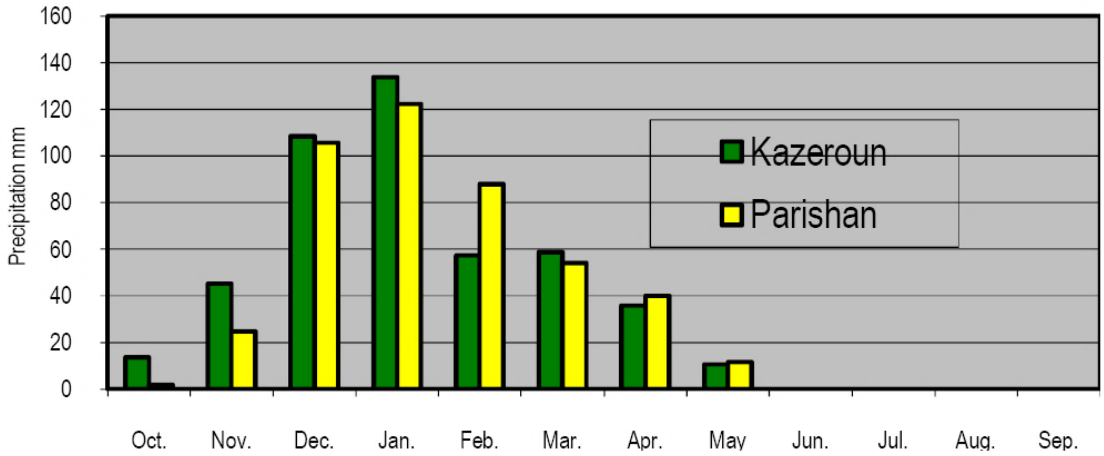


*Figure 2: Mean monthly precipitation [4].*

The monthly average of number of days with precipitation is 7-8 days in January. The maximum number of days with precipitation ever recorded in any month is 20 days in January. Probability analysis of maximum daily precipitation in Kazeroun indicates that with 80% probability (4 out of 5 years) the maximum daily precipitation is equal or less than 80 millimeters.

The moving average of annual precipitation of Shiraz and Bushehr (Fig. 3) display a very distinct drought during 1960s which then recovered in the following normal years. However since 2004, Shiraz station shows a continuous declining trend in precipitation which extends to the present time. Although such longer data are not available for Lake Parishan area, the completely dry lake in 1965 (a very similar status to the present condition of the Lake) could be referred to as a clear evidence that such a drought had been covering the entire Fars province, including Parishan Area [4].

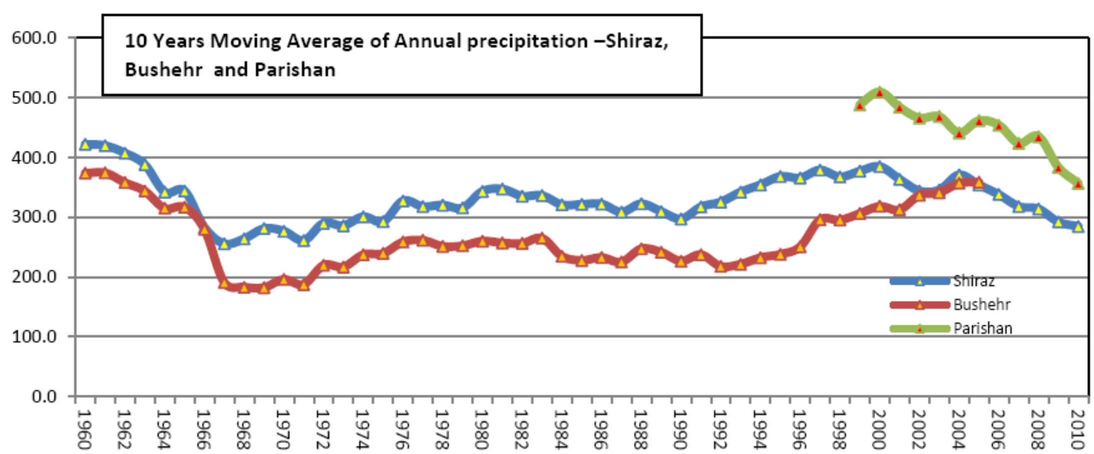


*Figure 3: Average annual precipitation via time [4].*

The Lake is recharged mainly through ground water and surface runoff from the surrounding areas. Lake Arjan also contributes to the underground flows to Lake Parishan. All these resources are directly linked with the precipitation over the Parishan and Arjan basins. Hydro-climatology of Lake Parishan has received little attention by researchers. No good quality long-term data is available for analyzing the conditions in the basin. Because of short duration of the climatic data, trend analysis would not produce reliable results. The nearest stations with long duration of data are Bushehr in the south and Shiraz, each about 150 km away. Bushehr, by the Persian Gulf, is particularly affected by climatic system which is in some aspect different from those inland stations. Both the stations have been analyzed to conduct a preliminary assessment of the trends through moving average techniques.

To assess the drought condition in LP area, Fig. 4 is presented below and displays the status in LP and explains that during the last two decades ending to 2009, the area has experienced 2 years of moderate, 3 years of severe and 2 years of very severe droughts (2008 and 09), the condition which still persists. Longer term assessment of droughts in LP area may be drawn up from the droughts in Shiraz station (Fig. 5) that displays the persisting droughts of late1950s that continued up to the mid 1960s. It seems that the same droughts were prevailing in LP area as well; and caused desiccation of the Lake in the mid 1960s.

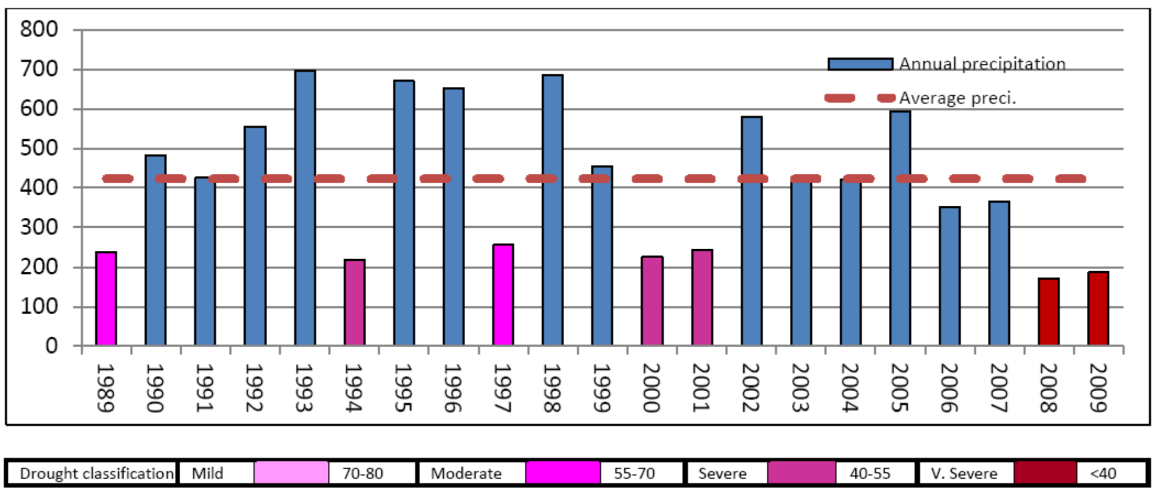


*Figure 4: Classification of drought in Lake Parishan area (precipitation in mm/year) [4].*

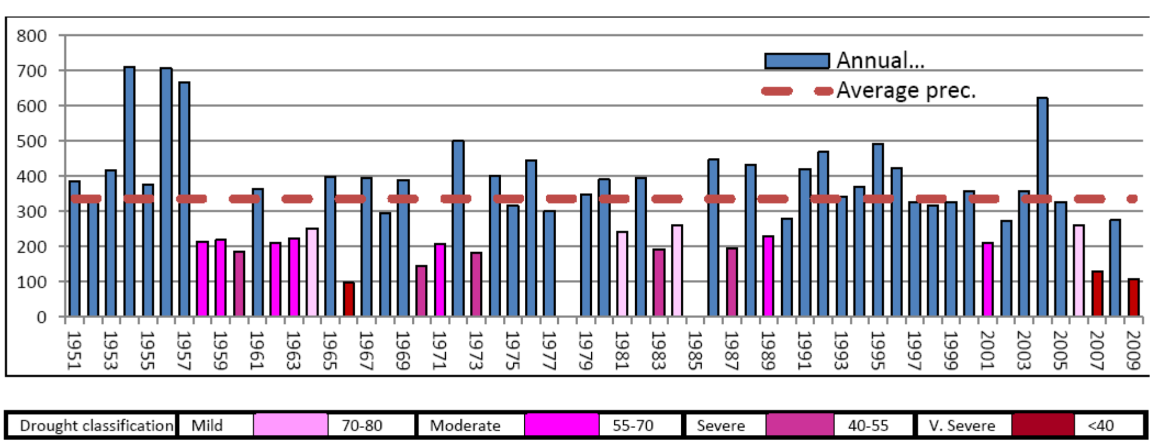


*Figure 5: Classification of drought in Shiraz synoptic station (precipitation in mm/year) [4].*

*2.3.2. Temperature*

Both the stations show an increasing trend (Fig. 6). However the trend in Shiraz is more significant and noticeable, particularly in summer and spring seasons. In the Parishan area the moving average data does not indicate a significant trend. One should consider the effects of higher humidity at Parishan as well as in Bushehr.

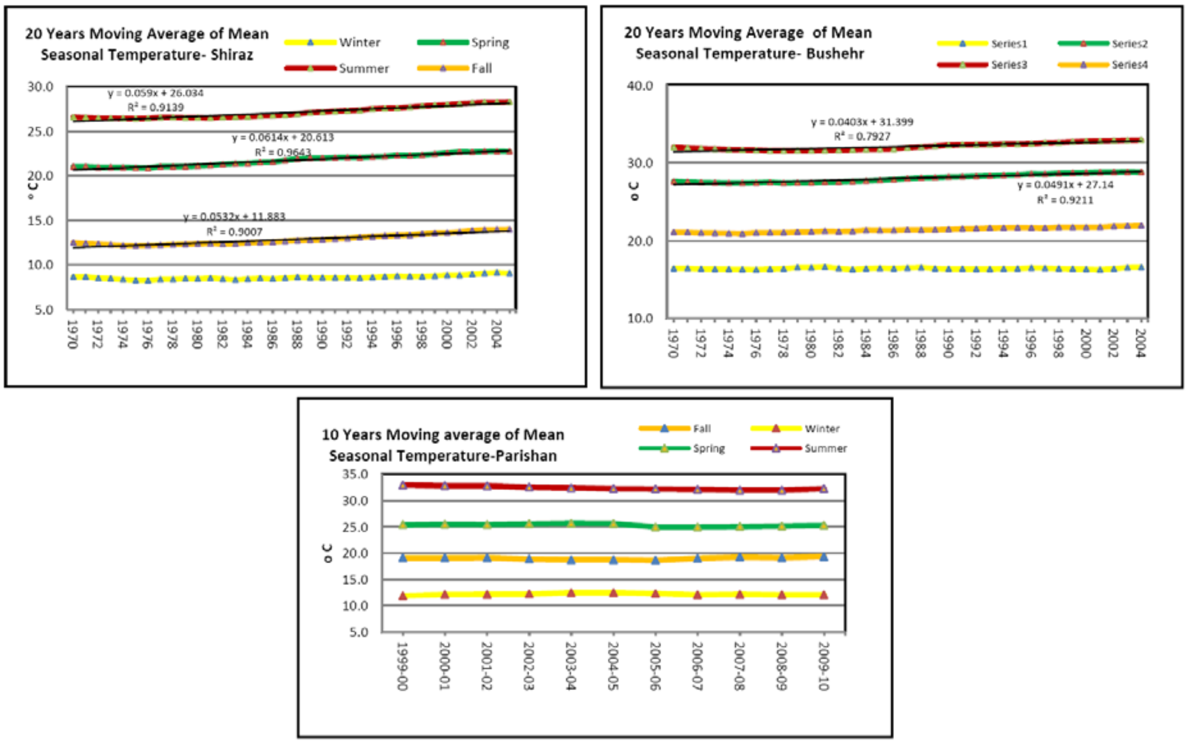


*Figure 6: Mean average of seasonal temperature [4].*

The Lake area has temperate winters with long and relatively hot summers. It seems that temperature in this area is more governed by latitudes rather than altitudes [6]. The temperature attributes of Parishan and Kazeroun stations are summarized in Table 1.

TABLE.1: SUMMARY ANNUAL TEMPERATURES (˚C) [4]

| Stations | Duration | Absolute maximum | Average maximum | Mean | Average minimum | Absolute minimum |
|---|---|---|---|---|---|---|
| Kazeroun (IMO) | 1957-1985 | 48.5 | 31 | 22 | 13.1 | -8 |
| Parishan (FPWA) | 1988-2005 | 48 | 28.5 | 22.2 | 15.9 | 0 |
| Parishan (FPWA) | 2007-08 | 48 | 31.1 | 22.3 | 13.6 | -3 |

Although temperature data from Kazeroon and Parishan stations are not from the same period, the narrower ranges of variations between monthly average maxima and minima in Parishan station in comparison with similar data from Kazeroon, particularly in the cold seasons clearly indicate moderating effects of the Lake which is brought about by the higher humidity around the Lake environment.

The temperature regime of Parishan station for the year 2007-8 when the lake surface was significantly reduced is also indicated in the table to confirm the above conclusion. January and February with monthly averages in the range of 10-12°C are the coldest, and July- August with a monthly average in the range of 33-34°C are the warmest months of the year. Absolute maximum temperatures during the summer rise up close to 49°C. Winters are generally temperate and freezing happens but not frequently.

Freezing may start from mid-December and may happen up to late February. Minimum temperature ever recorded for Kazeroun station is -8.0°C for December. However this should be considered as an exceptional record. Recent data from both Kazeroon and Parishan has not shown minimum temperatures less than 0°C.

Freezing hours are normally from around midnight and continue no later than 0800-0900 hrs in the mornings. The total number of days with freezing temperature does not exceed 15 days per year.

A quick survey of changes in climate was exercised using Bushehr longer data on temperature. Fig.7a to e depicts the 20 year moving averages of the mean seasonal and annual temperatures. As can be seen, during the last 30 years the mean annual temperature has increased about 1 degree centigrade. The rate of increase is almost nil for winter but is highest for summer (1.5 degrees). This could be in line with the general increase of ambient air temperature due to the global climate change.

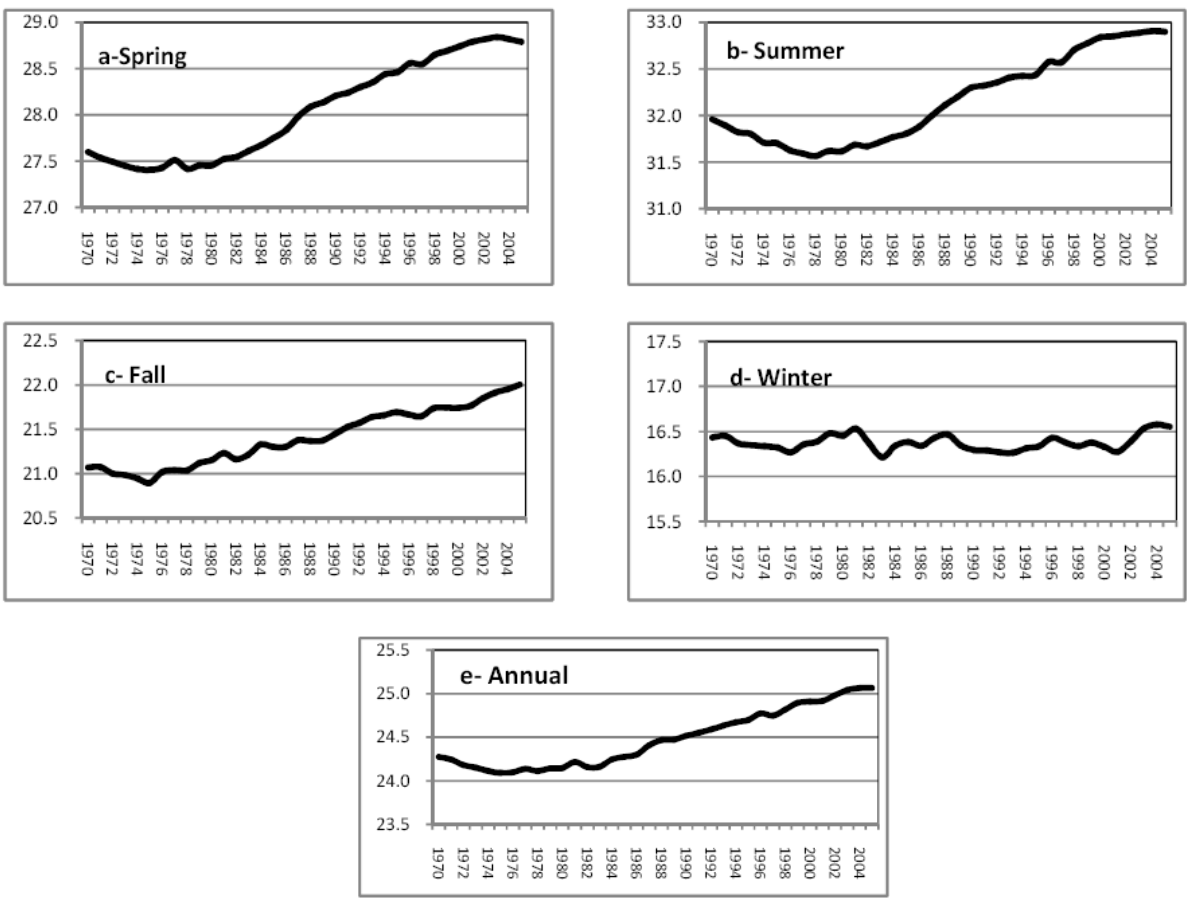


*Figure 7: Long term trends in ambient air temperature for Bushehr station [4].*

### *2.3.3. Humidity*

Relative humidity is usually measured three times a day at 06.30, 12.30 and 18.30. The observation at 06.30 accounts for daily maximum and that of 12.30 represents the daily minimum relative humidity. The average humidity in Parishan station is generally higher and more uniform during the seasons than in Kazeroon which again is an indication of moderating effects of the Lake. This moderation effect is more significant during the summer months i.e. May through Sept. Evaporation Class A pan evaporation data is recorded in Kazeroon and Parishan since 2001 and 1988 respectively by FWA. IMO has started recording pan evaporation in Kazeroon station since 2005. Table 2 indicates records for pan evaporation. One may notice that the annual rates of pan evaporation range between 2,400-3,100 mm. The maximum monthly evaporation occurs in summer months, i.e. June through August, and in the order of 380 to 400 mm per month. Minimum evaporation normally occurs in January and around 20-60 mm.

Measurements of pan evaporation in Parishan during 2007-08 (very dry period in which water body was almost disappearing), has increased up to 3,818 mm, while that of Kazeroon does not reveal such deviation. This is a clear indication that increase in the evaporation is due to decrease in ambient humidity because of diminishing Lake's water surface area.

TABLE 2: MEAN MONTHLY EVAPORATION (FIGURES IN MM) [4]

| Stations | Oct | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parishan,1 | 218 | 121 | 57 | 42 | 52 | 76 | 133 | 247 | 349 | 402 | 403 | 339 | 2439 |
| Kazeroun,1 | 233 | 148 | 64 | 57 | 66 | 98 | 164 | 285 | 389 | 400 | 385 | 326 | 2614 |
| Kazeroun,2 | 279 | 150 | 60 | 21 | 36 | 171 | 208 | 357 | 487 | 512 | 471 | 406 | 3157 |

### *2.4. System Dynamics Model*

Systems thinking helps recognize water resources as a system that includes disparate but interacting parts, which function as a unit that must be treated as a whole [7]. System dynamics, which is based on dynamic and closed loop theories of systems thinking, is a method to capture complex systems and monitor their dynamic behavior [8,9]. Due to the complex nature of water resources management problems, they have been highly resistant to solutions developed based on linear thinking or an event-oriented view of problems [7,10,11].

Therefore, a shift from looking at isolated problems and their causes to systematic thinking about water problems is essential for developing effective solutions. System dynamics provides a framework to see interrelationships and processes rather than individual components, and for capturing patterns of change rather than static snapshots of the problem [7]. It can thus be a suitable approach to capture problematic trends of water resources and their root causes in an integrated framework.

System dynamics models can reproduce the system's response to interventions over time, which facilitates addressing the existing problems at appropriate scale and scope [11]. However, the ability of these models to provide insights into potential consequences of system perturbation is dependent on efficiently recognizing the main components and feedback loops between them [7].

In the field of water resources, system dynamics has been used for water quality and environmental planning, flood management, emergency planning and crisis management, reservoir operation, drought impact assessment, participatory water modeling and water resources policy analysis, management, and decision making [12].

Many water resources management models capture hydrological and related natural processes in water resources systems exclusively and assume socioeconomic aspects of these systems as exogenous drivers. In contrast, system dynamics models provide a holistic framework to focus on the interacting natural and socioeconomic processes in water systems as a whole. This ability of system dynamics is the main reason for its widespread application in water resources planning and management problems in the last century. This study pays particular attention to the qualitative modeling stage of the problem to identify the main drivers of the undesired issues in Parishan wetland. Running a quantitative system dynamics model, which is based on a detailed qualitative causal model, facilitates understanding the complex causal relationships within the wetland system. This approach helps simplify the extensive qualitative and quantitative models of the problem to a simple causal descriptive model, which clearly reflects the archetypal behavior of the system.

## 3. Result and Discussion

### 3.1. *Hydrology*

The surface area of the watershed is about 275 sq. kilometers and is bounded from the North and South by the divides on the Dashtak and Sarbalesh anticlines respectively (Fig. 8). It seems to be an isolated and closed catchment with no visual connection with either of the two said river basins. However, despite its visual topographical configuration, the actual basin of the Lake extends –through Karst formations- north towards Arjan Lake. Indeed, exploration and research proved that Lake Arjan, 15 km north of Lake Parishan, has a significant water contribution to the flows of springs around Lake Parishan through Karst formations.

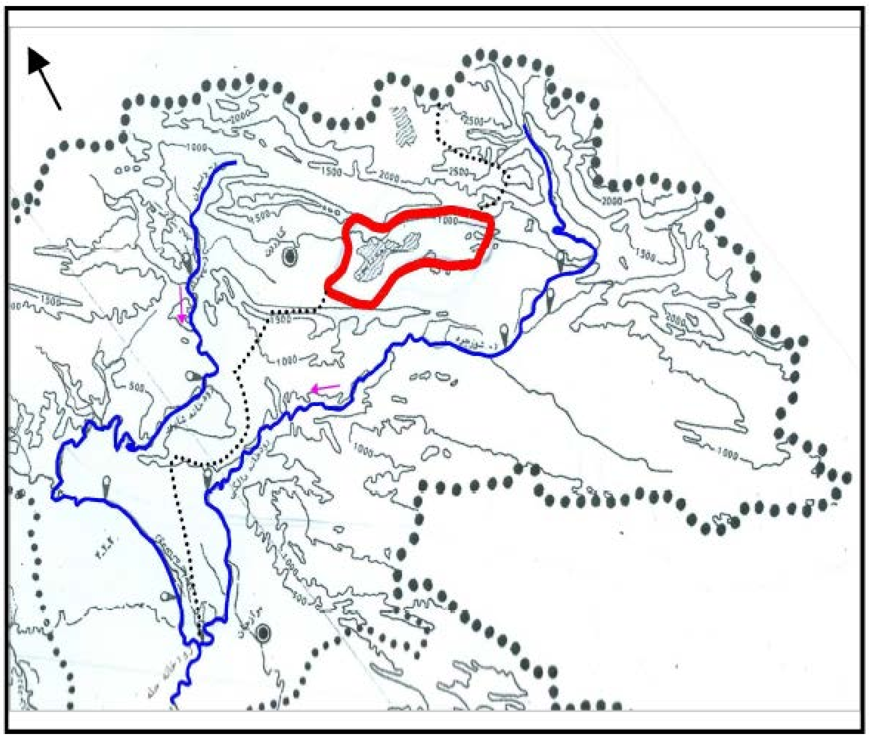

*Figure 8: Lake Parishan in between Shapour and Dalakiriver [4].*

#### *3.1.1. Catchments*

Considering the range of annual precipitation in the small catchment of the Lake, the surface water resources are restricted to occasional overflows produced after heavier precipitations that reach the Lake through small water courses. Using very restricted information, the average runoff coefficient is estimated at 12% ranging between 8-18% depending on the volume of precipitation. Given the average annual precipitation in the area to be 450 mm/yr, the contribution of surface runoff to recharge of the Lake is estimated at about 34.5 MCM/yr (Table 3).

TABLE 3: ESTIMATES OF WATER INFLOW INTO THE LAKE FROM PRECIPITATION IN AN AVERAGE YEAR [4]

| Sources of runoff | Area Km2 | Rainfall mm/yr | Runoff coef. | Volume of water, mcm/yr |
|---|---|---|---|---|
| Runoff in the catchment | 225 | 450 | 0.12 | 12.0 |
| Direct precipitation over the Lake | 50 | 450 | 1.00 | 22.5 |
| Total inflow to the Lake | | | | 34.5 |

As estimated, the average volume of water which directly flows into the lake is about 35 MCM/yr, equivalent to about 0.7 m of water column in the Lake. In different precipitation, the range of inflows into the lake varies between 25-50 MCM/yr.

*3.1.2. Groundwater*

Groundwater is another main source of water supply to Lake Parishan. Ten springs, the majority of which are karstic, discharge into the Lake after parts of their flow is diverted for irrigation. Several submerged springs, in the northwestern part of the Lake directly discharge into the Lake's water body. It is quite likely that other parts of the northern boundary of the Lake also discharge seepages from the foothills into the lake. These latter sources are neither visible nor measurable. Also, quite a number of wells (more than 900) exploit water from the alluvial aquifer around the Lake to supply water for irrigation. Such composition of ground water resources and interactions they have with the water body in the Lake somehow complicate the hydrological interpretation of the Lake.

*3.1.3. Ground water levels and depths*

Ground water levels are regularly measured in more than 21 observation wells around the Lake. Ground water levels in the aquifers north of the Lake are significantly deeper than in the southern aquifer and vary between more than 25 to less than 10 m. In the southern aquifer, the depths are shallower and vary between 20 to less than 5 m. There is an exception for the southwestern part of the Lake where ground water seems to flow away from the Lake. Because of the thick heavy deposits in the lake's bed, it is very unlikely that the lake is recharging the ground water in this part.

*3.1.4. Springs*

Ten springs expose around the Lake. Most of them are located in the eastern part of the lake while a few also expose in its northern and northeastern parts. The total volume of spring flows for the year 2004-05 exceeded 28 MCM/yr, much less than the existing records of 59 MCM/yr in 1999 and 2000.

*3.1.5. Wells*

Presently more than 900 wells are operating around the lake (Fig. 9). The density of the wells is more concentrated in the north, west and southwest around the Lake. They abstract groundwater from the aquifer which is directly in contact with the Lake's water body. The wells in the north and east directly intercept ground water flows before they reach the Lake. Wells around the Lake are clearly competitors to the Lakes water resources. The increasing number of wells and increasing volume of water uptake particularly in the northern and eastern parts of the lake has significantly reduced the inflows into the lakes. This is clearly reflected in the data in Fig.10 that the changes in the groundwater flows of different resources are displayed against variations in annual precipitation. It also seems that the drought period of 2001/03 accompanied with low springs' flows have been a reason for rapid increase in the number of wells and the volume of ground water depletion. This has resulted in an additional uptake of about 6 MCM/yr which has continued during the subsequent years.

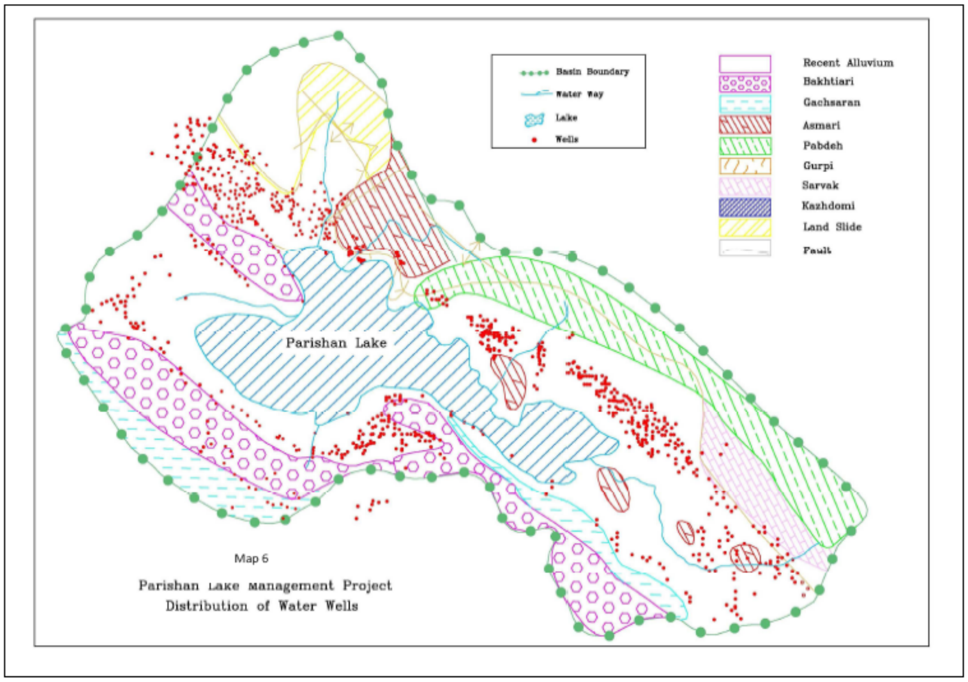


*Figure 9: Distribution of water wells [4].*

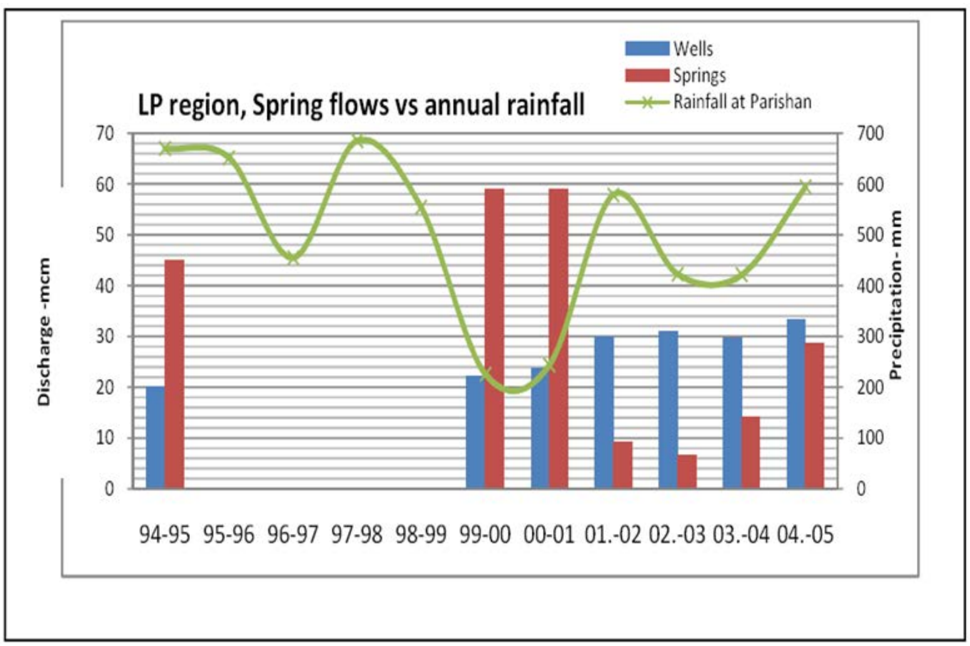


*Figure 10: Discharge of springs, wells and rainfall at Parishan wetland [4].*

According to existing information, in an average hydrological year the volume of water received by the lake from precipitation and surface runoff is estimated at about 35 MCM/yr. Also, ground water is a crucial contributor to water resources of the Lake. Existing data indicate that in hydrologically normal years, the springs discharge close to 30 MCM/yr of which about 50% is used for irrigated farming downstream of the springs and the remainder flows into the lake. Also, seepage from the alluvial aquifer and karstic formations around the Lake and particularly those in the northern foothills are important sources of water supply to the Lake. The range of contribution of the latter resources in a normal hydrological year is estimated around 35-45 MCM/yr. During the last decade the cultivated areas commanded by springs have been increasing, resulting in lesser flows towards the lake. Also, almost 1,000 water wells evacuate around 30 MCM/yr of water from the alluvial aquifer mainly for irrigation purposes. Some of these wells were built during the last decade (Fig. 11) and particularly as a means to provide additional water to compensate drought. Evidently any increased use of spring flows and any additional abstraction of groundwater would result in lesser recharge of the Lake from springs and groundwater resources.

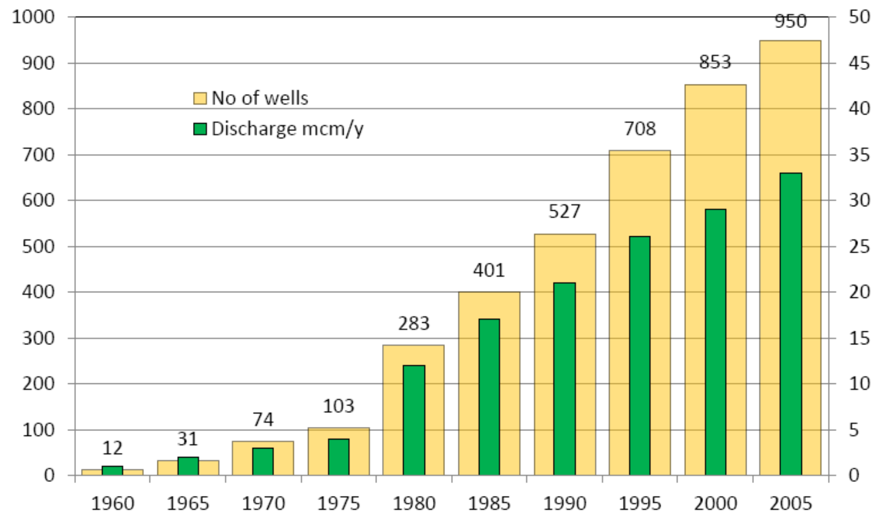


*Figure 11: Trends in construction of wells and discharge ground water- Lake Parishan area [4].*

The results of Granger Causality Test showed mutual causality between water level of lake and the groundwater table. Increase in extraction from agricultural wells caused a fall in groundwater table and decrease in lake level at the same time. On the other hand, decrease in water lake level causes fall in groundwater table due to decrease in penetration [13].

As in other parts of Iran, the main user of water resources around Lake Parishan is agriculture. Agriculture, as the easiest available opportunity for occupation for the increasing rural population of the area has been and is imposing great pressure on water resources. During the past decade, numerous new wells were dug to produce additional water for irrigation of expanding irrigated farms. Fig. 11 depicts the pace of constructing water wells and extracting groundwater around the wetland which implies direct competition with the water resources of Lake Parishan.

The very marked impacts of the drought in the Lake Parishan area are continuing and include desiccation of almost all the existing springs, even those with karstic origin, and a significant drop in groundwater level in the alluvial aquifer around the Lake, such that practically no effective flow or seepage has been entering the Lake since late 2009. As a result, the lake has been almost completely desiccated since then.

As a conclusion, the persistent drought of recent years combined with the impact from increasing abstraction of groundwater resources has resulted in rather complete stoppage of both spring flows and seepages from groundwater aquifers causing the Lake to almost entirely desiccate. A concerted effort is needed to control water abstraction to sustainable levels, while it is expected that the lake will re-flood once precipitation returns to normal levels. Tracks of vehicles provide evidence of the severe drought of the lake.

### 3.2. *Water Balance of Lake Parishan*

Because of several components interacting with water resources of the Lake, interpretation of its hydrological attributes in determining the following components are complicated: 1) the contribution of external resources (karst formation and Arjan wetland) to water supply of the LP and 2) the volume of seepage inflows into the lake.

Fingerlings gather close to the spring outlets Lake Parishan. A Concise Baseline Report [1] generalizing water balance at catchment level for an average hydrological year (Table 4) helps in estimating the contribution of Karst formations at about 31 MCM/yr. This flow is assumed to come in from outside the catchment area, i.e. from Arjan Wetland catchment.

TABLE 4: TENTATIVE WATER BALANCE CALCULATION IN THE LP CATCHMENT AREA [4]

| Description | Area, Km2 | Quantity, mm | Volume, mcm/yr In | Volume, mcm/yr Out |
|---|---|---|---|---|
| Precipitation over the catchment | 275 | 450 | 124 | |
| Evaporation from ground surface | 245 | 55 | | 13 |
| Evaporation from the Lake | 30 | 1680 | | 50 |
| CU by natural vegetation (range and pasture lands) | 190 | 350 | | 67 |
| Domestic uses (negligible) | | | | 0 |
| CU by cultivated crops | 38 | 650 | | 25 |
| GW outflow from the basin | | | | 0 |
| Total | | | 124 | 155 |
| Inflows from outside the basin (Karsts!) | | | 31 | |
| Balance | | | 155 | 155 |

Another study on groundwater resources of the wetland area [9] concluded that in 2007-08, a relatively dry year in which Arjan wetland was completely dry, a volume of about 10 MCM in-flowed into the area that could not have been from a source other than Karst formations. Also, an exercise of water balance at Lake Parishan has revealed that in a normal hydrological year, about 7 MCM flows into the lake through submerged springs and seeping foothills (Table 5).

TABLE 5: WATER BALANCE FOR THE LAKE PARISHAN IN NORMAL YEAR [4]

| Description | Area Km2 | Prec. /evap. mm | Flow mcm | Coef. | Volume, mcm/yr In | Volume, mcm/yr Out |
|---|---|---|---|---|---|---|
| Precipitation over the Lake | 25 | 450 | | 1.0 | 11 | |
| Surface runoff inflow from the catchment area | 200 | 450 | | 0.12 | 11 | |
| Inflow from spring flows | | | 35 | 0.6 | 21 | |
| Direct evaporation from the Lake | 30 | 1680 | | 1.0 | | 50 |
| Outflows or water abstraction from the Lake | | | | | | 0 |
| Changes in aquifer storage | | | | | 0 | 0 |
| Sub total | | | | | 43 | 50 |
| Groundwater inflows | | | | | 7 | |
| Balance | | | | | 50 | 50 |

Water level variation in the Lake Considerable information is available of water level variation of LP since 1973 with certain gaps due to different reasons (Fig. 12). Data indicates that higher water levels in the lake normally occur during February through June and lower water levels generally occur in late autumn.

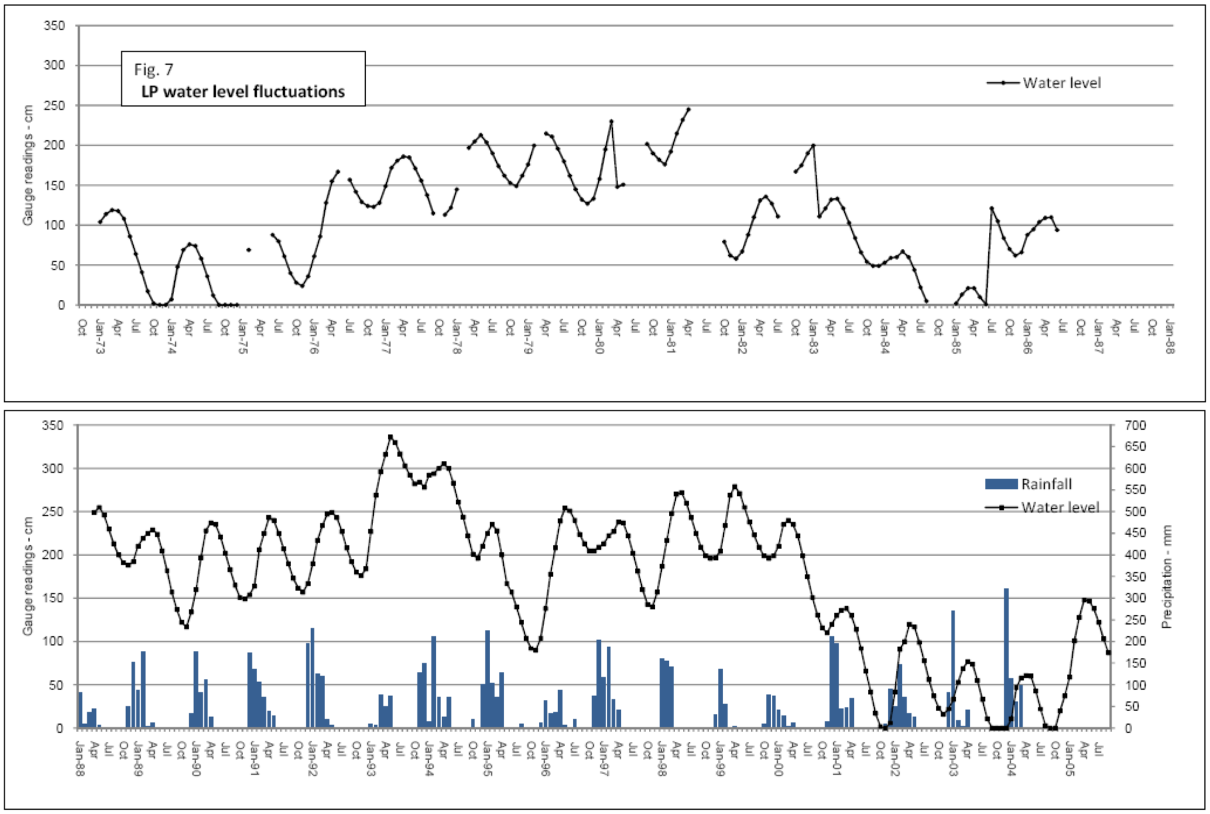


*Figure 12: Parishan wetland water fluctuation [4].*

There are occasions that the water level falls lower than the (0) on the staff gauge. Such cases have been experienced in 1973, 1974, and 1984 through 1986 and during the long drought period of 2001-05 and 2007 to 2009. Aerial photo of 1967 (Fig. 13) indicates that the Lake was completely dry late in summer season such that one could walk/drive across the lake. The records from Kazeroun climatology station show that, from February 1964 to March 1968, the total sum of precipitation was only 275 mm. With very limited number of wells during this period it is clear that severe drought is an undeniable fact and water resources in the Lake are directly related to regional precipitation. However with the current trends in climate change, accelerated water abstraction from groundwater aquifer exacerbates the condition for the Lake and such droughts may occur more frequently and may last for a longer time.


*Figure 13: Severe drought in Lake Parishan 1966-67 [4].*

### *3.3. Land Use*

The main occupation of the rural population is irrigated agriculture and animal husbandry. About 6,500 hectares of the land within the catchment area is used for irrigated farming. The main source of water for irrigation is supplied from spring flows and ground water. More than 800 wells (10-50 m deep) are pumping water from the alluvial aquifer. A few deep wells (more the 50 m deep) are also under operation. Presently the main common crops are wheat, barley and colza as winter crops and melons, cucumber, tomato, eggplant, pumpkins, pepper and green beans as spring/ summer crops. In some normal years, when adequate water is available, rice is also cultivated. Because of limitations in farming lands in the villages north to the lake, the cropping pattern is more inclined to summer cash crops. In these villages, early planting of cucumber and eggplant under plastic galleries has been developed for pre-season harvesting. In the southern villages, because of restrictions in water resources, most of the lands are used for producing cereals, corn and sunflower. In general about 60% of lands are used for producing cereals and 40% are under vegetables and summer crops. Extensive lands in the southwest of the wetland (Seyfabad, Molla arreh), which do not have permanent access to irrigation water, are normally used for rain-fed cultivation of wheat and barley. In general the recent prolonged drought has inversely affected the water yield of wells, particularly in the southern parts and thus has reduced the cultivated area and crop production.

#### *3.3.1 Rural economy*

The economic condition of the rural families is directly dependent on the size of their land tenure and the crops they grow. In general, with the exception of few families in each village who have been able to provide sufficient economic resources and / or have been lucky in their successful investments and business in Kazeroon or, the remainder rural families are generally suffering from lack of adequate economic facilities/opportunities, and hardly can obtain sustaining incomes. Rural youngsters particularly educated ones who have left the village, hardly have opportunities in their village for a satisfactory job.

*3.3.2. Agricultural activities*

Agriculture has been and still is the main activity in the rural society. Before motor pumps were introduced to the area, the main source of water supply for irrigated farms was gravity diversion from the spring flows. At this time only villages in the east (Famour, Arab gavmishi, Ghaleh mirzaee, Ghaleh narenji) and west (Zavali, Ayaz abad) of the Lake that had access to spring flows were practicing irrigated agriculture. The villages in other parts around the lake had their main occupations in rain-fed cultivation (wheat and barley), animal husbandry and fishing from the Lake. The earliest pump-wells were constructed in Parishan area late in 1950s. The number of wells increased rather slowly during the next decade. In 1967 the first studies for investigating ground water resources and their potential for development were initiated by the Ministry of Energy. At the same time soil and land resources of the region were investigated to evaluate their capacity for irrigation development. Investigations for evaluation of ground water potentials continued during later decades and the further potentials for groundwater development from karstic formation were discovered (none of these studies considered the water requirement of the Lake). This allowed and encouraged local people to construct their shallow (hand dug) wells to pump ground water for growing crops. Fig. 14 displays the pace with which construction of wells and extraction of ground water developed during the decades. Increase in the volume of ground water supply and the areas under irrigated farming have been the most significant developments around Lake Parishan, which at the same time has imposed crucial impacts on the Lake's status. The increase of water wells for abstraction of ground water has probably been the most important impact such development has had on the Lake conditions. Most of the wells are shallow and located in the northern foothills. These wells are extracting groundwater which otherwise would flow towards and enter the Lake, in other words increase in groundwater extraction in the northern foothills could be interpreted as abstraction of water directly from the Lake. Agricultural developments in the areas around the lake not only consume additional water resources (on the costs of the Lake's water budget) but also releases into the Lake a considerable amount of contaminants such as nutrients and pesticides.

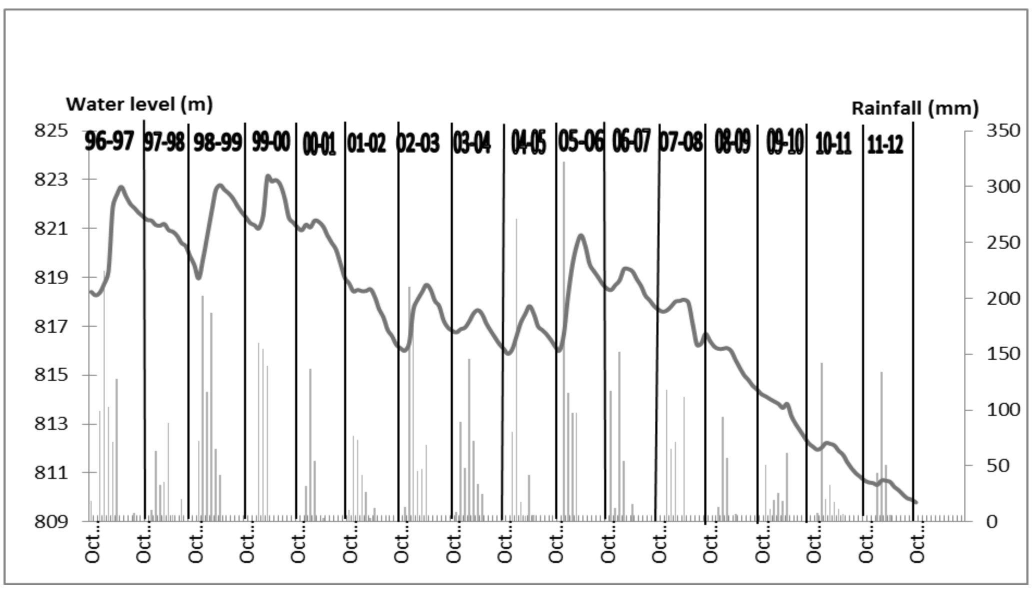


*Figure 14: Lake Parishan water level and precipitation trend [5].*

*3.3.3. Power plant*

A power plant has been constructed about 5 km west of the Lake. Although this is out of the catchment, its heat release from elevated chimneys may have some effect on the birds flying around or passing near/over them.

*3.4. System Dynamics Model*

Generally, the qualitative analysis phase of a system dynamics study involves two major steps: (1) developing a conceptual model or casual loop diagram (CLD) of the problem; and (2) developing the stock and flow diagram (SFD) of the problem based on its CLD. A CLD of the system, which is developed using an evolutionary approach, represents a holistic understanding of the system structure, determining its boundaries, and identifying the key variables [7]. In the next step, SFDs are developed to provide a clear picture of the stock and flow structure of the system [14,15]. In the system dynamics context, the main variables are either stocks, i.e., the state of the system, or they are flows, which reflect the rates by which the stock variables change [7]. A classic example of a stock variable in the water resources context is water storage in a reservoir that changes by the inflows and outflows, as flow variables.

A system dynamics model, Lake Parishan Water System Model (LP-WSM) was used to evaluate the hydrology of the basin. The LP-WSM model (Fig. 15) comprises hydrologic climate and agricultural sub-systems, incorporating different drivers of the water resources development. This model provides an illustration of the interactions between water resources sub-systems. The hydrological sub-system captures the regional elements of hydrologic cycle, water supply, and precipitation as the main ecosystem resources in the basin. As illustrated in Fig. 15, the regional climatologic and hydrologic attributes (i.e., temperature, precipitation, evaporation, runoff, natural flows, and groundwater recharge), groundwater and return flow govern the basin's water balance. Table 6 shows the DPSIR framework for Parishan wetland drought.

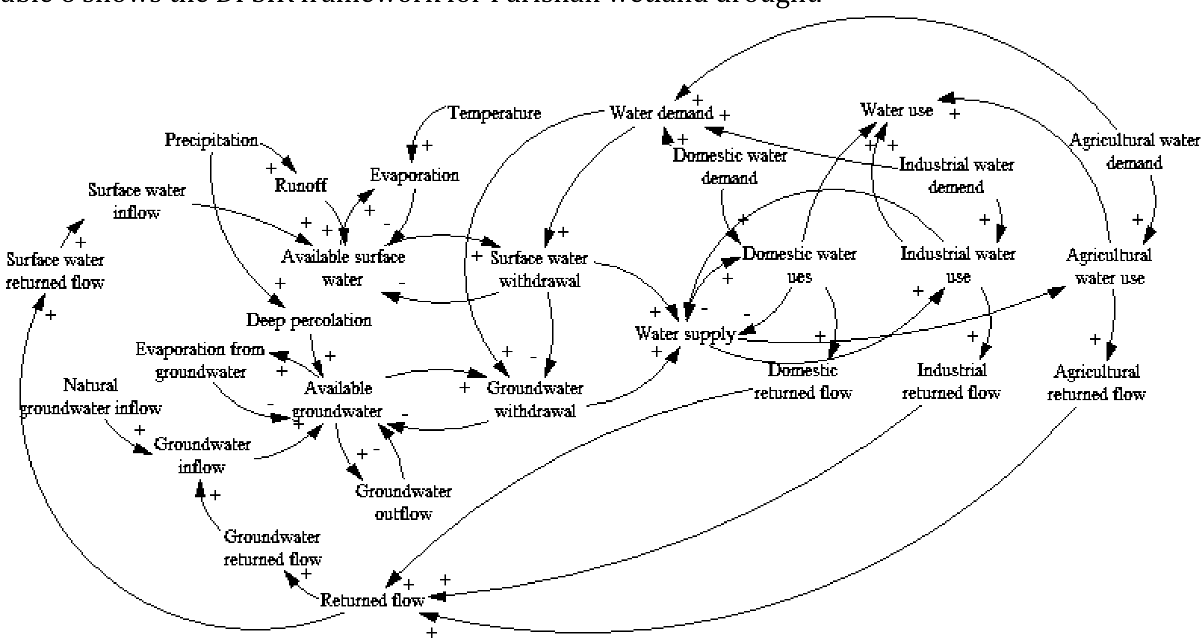


*Figure 15: CLD of the hydrological sub-system.*

TABLE 6: DPSIR FRAMEWORK FOR CONCEPTUAL MODEL

| DPSIR Chart | | | | | |
|---|---|---|---|---|---|
| **Problem** | **Drivers** | **Pressure** | **States** | **Impacts** | **Responses** |
| Parishan wetland drought | Agricultural activities<br>Climate change<br>Drought | Precipitation<br>Increase in cultivation<br>Temperature increase<br>EC increase<br>Well increase | Wetland's water level<br>Groundwater level<br>Humidity<br>Water quality | Springs drought<br>Water level drop<br>Biodiversity change<br>Wetland drought<br>Decrease in water supply<br>Ecotourism effects<br>Increase in surface water evaporation | Water use management<br>Stop illegal wells<br>Water transfer from dam<br>Change in cultivation and irrigation methods |

*3.4.1. Hydrological sub-system*

The CLD of the hydrological sub-system represents regional elements of the hydrologic cycle, water supply, and ecosystem (e.g., Parishan Marsh). The inter-basin water transfer projects, groundwater and surface water interaction, regional hydrology, and water supply are the main components of this sub-system. As illustrated in Fig. 15, regional climatologic and hydrologic attributes such as temperature, precipitation, evaporation, runoff, and natural flows, as well as groundwater recharge govern the basin's natural water balance. The CLD shows the dynamics among these components using polarized arrows denoting positive and/or negative causal relationships. Furthermore, the CLD shows the supply-oriented human interventions that have increased water availability to satisfy growing demand. The ordinal priorities of water allocation in the basin are considered as domestic, agricultural, and finally, environmental. Surface water is the first choice to meet these demands while groundwater is used when the surface water supply is not available. The return flow from non-consumptive portion of the water use from various sectors is fed back to the system in the form of surface water and groundwater recharge.

*3.4.2. Model calibration*

The ability of the model to capture the underlying system structure is assessed through behavior reproduction and sensitivity analyses. Once the model is calibrated it can be used to evaluate various water resources management strategies and policies using an annual time step. The spatial boundaries of the model are based on watershed boundaries and the time horizon of the model is 30 years (2015–2045). The hydrological CLD is simulated using data from the period of 1970–2005, assuming that historical hydrologic trends hold into the future. In this model, natural and transferred flows, precipitation, and temperature are input time series data. Evaporation and percolation to groundwater are defined as functions of temperature and precipitation, respectively. Runoff is calculated as a function of precipitation and area. Evaporation from groundwater, natural groundwater inflow, groundwater seepage, and transferred outflow are fixed variables in the model. Fig. 16 is a demonstration of the CLD in VENSIM software.

The observed data for a time period of ten years (1970–2005) is used for calibrating the parameters of the LP-WSM model. In the first step of calibration, most model variables were kept constant to run simulations without considering dynamic feedbacks within the system. This was necessary to identify critical variables in each sub-system. In the next step, the process of reproducing the system's historical trends with dynamic feedbacks was initiated by adjusting some hydrologic variables. Finally, further modifications of parameters were made by running the model with all feedback loops to mimic the trends of observed behaviors in the basin based on the available historical data.

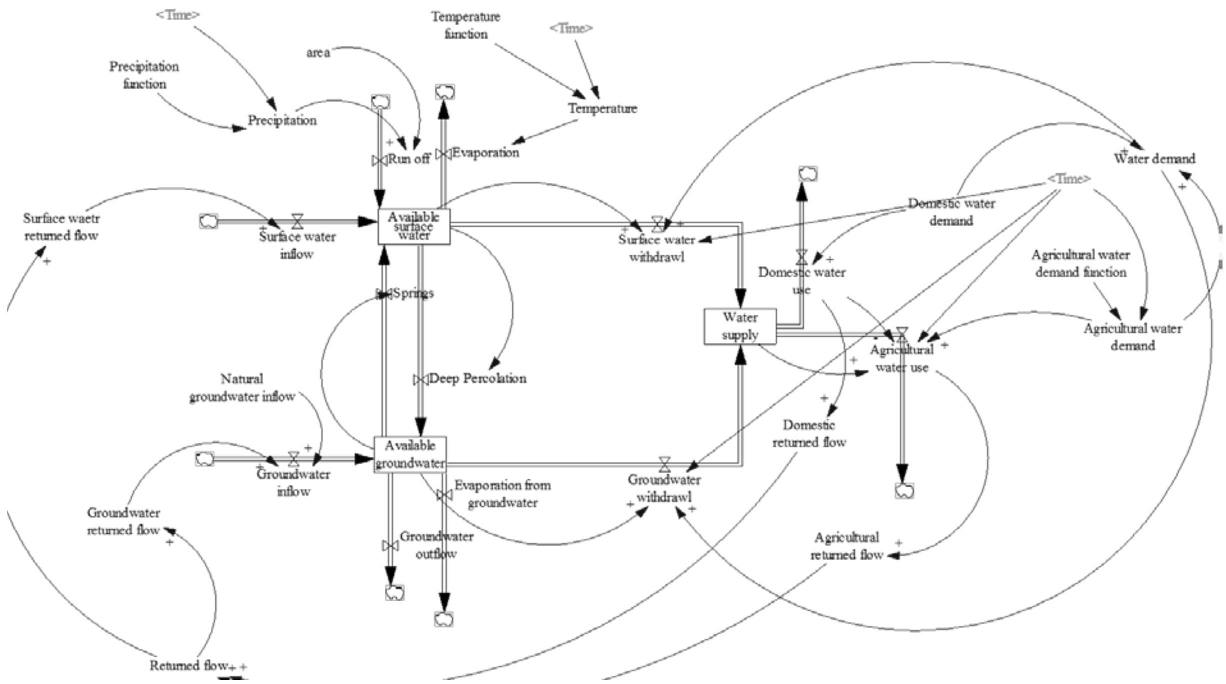


*Figure 16: Model of the hydrological sub-system in VENSIM.*

### *3.4.3. Model application*

The model is used in a two-step procedure to provide insights into the most effective strategies and policies to save Parishan wetland Basin. In the first step, different water resources management strategies are adopted to identify policy leverage areas. In the second step, a more focused analysis is performed to develop suitable water management policies with reference to the identified leverage areas.

### *3.4.4. Strategy identification*

Based on the different policies, the government may enact different strategies in the future to restore Parishan wetland. One potential strategy is transferring 10 MCM of water annually from Nargesi dam and then studying the potential to save available surface water. It can also be simulated with 3 different scenarios in dry, wet and average years to see if this strategy would be useful in the future or the wetland would remain dry despite water transfer according to mismanagement of water supply and water drainage from unauthorized wells. The software can apply different strategies to decrease agricultural water use according to ban the wells.

## 4. CONCLUSION

It seems that achievement of underground waters around the lake in the form of wells and aqueduct is the intensive factor for the reduction of underground inputs to the lake. The state of biosphere reserves in world and especially in Iran has many problems and that is the main reason for its incorrect management. The results of the modeling show mutual causality between water level of lake and groundwater table. Increase in extraction from agricultural wells caused a simultaneous decline in the groundwater table and a decrease in lake level. On the other hand, a decrease in water lake level causes a decrease in the groundwater table due to decrease in penetration. Finally, some recommendations are made to improve the situation including water transfer from Nargesi dam or banning of unauthorized wells from underground water extraction.

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# Managing Sea Level Rise in Coastal Wetlands: Testing Thin Layer Sediment Augmentation as an Adaptation Strategy

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### *Abstract*

Coastal wetlands are vulnerable to the effects of climate change, particularly sea level rise (SLR). Although salt marshes can generally respond to SLR by adjusting their elevations, their capacity to accommodate SLR is limited. Current projections indicate that most salt marshes in southern California will not be able to adjust to the accelerated SLR predicted over the next 80 years, with much of the salt marsh habitat predicted to convert to mudflat or subtidal habitat by 2100. Management actions for preserving salt marsh habitats are limited, but one promising technique is thin layer sediment augmentation, where sediment is added to the salt marsh plain to increase its elevation. Although thin layer sediment augmentation has been implemented in salt marshes in the eastern and Gulf Coast regions of the United States and internationally, this technique has never been tried along the west coast of the US. A pilot experiment using thin layer sediment augmentation over 3 ha (nearly 8 acres) of salt marsh has been implemented in the Seal Beach National Wildlife Refuge (SBNWR). SBNWR is a particularly appropriate test location because oil and gas extraction at this location has resulted in 28 cm of subsidence, effectively replicating the relative SLR expected by mid-century. This increase in relative sea level has negatively impacted cordgrass (*Spartina foliosa*) populations, and consequently populations of the endangered light-footed Ridgway's rail (*Rallus obsoletus levipes*). Sediments dredged from a nearby harbor were spread over the salt marsh using a spray nozzle. The target augmented sediment depth of 25 cm was generally achieved, although there were substantial differences in added sediment depth in different regions of the project area. Post-augmentation monitoring has begun and will continue for five years to document the success of this climate change adaptation technique and provide information that could be used for future applications.

***Keywords: Climate Change Adaptation, Salt Marsh, Sea Level Rise, Sediment Addition***

## 1. Introduction

California's coastal wetlands, while not as extensive as salt marshes in the East and Gulf coasts of the United States, are nonetheless distributed extensively along the coastline. Ranging from large bays to extensive wetland complexes at the mouths of major rivers to small creek-mouth estuaries (many of which were only intermittently open to the ocean), there were historically more than 300 coastal wetland systems comprising 19,591 ha of estuarine wetlands [1]. These wetlands provide important ecological values, including the support of many wetland-dependent species and migratory birds, and ecosystem services [2].

Despite their value, coastal wetlands in southern California have been subjected to substantial anthropogenic modifications, including filling for agriculture and commercial and residential construction, modification of hydrology from watershed modifications, and degraded water quality. Historical analyses suggest that only 25% of the original estuarine vegetated wetlands in southern California remain [1], and all of these are degraded to a greater or lesser extent. Coastal wetland managers have developed a set of tools to help protect and restore these valuable habitats. However, expected future climate change will pose a critical new challenge to coastal wetlands, particularly with respect to sea level rise (SLR).

Predicting future SLR has been challenging due to the large number of local and global factors influencing it and their associated uncertainties, particularly the extent of melting of ice in the Greenland and Antarctica ice shelves. The most recent Intergovernmental Panel on Climate Change report predicts a SLR of 0.26 m to 0.98 m, depending on the emission scenario, by 2100 [3]. More recent analyses project higher SLR than reported in the IPCC's AR5, with SLR of up to 131 cm by 2100 for the highest emission scenario [4], although other recent modeling suggests SLR of nearly 2 m by 2100 due to melting of ice on Antarctica [5]. The current best prediction of SLR specifically for the coast of California comes from the 2012 National Research Council report [6], which projects a sea level rise in southern California of 12-61 cm by 2050 and 42-167 cm by 2100. However, the recent studies predicting substantially greater global SLR would also mean higher sea levels in California than predicted by the NRC.

Although future climate change will include warmer temperatures, changing precipitation and runoff regimes, and changing wildfire frequencies, all of which can be expected to affect coastal wetlands, SLR is the most prominent threat. Of course, sea levels have changed substantially in the past, and coastal wetlands have persisted. The next section discusses how salt marshes respond to changing sea levels.

### *1.1. Expected Response to Sea Level Rise*

When sea levels increase, salt marshes persist through two general mechanisms: (1) transgression, and/or (2) changes in marsh plain elevation. Transgression refers to the expansion of salt marsh habitat up an elevational gradient, either to the sides of the existing marsh or up a river valley. Where the surrounding elevational gradient is not too steep and transgression is not impeded by natural or anthropogenic obstacles, transgression could be an important mechanism for maintaining salt marshes with rising sea levels [7].

Changes in marsh plain elevations will depend on current marsh plain elevation (i.e., elevation capital), sediment availability, and plant productivity. The elevation of the marsh plain is in a dynamic equilibrium determined by many factors, including tidal and fluvial forces, plant growth, and sediment availability. Most salt marsh plains are in reasonable equilibrium with current sea levels through interactions among all these factors [8,9]. However, the ability of salt marshes to keep pace with sea level, particularly in the latter part of the century when SLR is expected to accelerate [3,6], will depend on marsh-specific conditions. Marshes that start at a higher relative elevation (i.e., have large elevation capital), have abundance sediment available, and have high productivity will be best able to adjust to future sea levels. Even in these optimal cases, though, sea levels may rise faster than marshes can maintain themselves [10,11].

Although all factors are important, sediment availability is particularly critical for maintaining elevational stability of arid climate coastal wetlands. Sediment transport to salt marshes is a combination of tidal and storm forcing, sediment input, internal sediment cycling, and trapping by salt marsh vegetation. In southern California, extensive damming of coastal rivers has drastically reduced sediment supplies for many salt marshes. Although internal cycling can deliver some sediment to the marsh plain [12], this is generally minor compared to sediment delivered from upstream watersheds. Thus, sediment availability is a particular concern for managing southern California salt marshes.

Various studies have evaluated the capacity for salt marshes to adjust to predicted future SLR [11,13-15]. Thorne et al. have recently provided detailed projections for future salt marsh habitats in eight wetlands in California, including three wetlands (Mugu Lagoon, Upper Newport Bay and Tijuana Estuary) in southern California [16]. These projections were based on detailed mapping of elevations and plant species in these wetlands, and then modeling using the Wetland Accretion Rate Model of Ecosystem Resilience (WARMER) [17]. WARMER is a state-of-the-art marsh equilibrium model that incorporates marsh elevation, plant productivity, sediment supply and other factors. The effects of SLR will depend on its rate. For example, most (but not all) California salt marshes were projected to have increases in low marsh habitat at the expense of middle and high marsh habitats under mid SLR rates (93 cm by 2100), but most sites were projected to lose vegetated habitat and eventually convert to intertidal mudflats under high SLR rates (166 cm by 2100).

### *1.2. Climate Change Adaptation Strategies*

Strategies for helping coastal wetlands adapt to climate change largely focus on encouraging/managing transgression and/or helping the marsh maintain its elevational position in the tidal frame by managing sediment. In addition, salt marsh resilience to SLR could be enhanced by removing stressors such as nutrient inputs.

The ability of a marsh to transgress depends on a variety of physical and anthropogenic factors, including upland land use [18]. Compared to some other regions [19], there are limited opportunities for transgression in southern California. Detailed studies evaluating opportunities for transgression in southern California are currently being conducted, but the general situation is clear. California has a young geology, with relatively recent uplift of coastal mountains resulting in many wetlands being surrounded by steep slopes and bluffs. Although there are a few regions where large river valleys or flood plains result in relatively flat upstream regions (e.g., Tijuana Estuary, Santa Clara River Estuary), these are the exception. Moreover, southern California is highly urbanized. Most flat coastal areas have been developed. This combination of natural topography and human development limits the opportunities for managing transgression in southern California.

As discussed earlier, anthropogenic changes have greatly reduced the sediment input to coastal wetlands in southern California. Because these changes are so pervasive, some type of sediment management may be the best approach to increasing salt marsh resilience to SLR. One approach to sediment management would be to increase the sediment load from the watershed, which could be accomplished by removing dams or impervious surfaces in coastal watersheds. These management actions could improve a marsh's ability to accrete sediment, although there is uncertainty about how much sediment the watershed management actions would yield and how much would end up on the marsh plain. Moreover, even wetlands with adequate sediment supply may not be able to keep pace with high rates of SLR.

Another approach to sediment management would be to add sediment directly to the marsh plain to raise its elevation. Sediment augmentation has been used in limited settings in the United States and internationally [20]. Sediment augmentation grows out of the concept of beneficial uses of dredged material, originally considered as a way to make use of dredged sediments instead of disposing of it as “spoils.” The first thin layer placement was in 1978 in Georgia, with subsequent applications in Texas, Georgia, Louisiana, North Carolina and Maryland. As the nature and extent of SLR has become apparent, thin layer sediment augmentation has become part of the suite of tools available for climate change adaptation in salt marshes. This technique is often used where natural systems of sediment deposition have been altered so that it can compensate for a sediment deficit, but it could also be used in marshes with normal sediment inputs that simply cannot keep pace with SLR.

Thin layer sediment augmentation has not yet been tested in southern California wetlands (or anywhere on the west coast of the US). Southern California wetlands, occurring in a semi-arid (Mediterranean) climate with extreme year-to-year variability in sediment loads in coastal rivers, have sediment regimes that are distinctly different from other regions. Although sediment augmentation is still considered experimental in every region, there is a particular lack of information about how it would work and the ecological consequences (positive and negative) in southern California salt marshes. To develop an understanding of thin layer sediment augmentation as a management technique in southern California, sediment was added to a low-marsh portion of the Seal Beach National Wildlife Refuge. The objective of this paper is to describe the initial results of this pilot project, the monitoring program that will be used to evaluate its effects, and some of the initial lessons learned in its initial stages.

## 2. THE SEAL BEACH NATIONAL WILDLIFE REFUGE PROJECT

The feasibility and consequences of thin layer sediment augmentation on salt marshes is being tested in the Seal Beach National Wildlife Refuge (SBNWR). The goal of the project is to raise the marsh plain elevation in a portion of the Refuge to study how well this technique can improve habitat quality for the federally endangered light-footed Ridgway’s rail (*Rallus obsoletus levipes*) (formerly known as the light-footed clapper rail). Because the rail occurs mainly in low marsh habitats in southern California, which are most vulnerable to climate change, protecting salt marsh habitat and rail habitat quality are complementary goals.

### *2.1. Background*

The Seal Beach National Wildlife Refuge is a 391-ha (965 acre) refuge located within the Naval Weapons Station Seal Beach, in Orange County, California (33°44′N, 118°07′W) (Fig. 1). Orange County has experienced substantial loss of wetlands [1], and the SBNWR wetlands represent the remnant wetland that was originally part of the Anaheim Bay wetland complex. In the late 1800s, the Santa Ana and San Gabriel Rivers discharged large amounts of sediment into Anaheim Bay, but the rivers were channelized to bypass the salt marsh for flood protection [21], thereby reducing sediment inputs. The watershed surrounding the wetland is highly urbanized. Currently the wetland includes approximately 229 ha (565 acres) of salt marsh as well as subtidal habitat, channels and mudflats. The wetland supports a variety of species, including two endangered species, the light-footed Ridgway’s Rail and the California Least Tern (*Sternula antillarum browni*). Because much of the salt marsh is at a relatively low elevation, it is dominated by cordgrass (*Spartina foliosa*).

Studies conducted by USGS indicate that the Refuge has experienced a relative sea-level rise (RSLR) of 6.23 mm/yr, a rate three times higher than that of similar southern California marshes not affected by subsidence [22]. Much of the subsidence in due to oil and groundwater extraction, but isolating the salt marsh from its sediment supply likely limited the marsh's ability to keep pace with the RSLR. The low elevations of much of the Refuge salt marsh has resulted in stunted cordgrass that provide little habitat for the endangered Light-footed Ridgway's Rail. In many ways, the subsidence rates at SBNWR provide a preview of higher sea levels expected in the coming decades at all southern California salt marshes.


*Figure 1: Seal Beach National Wildlife Refuge.*

### *2.2. Sediment Augmentation Project*

The initial plan for the sediment augmentation project was to apply a thin-layer of sediment over 4 ha (10 acres) of existing low salt marsh habitat (mainly cordgrass-dominated habitat). The area chosen for augmentation is in the central portion of the wetland (Fig. 2). This area was chosen because of its relatively low elevation and proximity to the sediment source. A nearby marsh area was chosen as a control site.

The target sediment depth chosen for the augmentation project was 25.4 cm (10″). This depth was chosen for several reasons. It closely mimics the historical elevation loss at the site, which has experienced an elevation loss of about 29 cm since the 1960s due to land subsidence and sea level rise. This depth also seemed appropriate for biological reasons. It would keep the augmentation site within the elevations of the growing range for *Spartina foliosa*. Studies on another cordgrass species, *Spartina alterniflora*, indicated that their stems could penetrate a sediment depth up to 23 cm regardless of the sediment type [23]. In addition, a preliminary experiment at Seal Beach NWR indicated that *S. foliosa* was able to penetrate 25 cm of sediment in less than one year (K. Gilligan, unpublished data). Finally, there were logistical and financial reasons for limiting the sediment thickness to 25 cm, since the cost for engineering and mobilization for placing sediment in the Refuge was higher than open ocean disposal.

The actual area covered by sediment was slightly less than planned due to differences in application rate and limited supply of suitable sediment. A 25 cm (± an average of 5 cm) thin layer of dredged material was placed over approximately 3.2 ha (7.87 acres) of low elevation salt marsh from December 2015 to April 2016. Due to the lack of uniformity on the marsh plain and the fluid nature of the sediment slurry, low spots within the application site accumulated greater depths of sediment than had been anticipated. As a result, the original proposal to apply 7,646 to 10,321 $m^3$ (10,000 to 13,500 cubic yards) of sediment was not adequate to cover 4 ha of the project site. Ultimately, about 13,000 $m^3$ (17,000 cubic yards) of clean dredged material from the Main Channel West of Sunset/Huntington Harbour was placed over 3.2 ha of the site.


*Figure 2: Location of augmentation and control sites in Seal Beach NWR. The location of three additional plots testing effects of deeper layers of sediment are also shown as small squares in the east (right) portion of the site. (Source: K. Gilligan, USFWS).*

Dredged material was moved by temporary pipeline to the augmentation site. When the contract for sediment placement was bid, it was not decided whether the sediment should be added to the site using a moveable pipeline to add a sediment slurry or by aerial spraying. After discussions with the relevant parties, it was decided to use a rainbow sprayer and end-of-pipe baffle impingement (Fig. 3). A buffer (approximately 100 m wide) between the augmentation site and adjacent channels was established to reduce sediment runoff and avoid impacts to aquatic species, including seagrass. After initial sediment augmentation indicated that the buffer was not sufficient to prevent runoff, a hay bale barrier was installed around the entire augmentation site.

In addition to the main augmentation area, three additional 15 m × 15 m (50′ × 50′) experimental plots were established to evaluate the effects of adding a deeper layer of sediment (Fig. 2). The sediment in these plots was 30.5 cm (12″), 45.7 cm (18″) and 56 cm (22″) deep. These plots will be monitored for many of the same parameters as the normal augmentation area, with particular interest in the timing for re-establishment of salt marsh vegetation and invertebrates.

The added sediment effectively covered the marsh plain within the project area. Fig. 4 shows an edge of the project area, with the augmentation area separated from the natural salt marsh buffer by hay bales.

*Figure 3: Spraying dredge material onto marsh plain. Photo: R. Nye, USFWS.*

*Figure 4: Panoramic view of the sediment augmentation site after sediment addition. Photo: K. Gilligan, USFWS.*

The change in the marsh plain after sediment augmentation was, as expected, dramatic (Fig. 5). The vegetated marsh surface was transformed to a bare sediment surface. Initially, the added sediment retained substantial water content, making it difficult to walk across the study site without "mudders" (which function like snowshoes for muddy sediments). However, because the sediment characteristics were sandier than expected, it was possible to walk through the study site soon after the sediment was added, whereas a higher proportion of fine-grained sediments would undoubtedly make walking in the study area extremely difficult. Because of the sandy nature of the added sediment, it became consolidated relatively quickly, as can be seen by the photograph in the bottom of Fig. 5. This photograph was taken approximately two months after sediment augmentation, and the surface was quite firm.

*Figure 5: Sediment augmentation area before and after sediment addition. Left: salt marsh vegetation before sediment addition. PVC stakes mark various study plots. Right: Augmentation area after sediment addition. Photo was taken in June 2016, two months after sediment addition. PVC stakes and transect tape mark location of tidal creek before sediment addition, which is being re-surveyed to determine change in tidal creek cross-section. Photos: R. Ambrose (left) and A. Wagner (right), UCLA.*

## 3. MONITORING

The sediment augmentation project incorporates extensive pre- and post-augmentation monitoring. Pre-augmentation monitoring was completed in December 2015. Post-construction monitoring started immediately following the completion of sediment placement on the site and will continue over a time period of 5 years.

Pre- and post-augmentation monitoring on the project site and control site includes a variety of parameters to assess physical and biological changes in the augmentation site over time, as well as understanding possible impacts to water quality by measuring suspended sediments in the water column adjacent to the augmentation site and submerged aquatic vegetation (eelgrass beds) as a result of construction activities. In addition, there is interest in understanding how a sediment augmentation project like this might fit into a greenhouse gas mitigation scheme, so measurements of greenhouse gas emissions ($CO_2$, $CH_4$ and $N_2O$) and carbon sequestration will be made.

Substantial monitoring effort is being devoted to understanding the characteristics of the sediments after they were added to the study area and changes in the sediment characteristics and surface elevations through time. Shortly after augmentation, an aerial photogrammetry survey was conducted. This survey showed the spatial distribution of different sediment elevations. It demonstrated that most areas were close to the target 25 cm addition, but there were some areas that were lower or higher than the target elevation (Fig. 6). One high spot, in particular, is apparent on the western portion of the augmentation area; this area is clearly visible from the ground as well as in the elevation map. The elevation map also shows that the major tidal creeks of the pre-augmentation marsh have largely been filled to level with the surrounding area; one goal of the post-augmentation monitoring is to determine whether the tidal creeks re-establish themselves in the same location, a different location, or not at all (Fig. 5).

A variety of ground-based methods are also being used to assess site elevations and sediment dynamics. RTK GPS surveys were conducted prior to sediment addition and are being repeated after augmentation. Surface Elevation Tables (SETs) [24] were established to determine changes in surface elevation due to the added sediment as well as compaction of the subsurface sediments due to the weight of the added sediment. Changes in the thickness of the added sediment over time will also be determined using a grid of sediment stakes. In addition, feldspar plots will be used to measuring the thickness and bulk density of added sediment in the augmented area over time (from feldspar marker horizons established before the sediment was added) and net sediment accretion rates occurring after the sediment was added (from feldspar marker horizons established after the sediment was added).

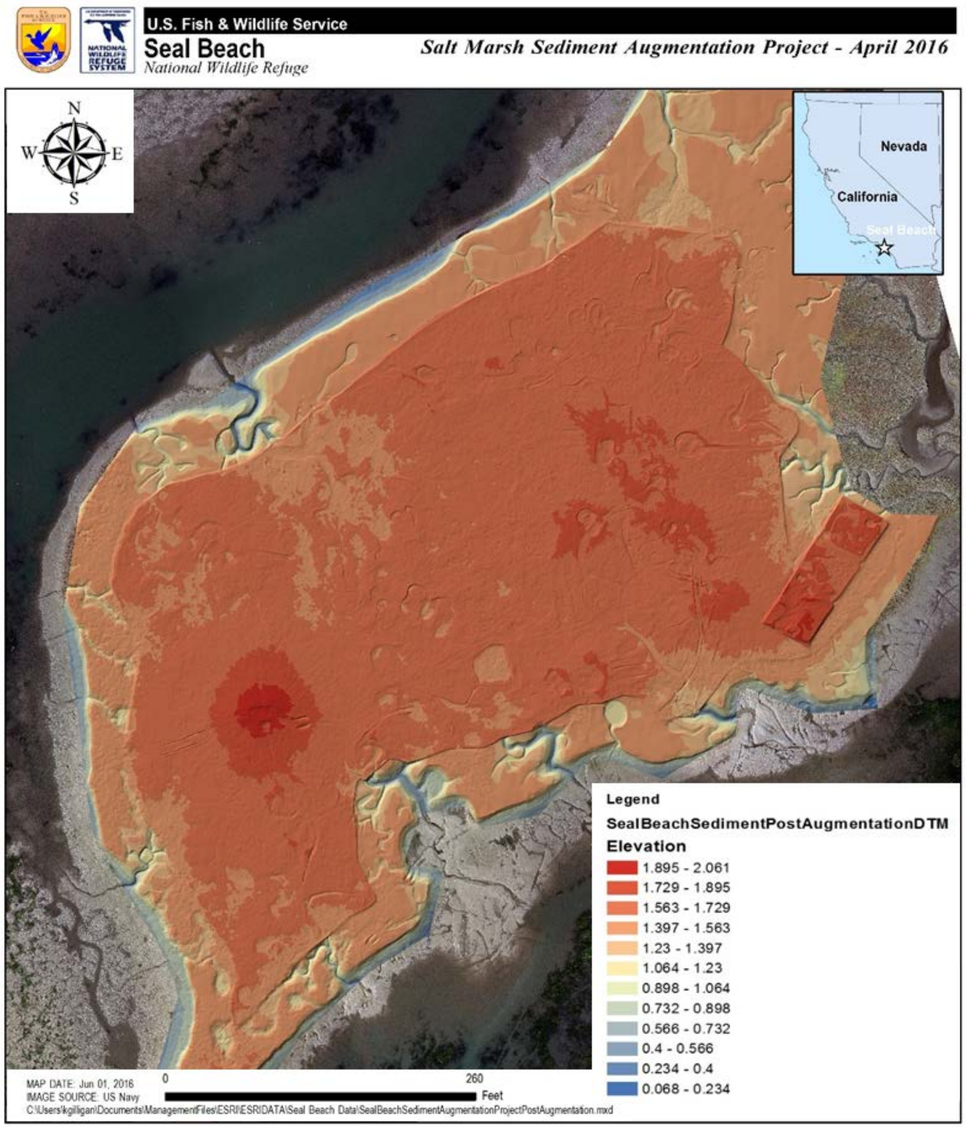


*Figure 6: Sediment augmentation site elevations following sediment addition. Elevations determined by aerial photogrammetry survey. Warmer colors indicate higher elevations. Source: K. Gilligan, USFWS.*

In addition to these sediment measurements, plant and benthic invertebrate communities and associated abiotic parameters (e.g., temperature, porewater salinity, redox) are being monitored, and there will be monthly general bird surveys and directed surveys for light-footed Ridgway's rail.

In some cases, unexpected conditions after the sediment was added meant the proposed methods were not feasible. This was largely due to the coarser sediment grain size added to the site, with much more sand than planned. Besides providing a coarser sediment, the sandy sediment did not hold as much water as a typical salt marsh sediment. In addition, significant variation in sediment characteristics as the sediment was added meant that the sediment column was often quite heterogeneous. The relatively low water content in the added sediment meant that the proposed cryogenic coring method, widely used to take samples from feldspar plots to determine sediment accretion in salt marshes, was unable to freeze intact cores.

Other traditional cores similarly would not remain intact due to the coarse relatively dry and heterogeneous nature of the sediment, which is essential for measuring the height of sediment over the feldspar marker horizon. A different corer, a Russian peat corer, was able to sample the feldspar plots properly (Fig. 7).

*Figure 7: Core taken from feldspar plot using Russian corer. Arrow marks the location of the feldspar marker horizon, used to indicate the pre-augmentation marsh surface. Sediment above the marker horizon (to the left in the image) represents added sediment. Photo: A. Wagner, UCLA.*

Although the initial post-augmentation samples have been collected, the results have not yet been fully analyzed. Most samples will continue to be taken for five years post augmentation.

## 4. Conclusion

Although one of the goals of this project is to improve habitat quality for the light-footed Ridgway's rail, it is too early to assess whether that goal will be achieved because salt marsh vegetation has not yet re-established itself on the site. The other major goal of this project is to evaluate sediment augmentation as a potential technique for helping salt marshes adapt to sea level rise. Although much will be learned over the next five years as the project is monitored, there are already some lessons that have been learned.

Because thin layer sediment augmentation has not been used on the west coast of the US before, contractors were not familiar with the method that would work best. Designing the sprayer and developing the technique for spraying the sediment onto the marsh surface took some trial and error, and initial sediment application went slowly. However, once the contractor was familiar with the process, sediment application went quite rapidly.

Despite pre-project sampling to predict the characteristics, especially grain size, of the applied sediment, the actual sediment applied was much sandier than expected. While this sandy sediment effectively filled the project area to the desired depth, there are some potential downsides. In particular, it is not known whether the sandier substrate might retard the development of salt marsh vegetation and/or invertebrates, although that seems possible. We will be able to evaluate this to some extent with the five-year monitoring program.

The sediment augmentation also required more sediment than expected to reach the 25 cm depth. The sediment surface was more or less flat after sediment addition, which meant that sediment filled tidal creeks and other low spots in the marsh plain to a much greater depth.

Although more sediment was added than originally expected, it still was not enough to cover the originally proposed area.

Finally, the sediment depths were more variable than expected, which means the final surface elevation was more variable than expected. This may not be a problem, since habitat heterogeneity often helps a site support a greater diversity of organisms. This feature will also be evaluated closely in the monitoring program.

Despite some unexpected outcomes, it is clear that the major objective of the thin layer sediment placement - to increase the elevation of the marsh plain - was successful. This project has demonstrated the feasibility of that technique and has helped identify some of the issues that are likely to arise in future projects. The monitoring program will provide valuable information about the biological responses to this sediment addition. Ultimately, the results of this project will help coastal management agencies understand the potential usefulness of thin layer sediment addition as a tool to help preserve coastal wetlands during future sea level rise.

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# Phytoremediation of Cesium, Metformin and Arsenic in Hydroponic Mesocosm Constructed Wetland

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## Abstract

Uptake rates of different concentrations of cesium, metformin and arsenic in hydroponic mesocosm constructed wetlands by different plant species were studied. These plant species grow abundantly in arid and semi-arid regions. When initial Cs concentrations were 2.35, 7.90 and 19.75 mg $l^{-1}$ in constructed wetlands, 89.36 ± 0.42%, 88.56 ± 0.19% and 84.72 ± 0.15% of cesium was remediated by *Amaranthus chlorostachys* plants. In the same cesium concentrations in mesocosm constructed wetland, 18.43 ± 2.76%, 78.98 ± 0.25% and 89.35 ± 0.25% cesium were found to be remediated by *Calendula alata* plants. When exposed to 20 and 50 $mgl^{-1}$ metformin solutions, 63 ± 14% and 58.4 ± 8.60% metformin was remediated by *Amaranthus retroflexus* plants. Uptake rates of arsenic at three different concentrations (0.3, 0.5 and 3 $mgl^{-1}$) of sodium arsenate solution were also studied. When exposed to 0.3 $mgl^{-1}$ sodium arsenate solution, 85.5% and 93.1% of arsenic were remediated after 14 and 21 days. When exposed to the highest arsenic concentration, 89.2% of arsenic was remediated by *Vetiver zizaniodes* after 21 days. The highest concentration ratio value was 4.89 for *Amaranthus chlorostachys* in the case of cesium uptake and the lowest concentration ratio was 0.01 in the case of arsenic uptake by *Vetiver zizaniodes* after 21 days.

***Keywords: Constructed Wetland; Cesium; Metformin; Arsenic***

## 1. INTRODUCTION

Centralized energy and cost intensive technologies have become ineffective in solving the water and waste water problems. Consequently, constructed wetlands, as one of the least energy consuming methods, have become an interesting option for wastewater treatment during the last decades. This technology can be applied for removing various contaminants from water, wastewater and sediments. Constructed wetlands can be designed in various types. Hydroponic constructed wetland are better used in milder climate in which freezing is unlikely. The mechanism used for uptake of contaminants depends on the type of contaminants and the potential of different plants in phytoremediation.

Phytoremediation is a process of decontaminating wastewater, water, sediments and soil by using plants and trees to absorb or break down pollutants. In phytoremediation process it is important to consider how tolerant different plant species are to various concentrations of pollutants [1,2]. Having minimum engineering costs [3], this technology can be used both in situ and ex situ. Phytoremediation is applied for treating an extensive range of environmental contaminants. Minimal disruption of the environment and feasibility of the reuse and recovery of valuable metals and products after harvesting processes are other advantages of this method. The volume and weight of harvested plants after the harvesting process can then be reduced by means of thermal, microbial and chemical processes [4].

Radioactive pollution, one of the important types of pollution in the environment, usually occurs after nuclear power plant accidents [5,6]. Moreover great quantity of $^{133}Cs$ and $^{137}Cs$ have been reported in spent fuel and reprocessed waste [7,8]. $^{137}Cs$ is the most abundant anthropogenic radionuclide in the marine ecosystems [9]. Furthermore alkali metal cesium occurs naturally in sedimentary and igneous rocks at concentration of about 3 mg $kg^{-1}$ [10,11] and in soils ranging from 0 to 26 mg $kg^{-1}$ [12]. Cesium chemical properties are similar to potassium so it can easily be absorbed by plants. Plants do not discern well between unnecessary toxic ions and micronutrients consequently they uptake and accumulate different levels of both by micronutrient/metal transporters [13]. Cesium uptake and accumulation in plants has potential risks for human health.

During the last two decades, the occurrence of pharmaceutical products in sewage and wastewaters has become a serious concern. By the increasing use of human and veterinary medicines, the amounts of these products have also increased in the environment. Sewage and wastewater produced by pharmaceuticals and hospitals have a significant role in soil and water pollution [14-17]. A large number of pharmaceutical products cannot fully become metabolized and digested in the tissues and organs of humans and animals and therefore, enter the sewage system in their native form via urine and feces [18,19]. Even low levels of these pharmaceutical products together with their metabolites and transformation products, from different sources, have become a potential risk to the health of aquatic ecosystems and humans [15, 20-24]. Adverse impacts on aquatic species are the feminization of the male fish [15,24], injury to renal, gill and liver in fish [15,21], increase in pathogen resistance [23], and decrease in plankton biodiversity [25].

Metformin (N, N-dimethylimidodicarbonimidic diamide; Chemical Abstract Service registry number 657-24-9) is an aliphatic low molecular weight (129.16 g $mol^{-1}$) compound with a very high polarity. Metformin is used for treatment of type–2 diabetes (a blood sugar problem). The antidiabetic metformin is among the most abundant of pharmaceuticals found in sewage and wastewater and acts as an endocrine disruptor at environmentally relevant concentrations from 1 to 47 μg $L^{-1}$ [26]. Anti-diabetic metformin causes transcription of the mRNA for vitellogenin in adult male fish [26].

Another important toxic substance for humans and other living organisms is arsenic. Arsenic is known as the most hazardous substance by the U.S. Agency for Toxic Substances [27]. Exposure to low or high concentrations of arsenic (As), due to the direct or indirect consumption of As-contaminated drinking water or foods, may be fatal to human health [28]. More than 150 million people in the world are threatened by arsenic contamination [28].

Constructed wetlands as a green technology can be used for treatment of various waste waters. As a result, the potential of different plant species for phytoremediation of cesium, metformin and arsenic was evaluated in this study. These species grow in arid and semi-arid regions of the world. This growth pattern brings us a management strategy for phytoremediation of cesium, metformin and arsenic from the environment. Moreover there is no report on the application of these plant species for phytoremediation of cesium, metformin and arsenic from solutions.

## 2. METHOD AND MATERIAL

Four plant species (*Amaranthus chlorostachys, Amaranthus retroflexus, Calendula alata, Vetiver zizanioides*) were applied in this study with the aims to evaluate their potential for phytoremediation of wastewaters in constructed wetlands.

### 2.1. *Plant Material and Hydroponics Culture*

Healthy seeds of *Amaranthus chlorostachys, Amaranthus retroflexus and Calendula alata* were placed in plastic trays containing 10 L Hoagland solutions, constantly aerated with a pump [29]. The composition of macro elements per 100 l of solution was as follows: 100 ml $NH_4H_2PO_4$ (115 g $l^{-1}$); 600 ml $KNO_3$ (107 g $l^{-1}$); 400 ml Ca $(NO_3)_2$ .4$H_2O$ (236 g $l^{-1}$); 200 ml $MgSO_4$ .7$H_2O$ (246 g $l^{-1}$); 150 ml Fe-EDTA (5 g $l^{-1}$). The composition of micro elements (100 ml) was: $H_3BO_3$ (0.38 g $l^{-1}$); $ZnSO_4$ .7$H_2O$ (0.22 g $l^{-1}$); $MnSO_4$. 4$H_2O$ (1.02 g $l^{-1}$); $CuSO_4$. 5$H_2O$ (0.08 g $l^{-1}$); $(NH_4)6Mo_7$. $O_{24}$. 4$H_2O$ (0.02 g $l^{-1}$). Solution pH was adjusted to 5.5 to 5.8 by addition of 0.1 M NaOH or 0.1 M $HNO_3$. Hoagland solutions renewed at every seven days. Level of the solutions was made up with Hoagland when required. Plants were grown outdoors with temperature ranging from 28 °C to 36 °C (maximum daily temperature) and 17 °C to 28 °C (minimum daily temperature) with natural light during the experiment.

### 2.2. *Experiments Using Hydroponically Grown Plants*

#### 2.2.1. *Phytoremediation of polluted solutions*

After 10 weeks we designed our experiments to two parts. First, pollutants were added to Hoagland solution ($V_{P=}V_H$= 5L). Second, plants were transferred to flasks containing only contaminant solutions. In the first case, 5 L solutions with three different concentrations of CsCl (0.5, 2 and 5 mg $l^{-1}$) were added to trays containing Hoagland solution. In the second case 10 week old *Amaranthus retroflexus* plants were incubated with roots immersed in 250 ml metformin solution [29,30] containing with two different concentrations (20 and 50 mg $l^{-1}$). *V. zizanioides* plants were placed in plastic trays containing 7L sodium arsenate solution with three different concentrations (0.3, 0.5 and 3 mg $l^{-1}$). The pH of the solutions was adjusted to 5.5 during the pollutants uptake. The treatment group was exposed to wastewater for a period of 14–15 days [29,30]. The experiment was settled with each treatment in triplicate samples. Control plants were grown in water and distilled water was added to make up the evaporated water. After the treatment period, sample plants were removed from pollutant media and the solutions were tested for cesium, metformin and arsenic concentrations. In all experiments, the concentration of cesium and arsenic in the solutions was determined by atomic absorption spectrophotometry (AAS) and the concentration of metformin in the solution was determined by HPLC.

### 2.3. *Phytoremediation Efficiency*

The phytoremediation efficiency was calculated from: % Uptake = $[(C_0\text{-}C_1) / C_0] \times 100$ where $C_0$ and $C_1$ are concentrations before and after plant treatment of cesium, metformin or arsenic, respectively [29,31].

### 2.4. *Concentration Ratio (CR)*

The concentration ratio (CR) is the ratio of metal concentrations in plant shoots to those in the roots and shows the potential of plants in translocating metals to their aerial parts [32-34,35].

### 2.5. *Statistical Analysis*

The tests were implemented in triplicate and the statistical analysis was implemented using Statistical Analysis System (SAS) software package. To check the variability of results, all the data were subjected to analysis of variance to consider the significance differences. Furthermore Duncan test was applied to obtain means comparison between data.

## 3. RESULTS

### 3.1. Phytoremediation of Cesium in a Hydroponic Mesocosm Constructed Wetland

As shown in Fig. 1, seeds were generated in Hoagland medium aerated with a pump. In a hydroponic mesocosm constructed wetland, *Amaranthus chlorostachys* growth rate was very high. This plant species accounts as a fast growing weed. Moreover plants were tolerant to cesium pollution.

(a) (b) (c)

*Figure 1: (a) Hydroponically grown Calendula alata, (b) Amaranthus chlorostachys seeds generated in Hoagland solution, (c) Amaranthus chlorostachys used for phytoremediation of Cs from 5 mgl$^{-1}$ in hydroponic mesocosm constructed wetland.*

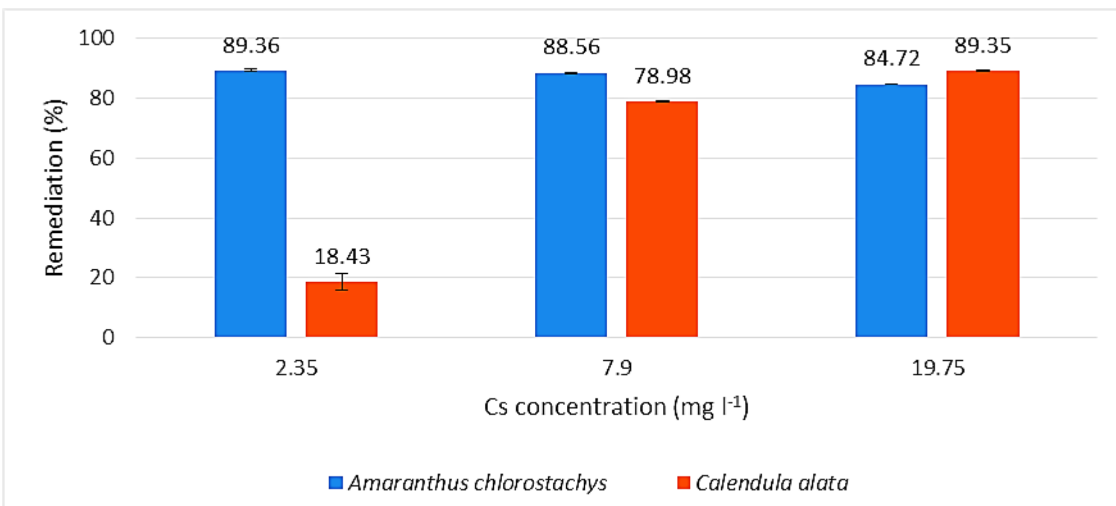


*Figure 2: Uptake of cesium from hydroponic mesocosm constructed wetland planted with A. chlorostachys and C. alata after 15 d. All the values are mean of three replicates ±SD. (Initial Cs concentrations were 2.35, 7.90 and 19.75 mg l$^{-1}$) $P<0.05$, data differences are significant.*

### 3.2. Phytoremediation of Metformin from Solutions

In this study, the different species of plants were found to be efficient in uptake of metformin from solutions (Table 1).

TABLE 1: REMEDIATION PERCENT OF METFORMIN CONTAMINATED SOLUTIONS BY AMARANTHUS RETROFLEXUS, AFTER 14 DAYS. ALL THESE VALUES ARE MEANS OF THREE DUPLICATES ± SD. $P < 0.05$, DATA DIFFERENCES ARE SIGNIFICANT.

| Plant | Initial Solution (mg $l^{-1}$) | After 14 days (mg $l^{-1}$) | Remediation (%) |
|---|---|---|---|
| *Amaranthus retroflexus* | 20 | 7.40 ± 2.80 | 63 ± 14 |
| *Amaranthus retroflexus* | 50 | 20.80 ± 4.30 | 58.4 ± 8.60 |

### *3.3. Phytoremediation of Arsenic from Solutions*

Phytoremediation of arsenic from sodium arsenate solution is shown in Fig. 3. The highest removal efficiency (93.1%) was achieved with the lowest arsenic polluted solution.

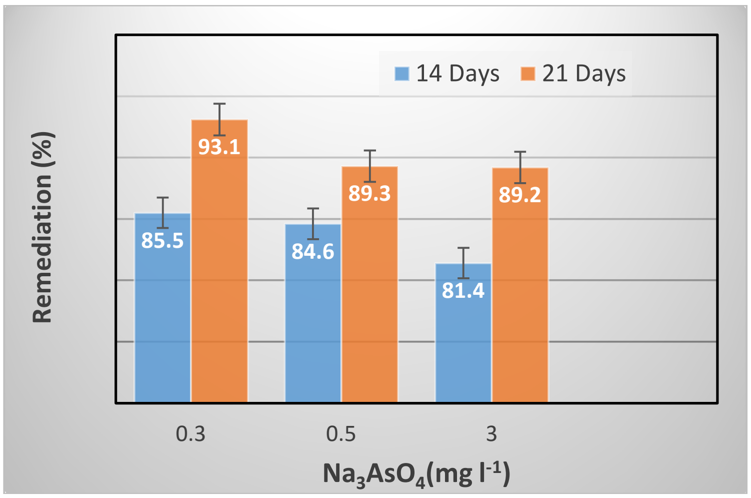


*Figure 3: Phytoremediation of arsenic from sodium arsenate solutions by Vetiver zizanioides. All the values are mean of three replicates ±SD.*

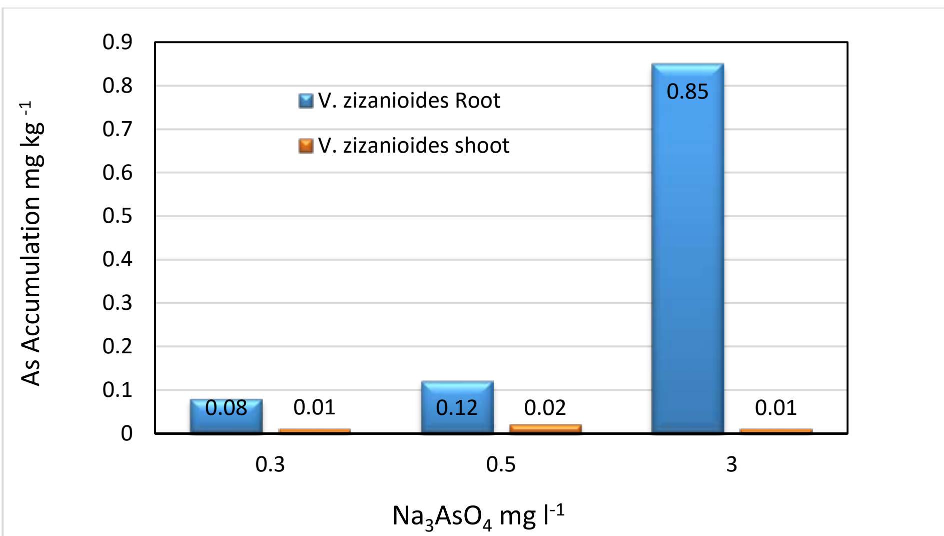


*Figure 4: Arsenic concentration in shoots and roots of Vetiver zizanioides L. Nash after 21 days. All values are mean of three replicates.*

All the concentration ratio values were less than 1.0, which shows low effectiveness of *Vetiver zizanioides* for arsenic translocation.

TABLE 2: CONCENTRATION RATIOS EXPRESSED BY THE MEAN OF THREE REPLICATES. P<0.05 DATA DIFFERENCES ARE SIGNIFICANT

| | ***Vetiver zizanioides*** | | |
|---|---|---|---|
| As (mg $l^{-1}$) | 0.3 | 0.5 | 3 |
| CR | 0.125 | 0.166 | 0.011 |

## 4. DISCUSSION

Cesium is phytotoxic at solution culture concentrations exceeding 200 μM [12]. Observed changes due to absorption and accumulation of cesium in our preview study showed an increase of crystals quantity in stem parenchyma and their color embrace [36]. In our previous study we calculated concentration ratio of cesium in *A. chlorostachys* and *C. alata* plants. The highest concentration ratio value was 4.89 for *Amaranthus chlorostachys*, whereas for the other tests it ranged from 0.74 to 3.33 [29]. Concentration ratio values show the effectiveness of *C. alata* and *A. chelorostachys* plants in uptake and accumulation of cesium.

There are few data on the occurrence of the antidiabetic drug metformin in the environment. Based on literature reviews [37], metformin has been detected in surface waters up to a maximum concentration of 0.15 mg $L^{-1}$. Predicted metformin concentrations in raw municipal wastewater of 37 ug $L^{-1}$ have been reported [38]. The uptake pattern of metformin and guanylurea varies within and between sewage treatment plants. On the other hand, in *Amaranthus retroflexus,* when plants are exposed to lower metformin concentrations (20 $mgl^{-1}$), more efficiency of phytoremediation was shown. Temperature and pH of wastewater in sewage treatment plants are important parameters that affect the metformin uptake ratio. Metformin and the degradation product guanylurea were taken up by plant roots and aerial shoots [39,40]. However, metformin produces negative impacts on growth of carrots grown in soil concentrations of 6-10 mg $kg^{-1}$ dry weight. In this study, plants were healthy during the remediation period. The percentage of metformin in these plants will be studied in future research. In our previous study when we used the Amarantceae family of plants for phytoremediation of solutions contaminated with cesium, *Amaranthus chlorostachys* could remediate 65 ± 4.11% of cesium from cesium chloride solution (2 $mgl^{-1}$). In the present study, *Amaranthus retroflexus* remediated 63 ±14% of metformin from metformin solution.

About 110 million people in 10 countries in South and South-East Asia, including Bangladesh, Cambodia, China, India, Laos, Myanmar, Nepal, Pakistan, Taiwan and Vietnam are threatened by arsenic contamination [29]. So, treatment of As-contaminated water and soil is necessary to minimize the health hazard. Untreated well water arsenic concentrations range from <10 μg $l^{-1}$ to 640 μg $l^{-1}$ [41]. Our study showed that in this range of arsenic pollution, constructed wetlands planted with *Vetiver zizanioides* can be used for remediation. Consequently this fast growing family of plants that grow on wide geographical locations in semiarid and arid regions of the world including Iran could be a potential candidate for constructed wetlands.

## 5. CONCLUSION

Hydroponic constructed wetlands present an effective method for remediation of waste waters by natural means. Moreover this system needs a low land requirement. Application of hydroponic constructed wetlands for removing various contaminants from wastewater in developing countries presents an effective strategy to reduce exposure to cesium, metformin and arsenic. This system provides developing countries an effective, low cost and sustainable waste water treatment system.

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**U.S.-Iran Symposium on Wetlands**

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# Evaluation of Constructed Wetlands for Treatment of Wastewater in Iranian Rural Areas

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### *Abstract*

This work is a collaboration between academic and industry sectors in Iran in implementing modern and advanced techniques for solving old and established problems in rural areas of the country. As environmental issues need cooperation between various teams of scientists, industry, policy-makers and local people, providing capital for academia by industry is in sharp rise in Iran aiming at finding comprehensive and long-lasting solutions to protect natural resources.

Water scarcity has become a growing severe threat in this part of the world. This work aims to study the potential of using more efficient, cost-beneficial techniques for treatment and reuse of water in arid areas in Iran. During the last two decades, more than 600 cities and towns in Iran have been provided with standard sewage works. Rural areas and villages are now in line to follow. By the end of this decade, 98% of population must be covered by effective and standard wastewater facilities.

Utilization of modern and engineered Constructed Wetlands (CW) for wastewater treatment or reuse is relatively new in Iran. A full-scale installation at city of Ghasre-Shirin, under successful operation for the last 8 years, indicates that CW could be a viable option for wastewater treatment in rural areas where abundant land is available whilst running costs and energy consumption are minimal. The possibility of cultivating more useful plants with side benefits could greatly increase the acceptance and attraction of this system to rural communities alongside with wastewater treatment or water reclamation.

For this purpose, a pilot study to investigate the potential of growing fodder plants instead of common reeds (*Phragmites australis*) in a subsurface flow CW was carried out. The raw wastewater was provided from west Tehran's main wastewater treatment plant (WWTP), Ekbatan. Different native plant species, including *Lactuca Sativa*, alfalfa and tumbleweed were experimented. The results indicated that at recommended loading rates all artificial CWs could remove over 90 to 94% of soluble chemical oxygen demand (COD). Total nitrogen removal was highest at 58% where alfalfa was grown and lowest (44%) where *Phragmites australis* was grown. Total phosphorus removal rates were also acceptable at 32- 49% in four box-plots. To enhance nutrient removal, phosphorus in particular, different bed types (gravel material) were experimented. Best results were obtained when pumice stone gravel was used and over 50% of phosphorus was adsorbed by the gravel particles.

This work also looks at potential of salt removal in wetlands by using Halophyte plants. Most parts of Iran produce saline wastewater that is not even fit for reuse after normal treatment processes. *Salicornia europaea*, a halophytic plant with relatively high distribution in Iran, provided a removal of 15% of salt concentration.

It is concluded that it is possible to construct subsurface flow wetlands with various plants that may have a much higher economical value than normal reeds. Plants with potential to reduce water salinity would be of special advantage. Other attractive options, considering Iran's economic and environmental condition, include plants that have more nutritional values, or economic advantages for cattle or indirect human use, such as cane sugar, sunflower, or herbal shrubs. Helping communities to benefit from financial gains while treating their wastewater should be a top priority in rural development throughout the world, and constructed wetlands may be well placed for reaching this goal.

## 1. INTRODUCTION

The use of constructed wetlands is relatively new in Iran. Although wastewater disposal by natural methods has long been in practice in this part of the world, mainly by discharge of sewage in wells, wetlands have never been a major choice, with exception of highly wet areas of Caspian coastline. However, in recent years the low cost and high efficiency in treatment have attracted people in towns and small communities to look at wetlands as a strong potential for their wastewater discharge.

In many developed communities, in addition to ecological attractiveness of secondary treatment of wastewater, wetlands have become to be known as an efficient tertiary treatment system for removal of organic residues and micro pollutants. The case for developing world is the acceptance of constructed wetlands due to its multiple merits. Ease of construction, lack of complicated and expensive machinery, very low energy consumption and ease of operation are enough to place CWs as a strong candidate for treatment of wastewater in small communities, towns, villages and rural areas and where land is abundant [1].

Sewage disposal by natural wetlands has a long history, especially for communities living in vicinity of natural water bodies. It was considered a common mean to discharge polluted waters in water bodies in European countries for centuries. Naturally the pollution caused by uncontrolled wastewater discharge was not accepted as a viable practice and lead to development of different types of constructed wetlands. Fig. 1 shows the major type of wetlands under operation in many parts of the world [2,3].

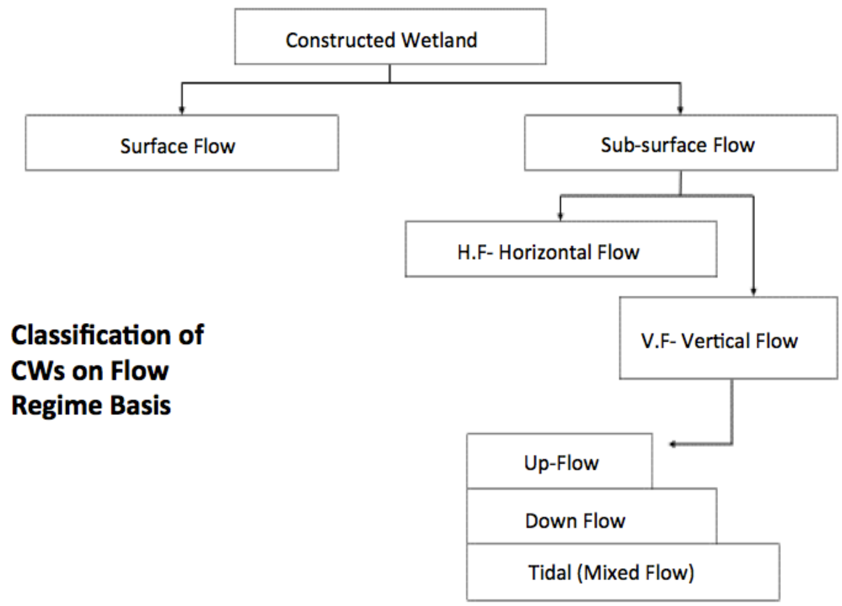


*Figure 1: Different types of Constructed Wetlands.*

Original wetlands were so called surface flow constructed wetlands (SFCW), consisting of shallow ponds with plants adopted to grow in water. SFCWs are currently not very popular, at least in tropical climates, due to high water loss and the possible pest and mosquito breeding problems. Development of sub-surface flow constructed wetlands (SSFCW) attracted more attention, as it appeared to have solved the negative points of open surface wetlands. Different types of SSFCWs have been used including horizontal or vertical flow systems, claimed to be more practical in construction with superior efficiency in removing organic and other contaminants. Flow variations were mainly applied to SSFCW as it appeared to be a more acceptable option in wetland development. Worldwide trends in development of better sanitation and healthier environments, reported by public health engineering, indicate that SSF wetland process is fast substituting natural (un-mechanical) sewage treatment systems such as Lagoons and Stabilization Ponds due to its numerous merits and higher flexibility.

The need for improved sanitation has forced many countries to discharge their wastewaters by properly engineered treatment systems. In Iran, more than 600 cities and towns have been equipped with sewage works during the last 20 years. By end of 2020, 98% of population must be covered by standard wastewater facilities. However standard treatment works are expensive to build and often difficult to operate efficiently. Plant failures are thus very common. Lack of experienced operators, energy needs and equipment spare parts are the main causes of plant failure in Iran. Un-mechanical treatment plants, such as lagoons and wetland systems are therefore a serious consideration especially for small towns and villages. If side benefits, such as treated wastewater recovery and reuse or cultivation of useful plants, where wetlands are considered, are also included in the wastewater treatment program, then the chances of success will highly grow.

Constructed wetlands have proved to be reasonably efficient for removal of organic material (indicated by $BOD_5$ or COD) and nutrients (nitrogen and phosphorous) from wastewater [4,5]. In some studies industrial contaminants, such as heavy metals and complex chemicals, have also been reported to be removed by wetland plants [6-8].

Wetland plants play an important role in satisfactory performance of up-taking and removing organic contaminants and nutrients from wastewater [9]. Therefore plant selection can be critical in operational efficiency of a wetland. Plants used in SSFCWs must tolerate water-saturated soil as well as natural environment of wastewater including many chemicals that are present. In cases where industrial wastewater may also be present, further consideration in plant type is necessary.

In southwest Europe, successful industrial use of plants species such as *Phragmites australis*, *Iris pseudacorus,* and *Cyperus* spp, used as macrophytes in wetlands, have been reported [7]. *Phragmites australis,* known as common reed, is the main choice of vegetation used in many wetlands. Other species such as *Typha* spp.*, Scirpus* spp., and *Phalaris arundinacea,* which are classified as common wide plants grown in many parts of the world, are also used in wetlands [9].

Plants used in wetlands must have strong roots adoptable to marshy environment. *Cyperus alternifolius,* commonly known as Umbrella sedge, is another typical plant that has been cultivated in wetlands successfully. This species showed more potential for nutrient removal. However very little effort is reported on plants that may have other useful merits that could work as dual purpose in wetlands. Capacity to be used as cattle feed, or other side benefits could be highly attractive to wetland management [10].

Another important issue in dry climates is existence of saline wastewaters that may not be suitable for irrigational applications even after normal wastewater treatment procedures [11]. Many researchers have focused on selection of plants for phytoremediation (use of plants for pollution removal) in saline environment [12]. Halophytes (salt tolerant plants) may have a possibility to be used in wetlands to treat wastewater and remove organics as well as reducing salt concentration. These type of plants are considered favorable due to their potential for accumulating salt in their tissues, which is one of the mechanisms of coping with and resisting against salinity [9,10].

This characteristic, along with other mechanisms, to absorb and remove various kinds of pollutants could prove highly attractive where saline wastewater is to be treated and reused. Many arid climates, including most parts of Iran, produce saline wastewater that is not even fit for reuse after normal treatment processes. Furthermore salinity can damage cultivable land and enhance desertification. Therefore, the idea to reduce salt concentration from saline wastewater, by wetland systems, is a very appealing task for rural farming communities and environmentalists.

The efficiency *of Salicornia europaea* species of plants in salt phytoremediation of solutions in hydroponic systems had already been tested in previous studies [13]. This study looks at this plant in a pilot wetland system, as *Salicornia europaea* is a halophytic plant with relatively high distribution in Iran and countries with similar climates [14]. Salicornia is a genus of annual herbaceous plants with fleshy succulent stems in the Chenopodiaceae family that grow and develop naturally along sea coasts and in the margins of salt marshes. Research has shown Salicornia producing seeds with oil content of 28%, which offers the option of oilseeds production [15]. Considering the halophytic nature of this plant and its habitats (salt marshes), it appears to be a good candidate for salt phytoremediation. Other studies, utilizing plants that could be used for bioenergy production have also been reported [16], indicating the high potential of this system for various applications.

As explained, the advantages of wastewater treatment in wetland systems, mainly of SSF type, could be highly enhanced if other objectives could be attained as well. For developing countries in which skilled operators are not at hand but land is available, secondary purposes, such as purposeful plant cultivation and salt reduction, may have more weight than wastewater treatment itself. The purpose of this study was to assess the potential of SSF constructed wetland for application in rural areas in Iran, where side benefits could play an important role in development of their wetland system.

*Figure 2: Ghasre-Shirin is a small city in west of Iran. It has a hot climate reaching nearly 42°C during summer time and mean winter temperature is about 20°C.*

## 2. MATERIALS AND METHODS

The present study reflects the results of several independent and yet related research works, with the objective to assess the viability of CW for Iranian villages and rural areas. The performance of a full size SSFCW (Ghasre-Shirin city) over a 12-month period was studied. The outcome could indicate the efficiency of similar structures for wastewater treatment under alike climatic and environmental conditions. A second goal was to evaluate the possibility of enhancing more nutrient removal by cultivation of more suitable plants.

Therefore the second study was carried out at Ekbatan wastewater treatment plant (WWTP) where a pilot plant consisting of four wetland boxes were used to assess efficiencies of fodder plants grown in wetland environment. In the first three box-plots, different native plant species, *Lactuca Sativa*, Alfalfa and tumbleweed, all used as feed for cattle by local farmers, were grown. A forth box-plot was similarly fabricated and seeded with common wetland reed. All four were fed with raw wastewater from Ekbatan WWTP and by a controlled pre-defined program. The performance in organic and nutrient removal of the four box-plots at two loading rates was measured and recorded over a period of 16 months.

The third study was carried out to find out the effect of bed type in nutrient (mainly phosphorus) removal. A final pilot plant, using a native halophyte plant was used to evaluate the salt reduction capacity of this species in Iranian rural areas, in an experimental wetland environment.

### *2.1 Pilot Wetlands Units*

Four polyethylene box-containers with dimensions of 1.0 × 0.75m by 0.8m deep filled with normal gravel were used to grow four different species of wetland plants. Inflow and outflow channels were implanted to ensure a uniform flow as expected in full size wetlands. The roots of four plants; alfalfa (*Medicago sativa*), common tumbleweed (*Amaranthus albus*), Wetland Lettuce (*Lactuca sativa*) and common reed (*Phragmites australis*) were planted in box containers. Approximately 20-30cm of plant roots were placed in water while the shoots and upper parts were within the gravel layer (beads) and above the surface of the SSFs that was totally dry. The four units were fed from settled sewage from Ekbatan wastewater works. Periodic sampling and measurement of COD, total nitrogen, ammonium nitrogen, total phosphorus and turbidity were carried out to analyze each CW's performance.

A second set of experiments was performed in similar situation where gravel was replaced in two box-containers. Pumice stone with effective diameter size of 15-20mm and expanded clay were used in place of normal gravel in two boxes. The porosities of the two bed types were similar to gravel bed and was on the order of 65 to 70 percent approximately. Common reed was grown in pilot CWs and fed with settled sewage of Ekbatan WWTP. Assessment of bed-type material in the removal of nutrients, particularly phosphorus, was carried out in this set of experiment.

The third series of experiment were carried out in a different environment where a local species, *Salicornia europaea,* was used to test the salt removal efficiency of the plant in wetland environment. In each case, several loading rates, known as typical loading rates of wetlands, were selected by changing the inflow rate of the settled sewage to the SSFCWs. Other features of the CW boxes were similar to previous studies. Sodium chloride was added to Ekbatan inlet settled sewage to resemble saline wastewater with electro-conductivity (EC) of 2,000 to 10,000 micro mhos. It represented sewage with salt content of 1,500 to over 6,000 mg/L. In each series of experimentation two boxes were used. The first box was used as control box, were no salt was added, and second box was fed with saline wastewater.

### *2.2. Sample Analyses*

Samples were collected and if necessary stored in near zero °C temperature and tests were carried out according to Standard Methods [17]. Several samples were taken under each operational conditions and were repeated to ensure the accuracy of results. All chemicals used in tests were pure laboratory chemicals supplied by Merck Chemical Co.

## 3. RESULTS

### *3.1. Ghasre-Shirin Wetland Performance*

Ghasre-Shirin is a small city in west of Iran. It has a hot climate reaching nearly 42°C during summer time and mean winter temperature is about 20°C. The constructed wetland treatment system, expected to be a large pilot plant project, came into operation in 1995. The plant was under investigation throughout these years to be copied for other small towns and small cities if successful. Ghasre-Shirin's SSFCW consists of 12 plots each 125 × 25m with a 0.8m deep gravel bed media (Table 1). Common reeds (*Phragmites australis*) grown abundantly in the side of local streams were planted in the wetlands. This plant is the usual choice for wetlands as its efficiency for organic removal and nitrogen removal is well proven. However this plant is not very efficient in phosphorus removal as experienced during the current study (See Table 2).

The plant consists of 1-Inlet Bar screen, 2-Two settling ponds for grit removal, 3-Set of SSF constructed wetlands and 4-Contact tank for chlorination. The plant's performance is shown in Table 2. The data shown are average values of several samples (mainly once a week) taken during the recorded months.

TABLE 1: CHARACTERISTICS OF THE GHASRE-SHIRIN CONSTRUCTED WETLAND TREATMENT PLAN

| | | | |
|---|---|---|---|
| **Population served** | 12500 (future 30.000) | **Surface loading rate** | 12-15 gr $BOD_5/m^2$ |
| **Average flow rate** | 2180 m3/day - average | **Hydraulic Loading rate** | 60 L/m2/day |
| **Influent $BOD_5$** | 250- 310 mg/L | **Retention time in Bed** | 12 days |
| **Influent COD** | 360-490 mg/L | **Retention time (free space)** | 7.8 days (65 % free space) |
| **Total area and dimensions** | 12 beds, each 125 x 25 m | **Media Type** | Gravel of 20-60 mm diameter |

TABLE 2: GHASRE-SHIRIN CONSTRUCTED WETLAND PERFORMANCE. ALL CONCENTRATIONS ARE IN MG/L AND ARE AVERAGE VALUES OF SAMPLES TAKEN DURING THE MONTH RECORDED

| Time | BOD5 Inlet | BOD5 Outlet | COD Inlet | COD Outlet | T-Nitrogen Inlet | T-Nitrogen Outlet | T-Phosphates Inlet | T-Phosphates Outlet |
|---|---|---|---|---|---|---|---|---|
| **Sept. 2012** | 280 | 19 | 390 | 35 | 42 | 18 | 19 | 12 |
| **Oct.** | 275 | 22 | 380 | 32 | 40 | 15 | 18 | 13 |
| **Nov.** | 252 | 19 | 365 | 40 | 33 | 14 | 15 | 11 |
| **Dec.** | 266 | 24 | 370 | 42 | 40 | 16 | 16 | 10 |
| **Jan. 2013** | 290 | 27 | 340 | 38 | 32 | 18 | 15 | 9.5 |
| **Feb.** | 310 | 36 | 420 | 38 | 38 | 15 | 14 | 8 |
| **Mar.** | 277 | 26 | 400 | 39 | 39 | 18 | 16 | 12 |
| **Apr.** | 255 | 24 | 410 | 36 | 45 | 15 | 16 | 11 |
| **May.** | 230 | 25 | 370 | 35 | 48 | 14 | 14 | 9 |
| **Jun** | 240 | 18 | 320 | 32 | 52 | 14 | 16 | 12 |
| **Jul** | 266 | 15 | 350 | 28 | 32 | 16 | 16 | 11 |
| **Aug.** | 256 | 17 | 380 | 28 | 42 | 12 | 15 | 10 |

As it is seen in Table 2, the performance of the plant is quite satisfactory in organic and nitrogen removal.

According to plant operators, Ghasre-Shirin wetland has been in operation for several years without serious complications in operation and maintenance. The only act of repairs, plant-keeping and maintenance was removing deposited grits and sludge at monthly periods and trimming of weeds once a year. Overall it appears that CW can be successfully used for rural area wastewater management with least man power, very low technical knowledge and almost no energy requirement. The only hang-up may be attributed to large area of land required, not always freely available, especially in marshy areas where land is covered with stones and unfavorable geographical situations.

*3.2. The Efficiency of Organic and Nutrient Removal by Different Plants and Vegetation*

To evaluate the effect of different vegetation in wetlands, four pilot plants, as explained before, were used. Roots of common reeds (*Phragmites australis*), alfalfa (*Medicago sativa*), water lettuce (*Lactuca sativa*) and tumbleweed (*Amaranthus albus*) were planted and allowed to be grown as full plants over a 18 month period. Some plants are traditionally used as fodder plants (namely alfalfa) and are treated favorably by farmers, to be grown in constructed wetlands. It is therefore an encouraging and inspiring act if such plants can be implied efficiently in CWs. The results of pilot CW boxes are shown in the following figures. Shown by Fig. 3, the $BOD_5$ outlet of the four pilot CWs are quite similar, indicating organic removal on the order of 90% to 95% efficiency. Similar behavior in removing total nitrogen is depicted in Fig. 4.

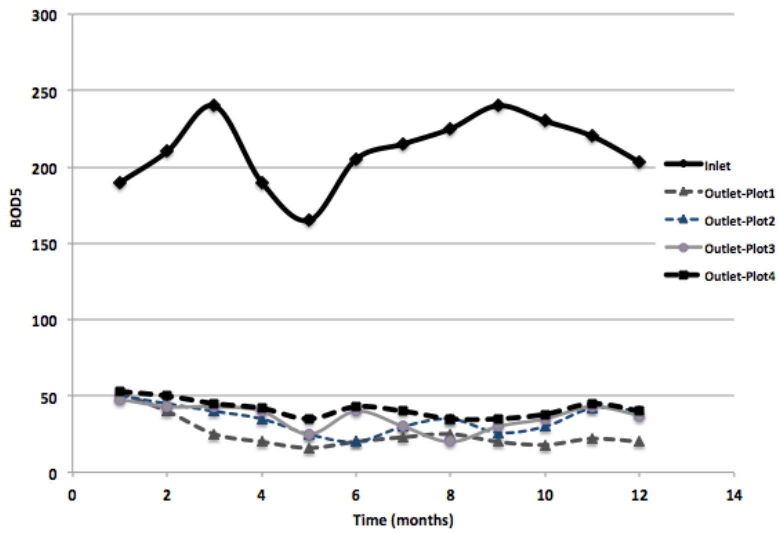


*Figure 3: BOD5 removal in four CV pilots with four different plants. Plot 1: common reed (Phragmites australis), Plot 2: alfalfa (Medicago sativa), Plot 3: tumbleweed (Amaranthus albus), Plot 4: water lettuce (Lactuca sativa).*

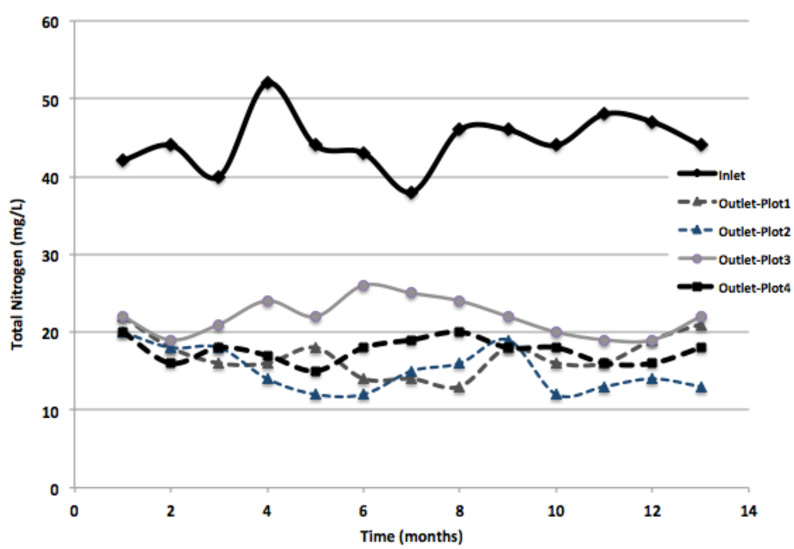


*Figure 4: Nitrogen removal in pilot plants. All concentrations are in mg/L and are average monthly values of multiple samples taken during the month recorded. Plot 1: common reed (Phragmites australis), Plot2: Alfalfa (Medicago sativa), Plot 3: tumbleweed (Amaranthus albus), Plot 4: Water Lettuce (Lactuca sativa).*

However, as shown in Fig. 5, the removal of phosphorous was not as effective as required. As has been previously shown and explained [18], removal of phosphorous in constructed wetlands is usually limited by the capacity of the media to adsorb, bind or precipitate the incoming phosphorus (P). Therefore, the life span of the CW in P removal is relativity short. To enhance P removal alternative medium with high P-binding capacity can be used.

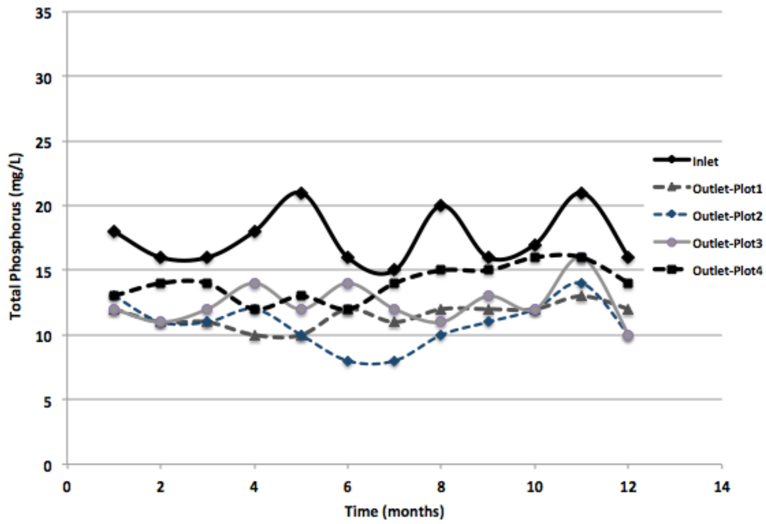


*Figure 5: Phosphorus removal in pilot plants. All concentrations are in mg/L and are average monthly values of multiple samples taken during the month recorded). Plot 1: common reed (Phragmites australis), Plot 2: alfalfa (Medicago sativa), Plot 3: tumbleweed (Amaranthus albus), Plot 4: water lettuce (Lactuca sativa).*

Also, as the main source of phosphorous is often household laundry detergents, it may be possible that low-biodegradable detergents used in rural areas may have a negative effect. However adequate data to conclude this presumption was not available.

During experimentation minor soil clogging was observed where tumbleweed was grown and water lettuce experienced low tolerance during cold weather (all boxes were protected from frost during cold winter day and nights). However the results clearly indicates that a plant such as Alfalfa can substitute common weeds in wetlands providing nutritional value for local farmers' livestock. Naturally if the idea is well explored, farmers will be greatly encouraged to build and run constructed wetlands for the sake of feed stick cultivating. It will be their priority compared to wastewater treatment.

### *3.2 The Effect of Bed Composition*

Many researchers have indicated that phosphorous removal efficiency in constructed wetlands is very dependent on the type of gravel and bed material or composition [19].

To verify this theory a simple test was carried out incorporating three pilot CWs boxes each filled with different gravel types. The first was filled with normal gravel (silica-gravel), the second with expanded clay and the third with pumice stones. The sizing was the same with an average diameter of 1.5-3 cm. Common weed was grown in pilot CWs and fed with settled sewage of Ekbatan WWTP. Phosphorous removal was measured over a period of several weeks after the plants have been fully grown.

Results indicate that pumice stone is performing better on average and removing more phosphorous with higher efficiency (Table 3). Removal rate of 58% was recorded with pumice bed while expanded clay with a reasonably high specific surface area recorded a removal rate of 40%.

An explanation may be due to high porosity of pumice compared to other materials. The pores allow anaerobic conditions to prevail in the bed, where phosphorous can be better stored by microorganism and consequently up-taken by plant roots. Since pumice rock and gravel is abundantly available in many parts of Iran, it could be a natural material to be used in construction of wetlands at low cost.

TABLE 3: THE EFFECT OF BED FILTER TYPE (BEADS) IN NUTRIENT REMOVAL. THREE PILOT CWS BOXES FILLED WITH 1) NORMAL GRAVEL (SILICA-GRAVEL), 2) EXPANDED CLAY AND 3) PUMICE STONES. THE SIZING WAS THE SAME WITH AN AVERAGE DIAMETER OF 1.5-3CM. COMMON WEED WAS GROWN AND FED WITH SETTLED SEWAGE OF EKBATAN WWTP. CONCENTRATIONS ARE IN MG/L.

| | Total Phosphate at inlet | Total Phosphate at outlet | Removal (%) |
|---|---|---|---|
| Settling Tank | 16.5 | 14.1 | 15 |
| CW with normal gravel | 16.1 | 10.25 | 36.3 |
| CW with expanded clay | 16.1 | 8.8 | 49 |
| CW with Pumice stone | 16.1 | 7.0 | 58 |

### *3.3 Salt Removal Capacity*

Halophytic species known to resist saline environments have been used as wetland plants. A set of experiments, in controlled wetland boxes, as previously described, were planted with *Salicornia europaea,* a well grown and well adopted plant to Iranian environment. Sodium chloride was added to Ekbatan inlet settled sewage to resemble saline wastewater with electro-conductivity (EC) of 2,000 to 10,000 micro mhos (representing sewage with salt content of 1,500 to over 6,000 mg/L). In central areas of Iran, saline waters are found with similar salt concentrations.

The experiments were designed to evaluate the resiliency and performance of *Salicornia europaea* at various salinities and its potential to reduce water salinity. In some areas of central Iran saline wastewaters have damaged cultivable land and have created great problems in discharging treated wastewater. However if halophyte plants can be grown in SSFCWs then environmental damage could be reduced.

Fig. 6 shows the rate of salt removal (shown by EC) at three different concentrations. It appears that as EC is increased the amount of salt removal is increased accordingly. However the rate of removal is almost steady at 16-18% removal of EC.

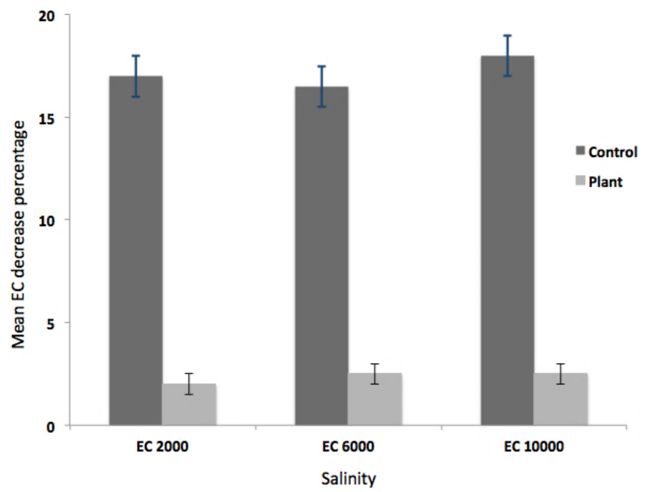


*Figure 6: Salt removal (shown as decrease in EC) by plants at three different salinities. Error bars: 95% Cl.*

Fig. 7 shows the rate of EC on sodium removal. Sodium is a main component of salinity therefore is often used as an indicator in this type of study. Overall it is clear that the plant species used in the CWs (*Salicornia europaea*) has the capability to grow under saline conditions and reduce salinity wastewater salt content.

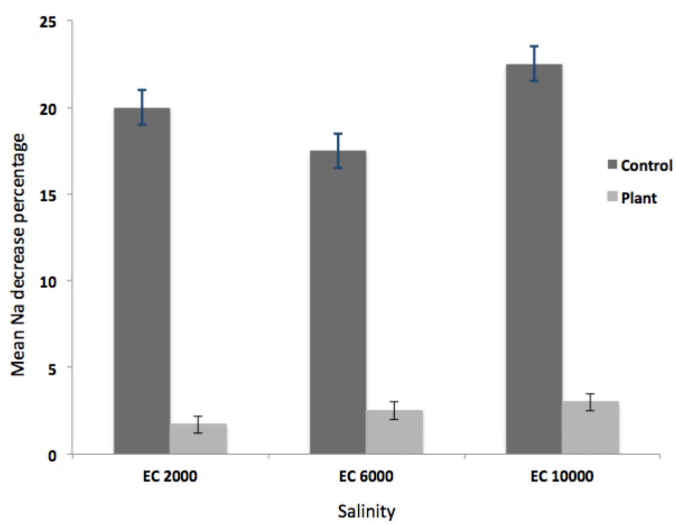


*Figure 7: Salt removal (shown as sodium decrease) by plants at three different salinities. Error bars: 95% Cl.*

## 4. Conclusions

As the use of constructed wetlands to treat wastewater is not well established in Iran yet, the impressive results achieved so far have prompted great expectations about the technology and what it can achieve. The wetlands can be used in a various set-ups with different pre-treatment options for removal of debris and grit. Diverse plantations can be used for harvesting useful vegetation while different media beds can be employed for removal of phosphorus, heavy metals, or other polluting material that needs to be removed, by adsorption or sedimentation.

The primary purpose of constructed wetland treatment systems is to treat various kinds of wastewater (municipal, industrial, and agricultural). If designed and operated properly it could provide animal feed, useful herbs and shrubs, and plants that could be used for secondary purposes, hence helping the economy of villagers and rural area population. However other objectives may also be followed. This study showed the efficiency of wetland in removal of organics as well as nutrients from wastewater. It is concluded that plant selection could play an important part in system efficiency. Plant selection is a vital factor if this system is to be presented to rural communities where basic utilities are not available and technical specifications must be minimal.

Furthermore the results indicated that wetlands have the potential to assist in production of livestock feed while treating wastewater and protecting the environment. It was concluded that specific plants could resist saline conditions and up-take salt from wastewater, although there is still a long way to go to desalinate water by phytoremediation.

Wetlands are a natural sanctuary for wildlife, especially migrant birds. They could also have site-seeing attractions for tourists and the local population, as Ghasre-Shirin wetland proves. When compared to mechanical wastewater treatment works, they provide a natural site where public and environmentalists can explore and use as a recreation spot.

This study shows the huge potential of constructed wetlands in Iran to be implemented in rural areas, where mechanical sewage works are expensive to run and demands complicated and expensive machinery and construction, high manpower and energy.

## ACKNOWLEDGEMENTS

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# Estimation of Evaporation from Chitgar Lake

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## *Abstract*

Evaporation is a threat to wetlands. It also increases the salinity which is harmful for the wetland's ecosystem. The first step to tackle this problem is estimating the evaporation rate. In this paper, different methods for estimating the evaporation rate are evaluated. An optimum estimation method applicable to Iran's climate is recommended with a fair tradeoff between cost and accuracy. The Penman, Montieth and Unsworth (PMU) model is found to provide consistent results by knowing the wind velocity, air temperature, relative humidity, and radiation. The first three parameters can be obtained from local meteorological stations, and the latter is a function of the wetland's location and time of the year. Other parameters (e.g. cloudy sky) are shown to have negligible effect on the evaporation rate. Using the PMU, it was found that the daily average evaporation from the Persian Gulf Martyrs Lake (located at northwest of Tehran) on August 2015 was more than 8 mm/day. This means that in each day on August 2015 the lake loses more than 11,300 $m^3$ of its water. By knowing the evaporation rate proper evaporation mitigation technology may be used.

***Keywords: Evaporation, Dam Reservoirs, Persian Gulf Martyrs Lake, Combination Method, Sun Radiation***

## 1. INTRODUCTION

Due to the extensive exposure of constructed wetlands to sun radiation and wind, a huge volume of the water evaporates [1]. This increases the salinity of wetlands and can be harmful for the wetland's ecosystem. The first step to tackle this problem is estimating the evaporation rate. In this paper, the factors affecting the evaporation rate are discussed. Different methods for estimating the evaporation rate are evaluated. An optimum estimation method applicable to Iran's climate is recommended with a fair tradeoff between cost and accuracy. The optimum model is used to estimate the evaporation from the Chitgar (also known as Persian Gulf Martyrs) Lake located at northwest of Tehran. By knowing the order of magnitude for evaporation of wetlands, the optimum evaporation mitigation techniques can be suggested.

## 2. FACTORS AFFECTING THE EVAPORATION RATE

Surface evaporation is governed by diffusion (random walk) of the water molecules at any temperature above absolute zero [2], due to the excess of water molecules at the water surface. Factors affecting the evaporation rate are categorized into two groups [3]: (i) environmental; and (ii) intrinsic factors.

### *2.1. Environmental Factors*

#### *2.1.1 Wind*

Wind dries the air atop the water surface and increases the evaporation rate. This effect leads to methods that describe the evaporation on the basis of mass transport (see Section 3.3.3).

#### *2.1.2 Solar radiation*

Solar radiation is one of the most important factors affecting the evaporation rate and is the radiation energy absorbed by the water surface [4]:

$$R_n = R_s - R_L \tag{1}$$

where $R_n$ (W/m$^2$) is the total radiation flux absorbed by water, $R_s$ (W/m$^2$) is the net radiation energy flux absorbed by water from the sun and $R_L$ (W/m$^2$) is the net radiation energy flux lost from the water. Note that $R_s$ is not equal to the radiation flux emitted from the sun ($\overline{R_\iota}$), and only a portion of radiation from the sun is absorbed by water [5] and the rest reflects. On top of that, clouds may prevent the sun light to reach the earth [4]:

$$R_s = (a_s + b_s\left(\frac{T_{day/clear}}{T_{day}}\right))\overline{R_\iota}(1-\alpha) \tag{2}$$

where $a_s = 0.25$ and $b_s = 0.50$ are the empirical factors, $\overline{R_\iota}$ (W/m$^2$) is the mean of radiation flux emitted from the sun in a day (see Fig. 1), $\frac{T_{day/clear}}{T_{day}}$ is a correction factor for cloudy sky [6] where $T_{day/clear}$ is the actual duration of clear sky during the daylight (s), and $T_{day}$ (s) is the duration of daylight from the sunrise to the sunset [6], and $\alpha$ is the Albedo coefficient [5] which indicates the amount of radiation reflected by the water surface.

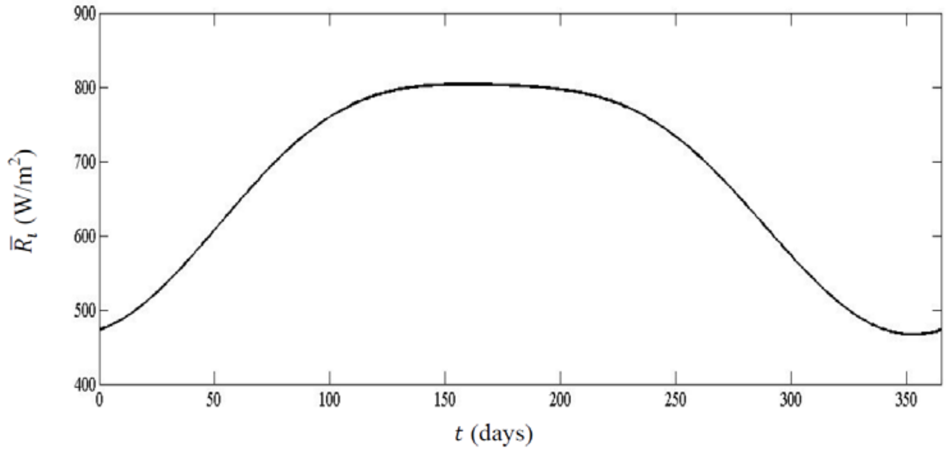


*Figure 1: The value of $\overline{\boldsymbol{R}_\iota}$ in Eq. 3 throughout the year for the location of the Chitgar Lake ( i.e. $\boldsymbol{\theta} = \mathbf{35.1^o}$) is estimated using the relation in [7].*

Assuming water is pure and its surface is planar and under direct radiation, $\alpha$ can be approximated as $\alpha_f$, Fresnel Albedo coefficient [7]. In Fig. 2, $\alpha_f$ is shown versus the elevation angle of the sun ($e$). For e $> 10°$**,** $\alpha_f$ is a proper approximation for $\alpha$ [7]. As shown in Fig. 3, for a major portion of the daytime for the Chitgar Lake, $e$ is larger than 10°. Using the Fresnel approximation for the Chitgar Lake, the average of $\alpha$ throughout a year is approximately equal to 0.06 (Food and Agriculture Organization of the United Nations, FAO, suggests 0.05).

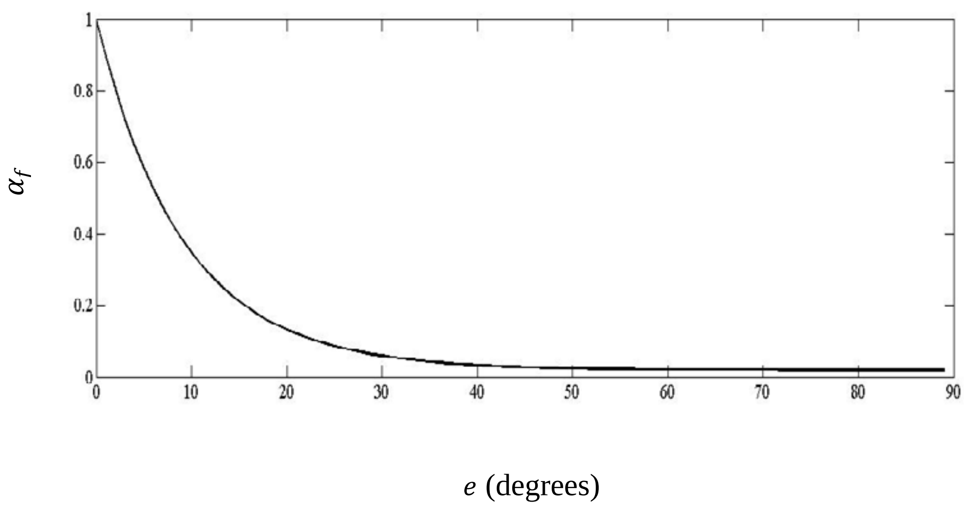


*Figure 2: Fresnel Albedo ($\boldsymbol{\alpha_f}$) versus elevation angle ($\boldsymbol{e}$) is shown. For $\boldsymbol{e} > \mathbf{10}°$, $\boldsymbol{\alpha_f}$ is almost equal to $\boldsymbol{\alpha}$.*

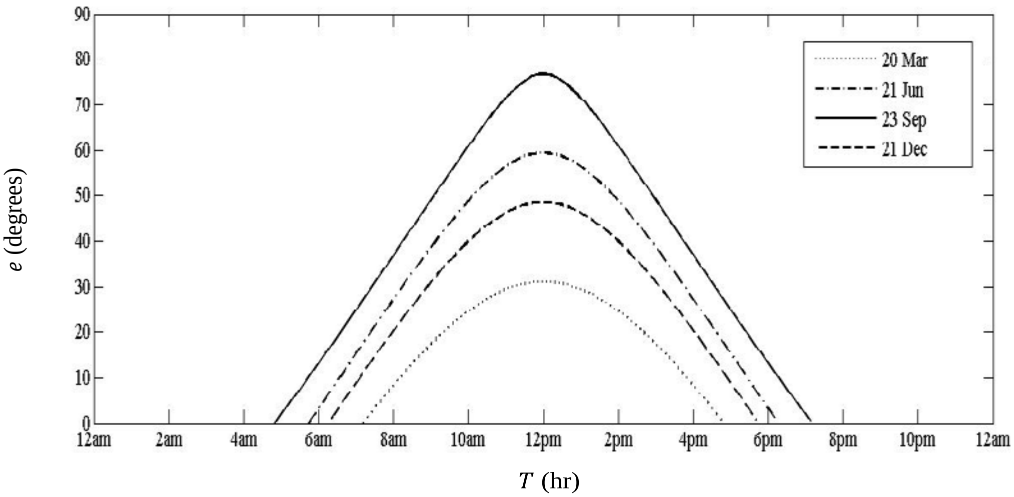


*Figure 3: Elevation angle (**e**) versus hour at four different days for the Chitgar Lake.*

For estimation of $R_L$ the following equation is suggested by FAO [6]:

$$R_L = \sigma\left(\frac{{T_{max}}^4 + {T_{min}}^4}{2}\right)(0.34 - 0.14\sqrt{P_v \times 10^{-3}})(1.35\frac{a_s + b_s\left(\frac{T_{day/clear}}{T_{day}}\right)}{a_s + b_s} - 0.35) \qquad (3)$$

where $\sigma$ (W/m²K⁴) is Stefan-Boltzmann constant ($5.670 \times 10^{-8}$W/m$^2$ K$^4$), $T_{max}$ (K) and $T_{min}$ (K) are maximum and minimum temperatures in a day, respectively and $P_v$ (Pa) is water vapor pressure in moist air which is calculated by multiplying the $RH$ (relative humidity) and $P_v{}^*$ (saturated water vapor pressure at the water surface temperature).

### *2.1.3. Stratification*

This phenomenon mostly occurs in deep waters [4]. The key element in this phenomenon is the changes of water density with temperature (maximum density of water is at 4°C). This phenomenon causes the temperature of water to be different from the air temperature [4]. De-stratification of stratified reservoirs may reduce the evaporation rate and boost the quality of water, e.g. [4].

## *2.2. Intrinsic Factors*

### *2.2.1. Latent heat*

This factor shows the desire of fluid to evaporation. A fluid with a large latent heat of evaporation is more resilient to evaporation as it needs more heat to evaporate.

### *2.2.2. Impurities in the water*

This factor does not have much effect on the evaporation rate throughout the year [3]. The reason is that impurities initially reduce the vapor pressure and the rate of evaporation. By increasing the amount of salt in water by 1%, evaporation rate decreases by 1% [4]. However, in the longer run, lower evaporation rate results in temperature rise. As the temperature increases, evaporation rate becomes higher. In general, it is suggested to neglect the effect of impurities on the evaporation rate [3].

## 3. EVAPORATION RATE ESTIMATION METHODS

Evaporation estimation methods can be grouped into: (i) experimental, (ii) theoretical-experimental and (iiii) theoretical methods.

### 3.1. *Experimental Methods*

#### 3.1.1. *Evaporation pan*

Popular pans are: Colorado Sunken Pan and Class A Pan of the U.S. Weather Bureau [8]. The evaporation from pans can be related to the surface evaporation through coefficients which vary between 0.66 to 1.5 [8]. These coefficients are not very accurate and many factors may impact the accuracy of the experiment, i.e. rain, and drinking water by birds and animals [2]. It should be noted that the coefficient values depend on the environmental condition and should be measured on site.

#### 3.1.2. *Adaptive network-based fuzzy inference system (ANFIS)*

In this method experimental data are used to train a fuzzy-neural system and the best prediction function is found, e.g. [9]. Parameters (e.g. solar radiation, temperature, and moisture) over a specific time interval are given to a computer and the computer estimates the evaporation with respect to the input data [10].

### 3.2. *Experimental-Theoretical Methods*

#### 3.2.1. *Bowen ratio energy balance method*

This method is used along with the Energy-Balance method (Section 3.3.2). The ratio of the gradient of the temperature with respect to the height over the gradient of the pressure with respect to the height should be measured to estimate the ratio of evaporation rate to the sensible heat flux lost from the water [2]. Although this method is very accurate, it requires special measuring equipment to accurately measure the temperature and vapor pressure change [2].

#### 3.2.2. *Eddy correlation method*

In this method using fast and accurate sensors, parameters like air velocity, temperature and moisture should be measured accurately. This method is very accurate, but it is hard to use and relatively expensive [2].

#### 3.2.3. *Area-based methods*

These methods require satellite systems and precise measurements [11]. The Surface Energy Balance Algorithm for Land (SEBAL) method is one of these methods [12]. Using the images taken from surface vegetation and according to the mining algorithms, rate of evaporation and transpiration from vegetation is calculated [2,11].

### 3.3. *Theoretical Models*

#### 3.3.1. *Water budget method*

This method is based on the conservation of mass [4]:

$$Q_{in} + P + \delta D = Q_{out} + S + E_{wb} \tag{4}$$

where $Q_{in}$ (mm/day) and $Q_{out}$ (mm/day) are the inlet and out rates, $P$ (mm/day) is the precipitation rate, $\delta D$ (mm/day) is the change in water surface, $S$ (mm/day) is the rate of water seepage and $E_{wb}$ (mm/day) is the corresponding rate of evaporation. As we cannot measure $S$ easily, usually this relation is used to estimate the seepage.

### 3.3.2. *Energy balance method*

This method is based on the conservation of energy [4]:

$$E = R_n - H - G + F_{in} - F_{out} + F_p \tag{5}$$

where $E$ (W/m²) is the total evaporation rate, $R_n$ is defined in Eq. 2, $H$ (W/m²) is the sensible heat transfer which includes the effect of wind [13], $G$(W/m²) is the sum of fluxes absorbed by the ground ($G_B$) and stored in the water ($G_S$) and $F_{in}$, $F_{out}$ and $F_p$ (W/m²) are the energy fluxes of inlet, outlet and precipitation, respectively. Assuming the inlet and outlet flow rates balance, Eq. 5 simplifies to [4]:

$$E = R_n - H - G \tag{6}$$

Some have also neglected the values of $H$ and $G$ [5]. To use the Eq. 6, we should calculate $R_n$, $H$ and $G$. In Fig. 4 these major parameters are shown.

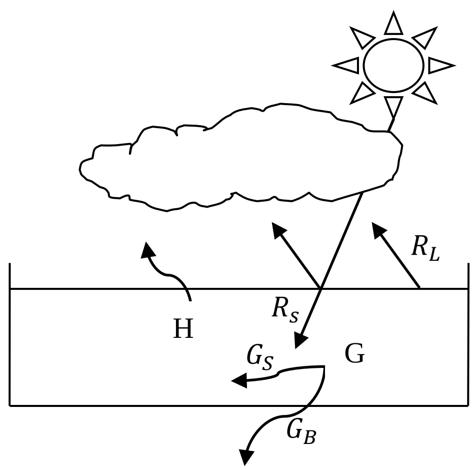


*Figure 4: Energy transfers in a water reservoir are shown.*

The value of $G$ can be estimated as a portion of $R_n$, i.e. $G \cong 0.1\ R_n$ for daytime and $G \cong 0.5\ R_n$ for nighttime [6]. However, most of these estimations are for shallow water [6]. For large and deep water reservoirs $G$ can be neglected [14]

### 3.3.3. *Vapor transmission method*

This method neglects the radiation and only considers the effect of wind on evaporation rate. The wind speed can accelerate the evaporation as follows:

$$E_a = f(u)\ (1 - RH)P_v^* \tag{7}$$

where $E_a$ (W/m²) is the evaporation flux due to the momentum flux and $f(u)$ (W/Pa.m²) is the wind function that explains how wind affects the evaporation rate. Theoretical and experimental [4], [15] and [16] values have been suggested for $f(u)$, e.g [4], [15].

### 3.3.4. *Combinational method*

This method combines the energy-balance and vapor transmission methods [17]:

$$E = \left(\frac{\Delta}{\Delta + \gamma^*}\right)(R_n - G) + \left(\frac{\gamma^*}{\Delta + \gamma^*}\right)E_a \tag{8}$$

where $\Delta$ (Pa/K) is the slope of water vapor pressure against temperature (which is inversely correlated to the air temperature) and $\gamma^*$ (Pa/K) is modified Psychrometric constant by Montieth [4], and is a function of air pressure.

To solve the Eq. 8, the value of $E_a$ is needed. The value of $E_a$ depends on the wind velocity (see Eq. 7). The following equation is an estimation to Eq. 7 [8]:

$$E_a = Ku_*\rho_a({q_a}^* - q_a)\left[\ ln\left(\frac{z - d_{0v}}{z_{0v}}\right) - \Psi_v\left(\frac{z - d_{0v}}{L}\right)\right]^{-1} \tag{9}$$

where $K$ =0.41 is the von Kármán's constant, $u_*$ (m/s) is the friction velocity, $\rho_a$ (kg/m$^3$) is the air density, ${q_a}^*$ and $q_a$ are the saturated specific humidity (note that the specific humidity is different from relative humidity, as it is defined as the ratio of water vapor density to the mixed air density) and the specific humidity [8], $z$ (m) is the measuring height, $d_{0v}$ (m) is the displacement height for water vapor, $z_{0v}$ (m) is the vapor roughness height, $\Psi_v$ is the integration of the vapor transmission similarity function [18], and $L$ is the Obukhov stability length described as [8]:

$$L = \frac{-{u_*}^3}{K \cdot g[\frac{H}{\rho_a c_a T_a} + \frac{0.61E}{\rho_a}]} \tag{10}$$

where $g$ (m/s$^2$) is the gravitational acceleration, $c_a$ (J/kg K) is the specific heat of air, and $T_a$ is the air temperature in Kelvin. Equation 11 relates the average horizontal wind speed $\overline{U}_{wind/z}$ (m/s) to $u_*$ as [18]:

$$\overline{U}_{wind/z} = \frac{u_*}{K}\left[ln\left(\frac{z - d_{0m}}{z_0}\right) - \Psi_m\left(\frac{z - d_{0m}}{L}\right)\right] \tag{11}$$

where $\overline{U}_{wind/z}$ (m/s) is the mean wind speed at the measurement height $z$ (m), $d_{0m}$ (m) is the momentum displacement length, $z_0$ (m) is the momentum roughness height and $\Psi_m$ is the integration of the momentum similarity function. Further investigation shows the dependence of $E$ to $d_{0m}$ and $d_{0v}$ is negligible [18]. As such, Katul and Parlange [18] assumed zero for $d_{0m}$ and $d_{0v}$. $\Psi_v$ and $\Psi_m$ are functions $\frac{z}{z_0}$ [18]. For roughness lengths we have [8]:

$$z_0 = \frac{{u_*}^2}{794.6} \tag{12}$$

$$z_{0v} = 7.4\ z_0 e^{\left(-2.25\left(\frac{z_0 \cdot u_*}{v}\right)^{\frac{1}{4}}\right)} \tag{13}$$

where $\nu$ (m$^2$/s) is the kinematic viscosity of water. Using Eqs. 6 and 8–13 evaporation rate (i.e. $E$) can be calculated. This method is known as Penman-Brutsaert (PB) [18]. In PB method, when you simplify equations, a system of equation with five equations and five unknowns (i.e. $E$, $H$, $u_*$, $L$ and $E_a$) is solved iteratively and within five to six iterations a solution with an accuracy of 0.1 W/m$^2$ is derived [18]. The PB method is suitable for daily estimations [15]. The advantage of this method is that, as explained there is no need to directly measure $H$ and $u_*$.

For simple calculation we can use Penman-Monteith-Unsworth (PMU) model. The PMU model is similar to PB except for that in PMU, the value of $u_*$ is needed (should be estimated using experimental methods), PMU neglect the $G$ in Eq. 8 and uses Eq. 14 instead of Eq. 9 [15]:

$$E_a = \frac{\rho_a\, c_a K^2\, \overline{U}_{wind/z}}{\gamma^* \ln(\frac{z}{z_0}) \ln(\frac{z}{z_{0v}})} (1 - RH) {P_v}^* \tag{14}$$

In [15], it is shown that the PB and PMU provide very close results. It is suggested that the PMU method is suitable for weekly and biweekly estimations. As it neglects the $G$, and for long periods of time (e.g. weekly test) due to the fluctuation of $G$, this assumption is proper [6]. To use the PMU model only a few simple meteorological data are needed, i.e. relative humidity, air pressure, average wind speed, air temperature, and energy fluxes. The energy fluxes can be approximated as radiation. For clear sky, radiation can be calculated as a function of the location, time of the year and time of the day.

## 4. Evaporation Rate of Chitgar Lake

Our goal is to estimate the evaporation rate from constructed wetlands without having to setup new instruments and use only meteorological data of nearby weather stations. It was found that both the PMU and PB methods are suitable for the mentioned purpose. PMU is easier to implement and provides more accurate estimates for weekly and bi-weekly estimations [18]. Both PB and PMU models require the value of sky clarity ($\frac{T_{day/clear}}{T_{day}}$). As calculating the sky clarity is not straightforward and requires accessing satellite images, a sensitivity check is performed to understand the error that we may encounter by assuming a clear sky. As shown in Fig. 5, by changing the clarity from 0 to 100%, evaporation rate change is less than 0.5 mm/day. Similar sensitivity analysis is performed for $z$, $z_0$, and $z_{0v}$; and it was found that the evaporation rate is not sensitive to these parameters. The evaporation rate is found to be sensitive to the wind velocity ($\overline{U}_{wind/z}$), air temperature ($T_a$), relative humidity ($RH$), and radiation ($R_n$). The first three parameters can be found from local meteorological stations and the latter is a function of location of the wetland and time of the year.

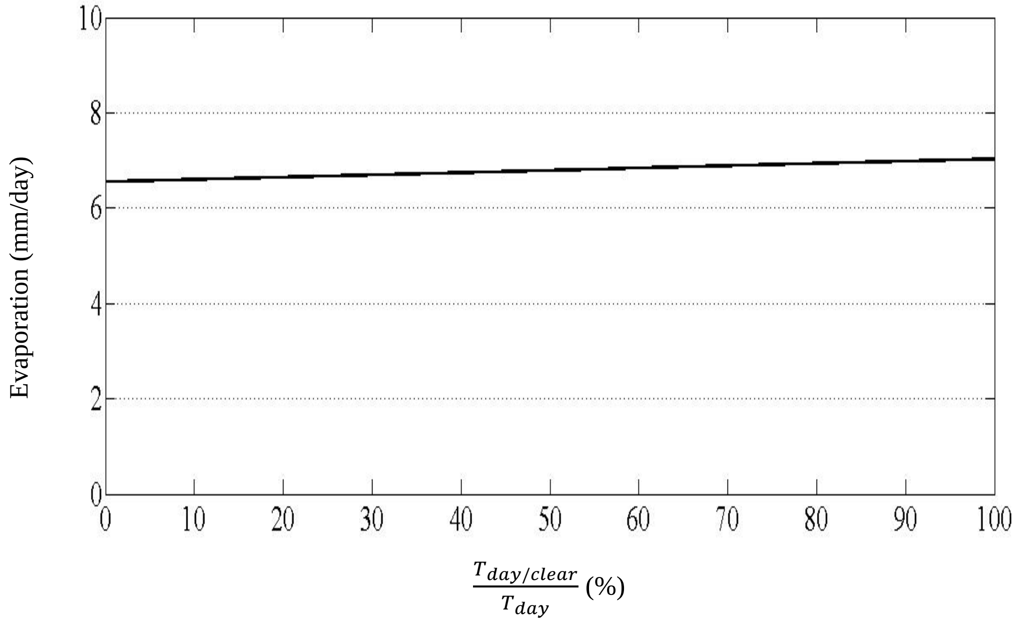


*Figure 5: Variation of evaporation rate (mm) with change of clarity ($\frac{T_{day/clear}}{T_{day}}$) at $\boldsymbol{z}$ = 10 m, $\boldsymbol{z_0}$ = $\boldsymbol{z_{0v}}$ = 0.001 m, $\boldsymbol{\bar{U}_{wind,z}}$ = 5 m/s, $\boldsymbol{RH}$ = 20%, and $\boldsymbol{T_a}$ = 20°C.*

The PMU model is applied to calculate the evaporation rate from the Chitgar Lake. This lake is considered as a constructed wetland located at northwest of Tehran. Before the construction it was a garbage and sewage point. Also, because of the region's soft soil, occurrence of sandstorms was very common. Now the lake is home to many aquatic and land creatures, attracts migrating birds, purifies the air, mitigates floods and controls surface waters. The evaporation rate from the Chitgar Lake for 14-day and 21-day durations on August 2015 are found using PMU model and results are shown in Table 1.

TABLE 1: EVAPORATION RATE RESULTS FOR CHITGAR LAKE, 1ST TO 21ST OF AUGUST 2015, CALCULATED USING PMU WITH 100% SKY CLARITY ARE SHOWN.

| PMU Method | Evaporation (mm/day) | Radiation effect | Wind effect |
|---|---|---|---|
| 1st to 14th of August 2015 | 8.94 | 80.1% | 19.9% |
| 1st to 21th of August 2015 | 8.77 | 81.6% | 18.4% |

The average daily evaporation in the mentioned period was more than 8.7 mm/day. Considering the area of the lake (130 ha), daily evaporation is in this period was more than 11300 m$^3$. The PMU evaporation model can be used to estimate the evaporation rate of different wetlands across the country. Having a proper estimation is needed to select the proper evaporation mitigation technique. In Fig. 6, the daily evaporation rate calculated using the PMU method is compared with the evaporation rate calculated using evaporation pan method (results are provided by Tehran Province Water & Wastewater). As shown in Fig. 6, the PMU is accurate enough for calculating the daily evaporation rate. The spikes in PMU results in Fig. 6 are due to error in recording the wind speed.

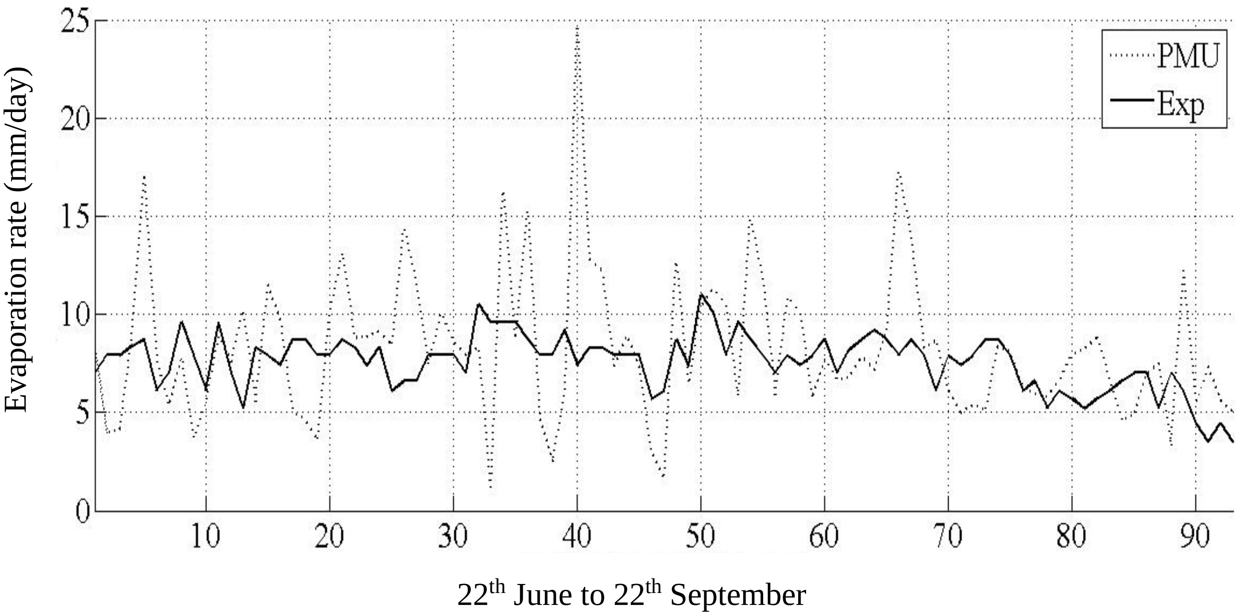


*Figure 6: Evaporation rate from 22th June to 22th September, 2015, solid line is for experimental data and dashed line is for PMU predictions.*

As shown in Fig. 7, the PMU results become more reliable for 14-day estimations as the harsh variation due to wind speed measurement fades out.

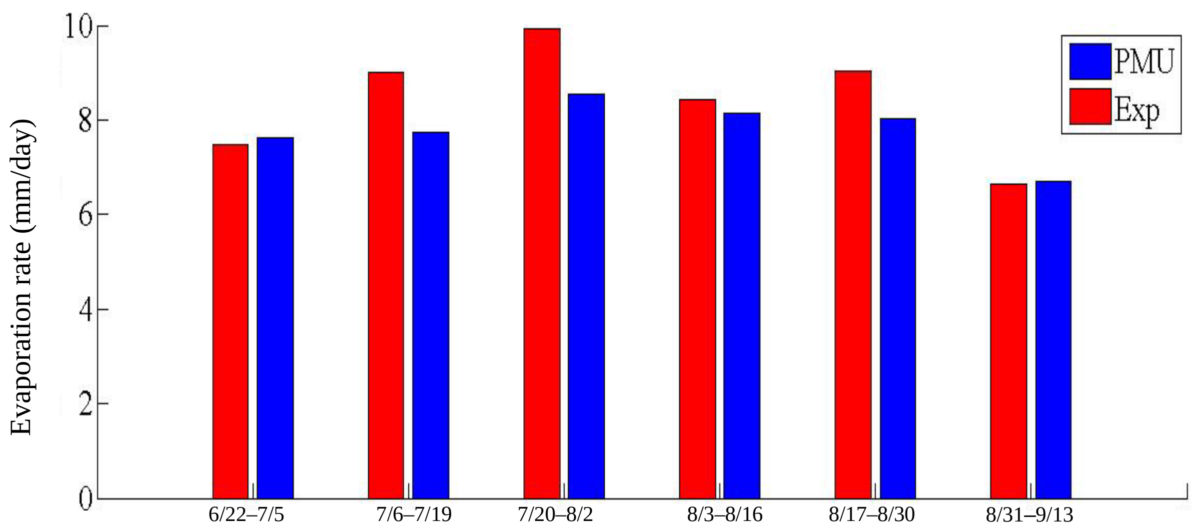


*Figure 7: Comparison between 14-day average evaporation rate predicted by PMU and experimental results are shown from June 22nd to September 13nd 2015.*

## 5. Conclusion

Evaporation is a threat to wetlands. Different methods of estimating the evaporation from water reservoirs are explained. The Eddy correlation and Bowen's ratio can potentially be very accurate. However, they require expensive equipment and installations. The combinational methods (PB and PMU) are relatively accurate and require only relative humidity, wind speed, air temperature, and energy fluxes. Energy flux can be approximated by the radiation. Radiation for clear sky can be easily calculated as a function of the wetland's location and time and day of the year. Cloudy sky only slightly changes the evaporation rate. Relative humidity, wind speed and air temperature values can be obtained from local weather stations. The PMU which is more accurate for a period of several days (e.g. weekly or biweekly) is used to calculate the evaporation rate from the Chitgar Lake. It was found that the daily average evaporation from the Chitgar Lake (located at northwest of Tehran) on August 2015 was more than 8.7 mm/day which is equivalent to more than 11,300 $m^3$. Estimating the evaporation rate enables one to use proper evaporation mitigation techniques.

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# Unnatural History: Biological Invasions into Coastal Ecosystems

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## *Abstract*

Biological invasions compromise the natural integrity of ecosystems, and can be viewed as both causes and consequences of ecological change. Estuaries are particularly vulnerable to invasion, accumulating species from the sea, land, and freshwater. The numerous estuarine systems of San Diego County, ranging from small coastal lagoons to large embayments, are no exception. There are now numerous marine, terrestrial, and freshwater invaders in these systems, which offer opportunities to broaden our understanding of biological invasions. At the same time, these invasions also challenge our ability to effectively manage the region's estuaries.

***Keywords: Biological Invasions, Exotic Species, Tamarisk, Pacific Oysters***

## 1. INTRODUCTION

Estuarine systems represent the one place on earth where the three major habitat types, - land, sea, and freshwater - all come together. Because of this, they are dynamic areas characterized by rich sets of abiotic and biotic interactions. However, management issues from these three different habitat types tend to converge here as well. One particularly problematic issue in estuaries is biological invasions, with estuaries accumulating invasive species from all sides. Herein we will consider the invasions within the numerous estuarine systems of San Diego County, California. This will focus on introduced, non-native species, but will also address invasions of native species due to changing environmental conditions.


*Figure 1: Estuarine systems of San Diego County. These include several relatively small embayments and lagoons, such as the Tijuana River Estuary and Los Peñasquitos Lagoon, as well as large bays and harbors, such as Mission Bay and San Diego Bay.*

## 2. INVASIONS BY UPLAND AND FRESHWATER SPECIES

Wetlands throughout the world tend to be invaded by some of the most problematic non-native weeds. One study indicated that although wetlands cover less than 6% of the land surface on earth, 24% of the most problematic exotic plant species are invaders of wetlands habitat [1]. Of the non-native plants in San Diego's tidal wetlands, there are few that are actually restricted to these marine habitats. One obligate wetland invader is the grey mangrove, *Avicennia marina*, which was intentionally introduced into Mission Bay wetlands in the late 1960s. Much more common are invaders from adjacent habitat types. One set of plants invading salt marshes are those more typically found in higher-elevation, non-tidal habitats. In general terms, the salt marsh - upland ecotone is known to be a site vulnerable to invasion [2], and is also a sensitive indicator of changing environmental conditions [3]. Another suite of plant invaders into marshes are those associated with fresh or brackish water conditions [4,5]. The incursion of both upland and freshwater plants into salt marshes is often limited by soil or water salinity [6,7].

### *2.1. Tamarisk*

One of the more problematic of the region's salt marsh-encroaching non-natives is tamarisk, or salt cedar, (*Tamarix chinensis* and *Tamarix ramosissima* x *T. chinensis*; [8]). This shrub or small tree is an ecosystem engineer native to Eurasia and African, and can dramatically alter invaded ecosystems [9,10]. It has not typically been considered an invader of tidal areas, but in salt marshes such as the Tijuana River Estuary and San Dieguito Lagoon (Fig. 1) it has become an abundant element of the plant community. Here it can completely alter the structure of invaded habitats, converting the low-lying salt marsh plain, dominated by pickleweed (*Salicornia pacifica*), into dense tamarisk thickets [9,10]. This thick, tall vegetation affects soil characteristics and light regimes, decreases understory plant cover, alters food webs, and attracts birds which may compete with or prey upon sensitive marsh-dependent birds (such as the Ridgway's rail and Belding's savannah sparrow). It also alters associated invertebrate assemblages, including benthic macrofauna [8,11], as well as arthropods associated with vegetative canopies (Fig. 2). Sweep-net sampling of native pickleweed and invasive tamarisk in the intertidal revealed dramatically higher total densities of arthropods (primarily insects and arachnids), including the also-invasive tamarisk leafhopper (*Opsius stactogalus)*, within tamarisk. An abundant treehopper (Membracidae) was found in lower abundances within tamarisk compared to pickleweed.

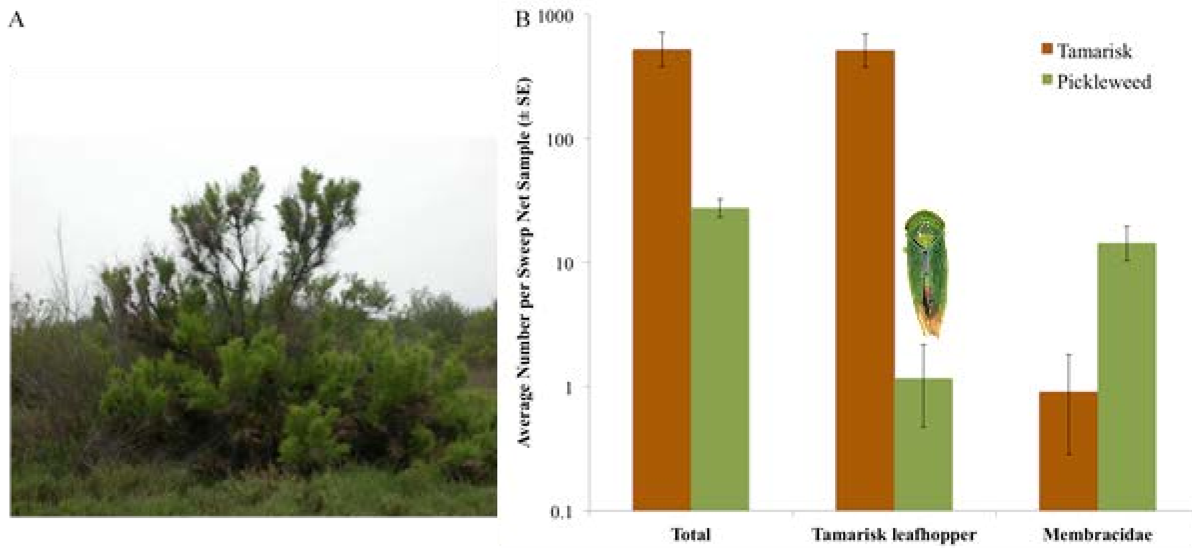


*Figure 2: A) Tamarisk (Tamarix spp.) growing in intertidal pickleweed (Salicornia pacifica) in the Tijuana River Estuary. B) Number of arthropods found in timed sweep net samples of tamarisk vs. pickleweed, including total arthropods, numbers of the non-native tamarisk leafhopper,* Opsius stactogalus*, and numbers of treehoppers (Membracidae). Tamarisk photo by J. Crooks, Opsius photo by Jason Eckberg, Creative Commons.*

Because of the problems associated with tamarisk in the Tijuana Estuary, there has been an effort to remove this plant over the last 15 years. The tamarisk invasion, and its control, provide an opportunity to evaluate the context for invasion species management. Typically, the goal of such efforts should not stop at invasive species removal *per se*, but instead focus on recovering native species. In many instances, it will be necessary to replant with native vegetation after removal of invaders. In some cases, though, removal of a target invader may be sufficient to achieve the goal of native species recovery. This is clearly seen with tamarisk removal in the Tijuana Estuary. Tamarisk had heavily invaded a site that included both intertidal salt marsh and adjacent upland transition zone. Monitoring of the site after a tamarisk clearing effort showed that in the upland, the only plants that returned immediately after the control effort were non-natives, primarily annual weeds (Fig. 3). In the lower-elevation, higher-salinity intertidal site, just a few meters away, the only plants that returned were native marsh species, such as pickleweed. This has important implications for management, which is typically resource-limited. In this case, re-vegetation efforts were focused on the upland site, while the intertidal site was left to recover naturally.

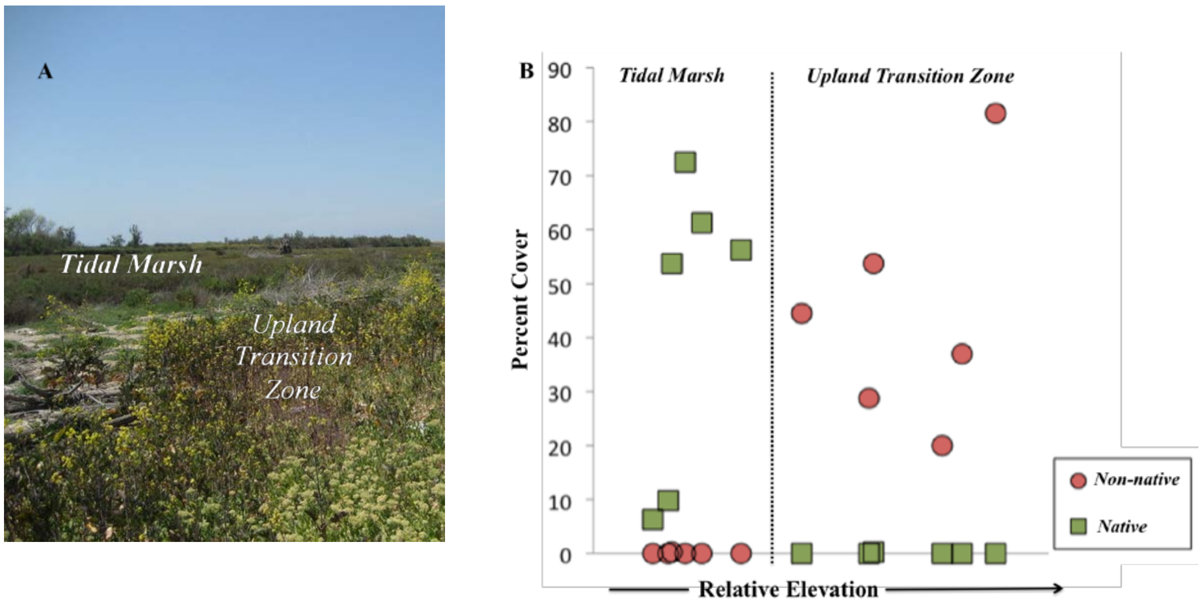


*Figure 3: A) A site in the Tijuana Estuary after tamarisk (Tamarix spp.) removal, showing the upland transition zone heavily invaded by non-native annual plants, and the tidal marsh with recovery of native pickleweed (Salicornia pacifica). B) Post-tamarisk removal monitoring results, showing differences in percent cover of natives and non-natives along the elevation gradient from intertidal to upland. Photo by J. Crooks.*

### *2.2. Invasions Associated with "Urban Drool"*

In addition to invasion of marshes via the upland / marsh ecotone, lowering salinities in coastal salt marshes also can facilitate invasions and changes in plant communities. One major issue in the semi-arid, Mediterranean-climate systems of Southern California is the addition of anthropogenic freshwater. San Diego imports over 80% of its water, primarily from the Sacramento - San Joaquin Rivers and Colorado River. When this water is used outdoors, such as for irrigation, it can dramatically alter both the amount and timing of water entering coastal wetlands. In Los Peñasquitos Creek, one of the tributaries of Los Peñasquitos Lagoon (Fig. 1), a United States Geological Survey stream gage shows dramatic increases in the amounts of freshwater flowing in the creek (Fig. 4). This is particularly pronounced during the dry-season (June 1 - September 30; [12]), when creek flow should essentially be zero. This "urban drool" is effectively perennializing the normally ephemeral streams of the region.

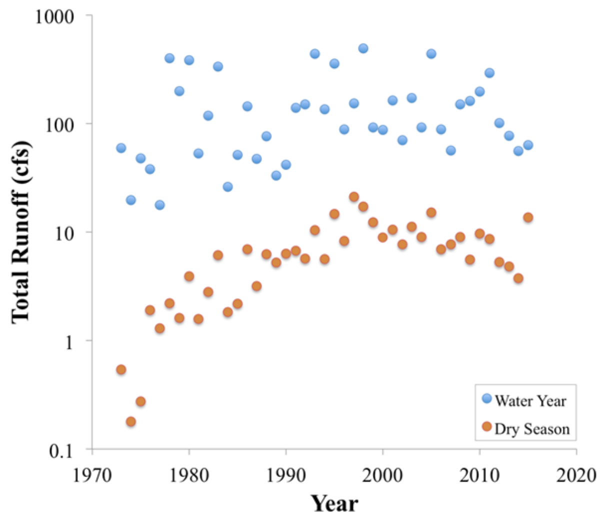


*Figure 4: Runoff (cubic feet per second) at the United States Geological Survey's Los Peñasquitos Gage, including the water year (October 1 - September 30) and the dry season (June 1 - September 30). Adapted from White and Greer [12].*

Numerous management issues arise from this input of freshwater into naturally more saline systems. These include allowing non-native freshwater-associated animals, such as mosquitofish (*Gambusia affinis*), red swamp crayfish (*Procambarus clarkii*), and disease-carrying mosqituoes (*Aedes aegytpi* and *A. albopictus*) to push further downstream into formerly more saline habitats. Another major impact is vegetation type conversion. Using remotely-sensed imagery, Greer and Stow [5] have documented large-scale type conversion of Los Peñasquitos Lagoon habitats since 1927, due to this anthropogenic freshwater input. Haline community-types, such as salt panne and salt marsh, have decreased in recent decades, while fresh-brackish marsh and riparian habitat types have increased. Changes in plant species composition in field transects that have been monitored annually since 1991 are consistent with this pattern (Fig. 5). The former dominant at the site, the characteristic salt marsh plant, pickleweed (*Salicornia pacifica*), has been replaced by cattails (*Typha* spp.), which is characteristic of freshwater marshes, and jaumea (*Jaumea carnosa*). Although these two species are both native, freshwater-impacted areas of Los Peñasquitos Lagoon also have a much greater representation of non-native species known to increase with freshwater input in salt marshes [4,13], including rabbitsfoot (*Polypogon monspeliensis*) and brass buttons (*Cotula coronopifolia*)

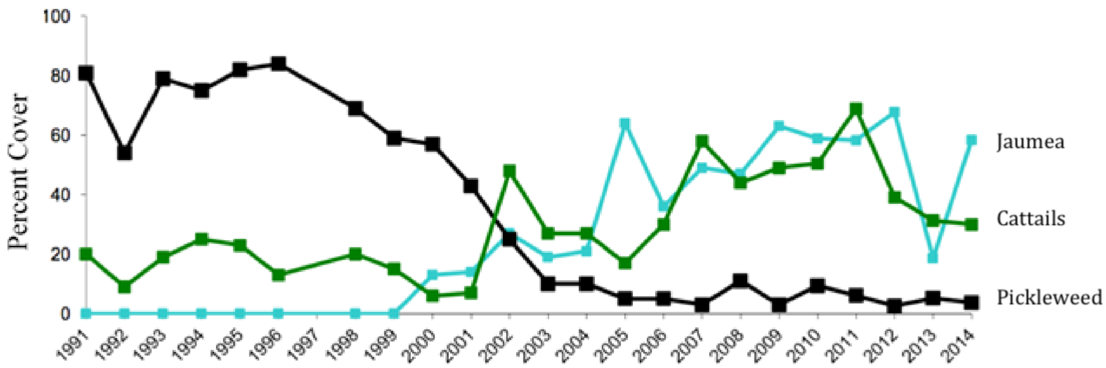


*Figure 5: Long-term trends in vegetative cover of pickleweed (Salicornia pacifica), cattails (Typha sp.) and jaumea (Jaumea carnosa) at a transect increasingly affected by freshwater in Los Peñasquitos Lagoon. Source: Pacific Estuarine Research Lab (San Diego State University), Los Peñasquitos Lagoon Foundation, and the Tijuana River National Estuarine Research Reserve.*

Habitat-type conversion from anthropogenic increases in freshwater flow is a complex issue, dealing with urbanization, land use, and, very importantly for Southern California, water. These watershed changes have also increased sediment loading to Los Peñasquitos Lagoon, and the California Water Quality Control Board has recently issued a Total Maximum Daily Load (TMDL) Waste Load Allocation for sediment. This explicitly recognizes that "impacts due to sedimentation are not clearly differentiated from the impacts associated with other stressors on the Lagoon such as freshwater inputs and physical barriers within the Lagoon." Planning for control of freshwater and sediment is currently underway, and implementation of the TMDL will occur over the next twenty years.

## 3. Invasions by Marine Species

The coastal waters of San Diego County now have over 130 recognized non-native marine species. As is seen in ecosystems across the globe, the rate of invasion in San Diego appears to be steadily increasing over time [14], with over 50 new species reported since 2000 (Fig. 6). This is due in part to an increasing ability to find and identify new species (e.g., using molecular tools), but also undoubtedly reflects an increase in the anthropogenic transport of species. Most of San Diego's non-natives are found in estuarine systems, rather than the open coast, likely arising from transport vectors that operate between estuaries (e.g. ship traffic) as well as disturbance that facilitates invasions within estuaries [15,16,17]. Fouling organisms, such as tunicates, bryozoans, and polychaetes, are well-represented in local waters, particularly associated with marinas [18]. Other invaders include the newly-discovered Japanese mud snail, *Batillaria attrimentaria* (Lorda, pers obs.) and the Manila clam, *Ruditapes phillinarum* [19] . Some invasive ecosystem engineers, which can cause dramatic, cascading effects on resident biota through their alteration of the physical nature of habitats [20], include the mat-forming Asian mussel, *Musculista* (=*Arcuatula*) *senhousia* [21, 22, 23] and the salt marsh burrowing isopod *Sphaeroma quoianum* [10, 24, 25].

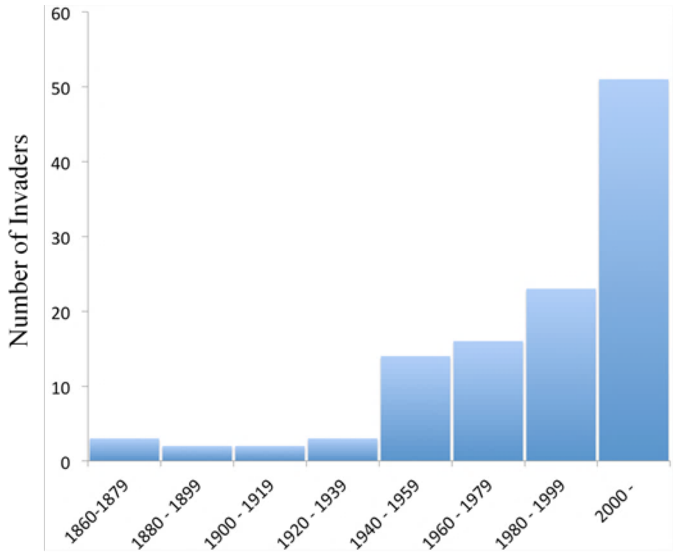


*Figure 6: Dates of first record for non-native marine species in San Diego County.*

### *3.1. El Niño*

The warm waters associated with the recent El Niño caused remarkably quick changes in the local biota, including appearance of tropical species. Many of these represent natural invasions via temporary expansions of the northern limits of species native to the North American west coast. Some examples of tropical species appearing during the El Niño include a yellow-bellied sea snake (*Pelamis platura*) found on the beach north of the Tijuana Estuary, a bullseye puffer (*Sphoeroides annulatus*) found in the Tijuana Estuary itself (Deza pers. comm.), and a longnose puffer (*S. lobatus*) found in Mission Bay (Tuskes pers. comm.). There was also a bloom of the non-native Australian spotted jellyfish, *Phyllorhiza punctata*, in both San Diego and Mission Bays. This tropical species was first reported in the 1980's [26, 27], and the recent bloom, which became a local news story, likely represents the temporary ecological release of invader when conditions become more favorable. In general, biotic responses during this El Niño indicate how quickly changes can occur, both through expanding ranges as well as altered dynamics of already-present species. Such events offer intriguing opportunities to examine and anticipate potential effects of climate change [28].

### *3.2. Lag Times and the Invasion of Pacific Oysters*

Biological invaders are notorious for causing "ecological surprises" that challenge both our understanding and management of invaders [29,30]. While some invasions can occur very quickly, some biological invaders are notorious for having long lag times before sudden changes in invasion dynamics. An example of a long lag in invasion is provided by the invasion of the Pacific (or Japanese) oyster, *Crassostrea gigas*, in Southern California [31]. In the early 20th century, there were repeated efforts to establish this large, commercially-desirable species throughout the west coast of North America. In the Pacific Northwest, the oyster has established and become an important fishery resource. In California, however, despite early introduction attempts and continuing grow-out of Pacific oysters, the species was deemed not able to survive in California waters. In the early 21st century, however, reports of Pacific oysters began to come from several systems in southern California. Today, the Pacific oyster is becoming a conspicuous element of the biota living in the estuarine systems of San Diego County (Fig. 7) [31].


*Figure 7: Non-native Pacific oysters (Crassostrea gigas) in San Diego, including (A) growth on roots of marsh plants in Los Peñasquitos Lagoon and (B) cover on rip-rap in Tuna Harbor, San Diego Bay. Photos by J. Crooks.*

### *3.3. Management of Non-Native Marine Species*

Typically, it is very difficult to remove an invader in a marine setting once it has established itself, although one of the few success stories comes from San Diego's coastal lagoons - the eradication of the "killer alga" *Caulerpa taxifolia* [32]. Therefore, management of invasion vectors, such as ballast water and ship fouling, remain the key management interventions for marine invasions [15]. Another management approach relies on the observation that invaders - which are often "weedy" species - tend to outperform natives in disturbed, polluted areas. This suggests that improving environmental conditions might, among other things, help limit invader success [17].

While the process of unchecked invasions into ecosystems is undesirable, it is possible that individual invasive species might have benefits deemed desirable. This is well illustrated with the Pacific oyster, *Crassostrea gigas* [31]. This large shellfish is a highly sought-after, edible species. In fact, much of the concern regarding potential effects of ocean acidification on shellfisheries in western North America comes from impacts to this non-native species. In Southern California, the oyster might present a similar resource, but food safety concerns related to pathogens (e.g. Vibrio bacteria) and uptake of contaminants in the urbanized and warmer conditions of Southern California need to be addressed [31]. Oysters also represent quintessential ecosystem engineers, creating dense biogenic beds through shell production. Oyster beds are valued throughout the world, and there are proposals to utilize already-introduced Pacific oysters in Northern Europe to create "living shorelines" that can help filter water, prevent erosion, and, importantly, dynamically respond to changes in sea level. Similar efforts to create living shorelines are underway in southern California, focusing on restoration of the smaller, native oyster, *Ostrea lurida*. The potential impact, negative or positive, of the invasive Pacific oyster on these efforts is being considered, with attention being paid to the role of invaders in causing unintended consequences.

## 4. CONCLUSION

Invasions are changing the face of the globe - homogenizing the Earth's biota and compromising diversity at a global level. San Diego Bay is looking more and more like Tokyo Bay, and Tokyo Bay like Sydney Harbor. In light of the massive changes that have occurred, and will continue to occur, there is a growing chorus suggesting that we be less concerned about where a species is from, and be more concerned about what it does [33]. Lessons from invasion biology indicate that origin does matter, however [34]. Invaders erode the unique sets of species and interactions that characterize different systems across the globe, are prone to ecological surprises due to lack of co-evolved relationships, and can fundamentally transform invaded ecosystems. But it is counterproductive to argue that each and every invader is "bad" [35], especially when faced with the implications of climate change. A robust conversation is needed, informed by our understanding of the changing nature of ecosystems, how we can protect them, and how ecosystems can in turn can benefit human well-being.

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# Participatory Management of Harra International Wetland towards Mangrove Ecosystem Restoration and Bio-Cultural Diversity Conservation

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## *Abstract*

A number of protected areas including international wetlands, biosphere reserves, national parks and wildlife refuges24 are located in the north part of the Persian Gulf and Oman Sea, along three Maritime Provinces in the south of Iran. According to national law, commercial use of these ecosystems is restricted to fishing, tourist boat trips and limited mangrove cutting for animal feed. However lack of comprehensive management, with the participation of stakeholder groups, leads to increasing degradation. The wetland ecosystems form major habitats for migratory birds and are the appropriate and suitable seabed conditions for the ovulation of fish in the Persian Gulf. The biodiversity significance of these habitats in addition to some strong traditional community governance structures brings together the appropriate condition for practicing and applying a participatory comprehensive management plan for each of the habitats, ecosystems and protected areas. This project intends to identify all the stakeholder and beneficiary groups aiming to transfer of governance responsibility to key stakeholders, notably the local and indigenous people, under the supervision of official agencies. The participatory plan will be prepared using participatory action research PAR and brainstorming techniques, focusing on the conservation and restoration of the bio-cultural diversity, wetland ecosystem and mangrove forests towards the empowerment of local communities and indigenous peoples and achieving sustainable livelihoods. The desired compromise between all stakeholder groups is to develop a co-management model that will be suitable for extension and application to many other marine and coastal protected areas in the country.

***Keywords: Participatory Management, Wetlands, Marine and Coastal Protected Areas, Mangroves, Sustainable Livelihood, Conservation Plans, Stakeholders***

## 1. INTRODUCTION

The increasing well-being of many countries in the Near East – especially of those overlooking the Persian Gulf and the Straits of Hormuz – is alleviating the pressure on mangrove ecosystems. On the other hand, the negative effect of this rapid economic growth is represented by the increased solid, industrial and oil pollution, which may threaten local flora and fauna, potentially leading to the death of mangrove trees (e.g. *Avicennia marina*) [1].

Iranian mangrove forests occur between 25°11′N to 27°52′N. These forests exist in the north part of the Persian Gulf and Oman Sea, along three Maritime Provinces in the south of Iran (Fig. 1). These forests represent an important ecological resource and are dominated by the species *Avicennia marina*, known locally as the "harra" tree [2]. A number of protected areas including biosphere reserves, international wetlands and national parks are located in this area where according to national law commercial use is restricted to fishing (mainly shrimp), tourist boat trips and limited mangrove cutting for animal feed. However lack of comprehensive management, with the participation of stakeholder groups, leads them to increasing degradation [3].

*Figure 1: Mangrove Ecosystem in the International Wetland of Harra.*

The mangroves form a major habitat for migratory birds in the cold season, and for reptiles, fish, and varieties of Arthropoda and bivalves. Green (or hooked) turtles and venomous aquatic snakes are also indigenous to these forests, while bird life includes herons, flamingos, pelicans, and angler eagles. Another important feature of these forests is the appropriate and suitable seabed conditions for the ovulation of fish in the Persian Gulf [4]. The biodiversity significance of these habitats in addition to some strong traditional community governance structures brings together the appropriate condition for practicing and applying a participatory comprehensive management plan for each of the habitats, ecosystems and protected areas [3]. The objective of this study was to design Participatory model practices in the management of protected areas of the southern marine and coastal areas of Iran.

## 2. METHODOLOGY APPROACH OF THE STUDY

This project intended to identify all the stakeholder and beneficiary groups aiming to transfer of governance responsibility to key stakeholders, notably the local and indigenous people, under the supervision of Department of Environment (DoE) and technical support of Forest, Rangelands and Watershed Organization (FRWO), as the current government agencies. The participatory plan was prepared using Participatory Action Research (PAR) and brainstorming techniques through a number of travels and meetings parallel to systematic and purposeful negotiations with the government, focusing on the empowerment of local communities and indigenous peoples towards conservation and restoration of the endemic flora and fauna species, and mangrove forests and achieving sustainable livelihoods.

### *1.1. The Pilot Protected Area*

There are many coastal and marine protected areas in south of Iran, which are partly covered by Mangrove ecosystems. Due to their valuable marine and avian diversity, and existence of local communities who are very cognizant of the ecosystem significance, the marine Protected Areas of this region can be brought into the last category of IUCN Matrix (classification system for protected areas comprising both management category and governance type) as "Governance by indigenous people and local communities."

Among them, "Harra" is chosen for this study, based on a number of criteria including:

- Being designated in different management categories of National Parks and Protected Areas, Biosphere reserve and international wetland;
- The importance of Mangrove habitats and criticality of existing threats;
- The presence of Indigenous people and local community as the main stakeholders of the area, who are not recognized by government;
- The running negotiations with government to achieve the vision of participatory management in these areas.

#### *1.1.1. Harra Biosphere Reserve and International Wetlands*

Covered with beautiful dense mangrove forests, the area has been protected since 1972 under different titles. It was recognized as Biosphere Reserve and International Wetland in 1976 and 1975, respectively. Located in Hormozgan Province (Fig. 2), Mehran river delta, this 86,581 ha region consists of aquatic and terrestrial ecosystems. Having an altitude range of 0 to 173 m, and mean annual temperature and precipitation of 27°C and 200 mm respectively, the area has a warm extra-arid climate. *Avicennia* is the sole plant species of the tidal zone. There also exist species such as Bean caper, Mountain spinach, different Saltworts, glasswort, Soda plant, Halocnemum strobilaceom, Groundsel, Seepweed in the vicinity of the area. The region is a winter refuge for a number of migratory birds. The main animal species include Dolphin, Black rat, Brown rat, Gerbil, Indian gerbil, Cape hare, Indian gray mongoose, different pelicans, Cormorant, night heron, Indian pond heron, flamingo, crab plover, sparrow hawk, osprey, vulture, kestrel, saker, heron, spoonbill, sandpiper, tern, marsh harrier, oystercatcher, gull, godwit, Montpellier snake, false cobra, lytorhynchus diadema goddi, green turtle, different crabs, fish species such as lenkoran, saddle grunt, chub, pomfret, tiger-toothed croaker, catfish, sardinella, dark-blotched mudskipper. The existence of terrestrial and aquatic ecosystems, the valuable *Avicennia* stands, animal diversity, beautiful landscapes, proximity to population centers and proper access roads have encouraged scientific research and tourist activities in the region [4].

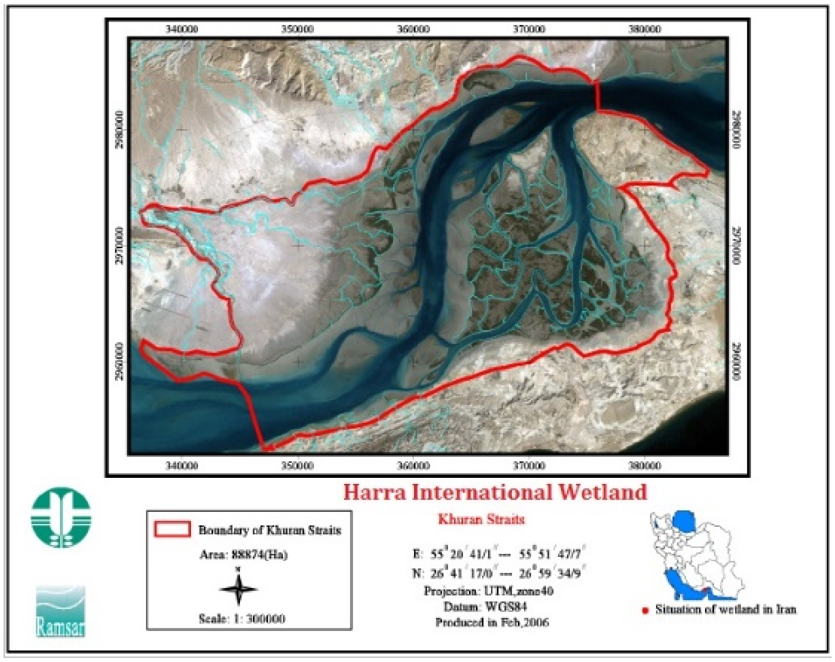


*Figure 2: The location of Harra International Wetland and the Protected Areas' Map of Iran [5].*

## 3. ACTION PLAN AND RESULTS

### *3.1. Participatory Training and Planning Workshop in Qesham Island (Plan for Restitution of Territorial Integrity)*

A workshop in Qeshm on the rehabilitation of the role of indigenous people and local communities (IPs and LCs) in the conservation of marine and coastal biodiversity was organised between local community representatives, local and national NGOs, university professors and experts, and local public and private authorities including members from the Department of Environment, the Board of Qeshm Island Geo-Park, and the Board of Qeshm Free Zone. The workshop covered a range of issues including introducing Iran's national and international obligations and responsibilities regarding protected areas and IUCN protected area governance, presenting how to properly identify, register, and recognise marine and coastal Indigenous and Community Conserved Areas (ICCAs), explaining how to document the biodiversity of the area using participatory approaches, proposing to help develop conservation-based sustainable livelihoods for indigenous/local communities and re-empower customary indigenous/local institutions to manage these customary management systems [6].

During this workshop, participants were divided into three working groups including: government, local communities, and NGOs in order to discuss each group's role in sustainable development and supporting ICCAs and what challenges these groups face in achieving these goals (Fig. 3). At the end of the workshop, each group presented their results to the other groups.

*Figure 3: Participatory Workshops with local community.*

- *Local community working group:*
  They tried to show the locations of their societies and ecosystems on the map. For example they marked Nayband National Park, and two cities: Assalouyeh and Nakhle Taghi. They also created a legend for the map. They also described the changes during the time, including the occupied lands in the map. In a part of the map, they showed the lands belong to Pars Special Economic Energy Zone (PSEEZ) which used to be grazing and farm lands.

- *NGO working group:*
  Due to the main subject of this workshop is Retrieving ICCAs' role in conservation of biodiversity in marine and coastal areas, the working group of NGOs discussed about two issues. First, the role of NGOs in supporting ICCAs and their upgrading; second, challenges and threats of NGOs in informing and making awareness about ICCAs.

- *Government working group:*
  They discussed about ICCAs, while the focus was on that how much the management should be shared with local communities. Considering sample models existing in Qeshm Island and other experiences in the whole country, they accepted that local communities are the best managers of their own ICCAs and they, as governmental organizations, should give them the supervision role.

Following the workshop, the next steps include establishing and strengthening local institutions and funds to enhance community performance and establishing local sustainable livelihood networks. The Qeshm workshop also facilitated discussion and documentation of indigenous peoples' traditional governance systems in protected areas and the legal issues infringing on these customary approaches. The project hopes to continue this bilateral cooperation between the Department of Environment of Qeshm and NGOs to continue empowering the indigenous people in the governance and conservation of local territories.

Following are some of the outcomes of the workshop in Qeshm:

- Participatory Mapping of customary territories, specifying wildlife habitats, and areas related to the livelihoods of local people;
- The workshop allowed NGOs to collect preparatory information for a richer assessment of the community's livelihood activities;
- the progression of the inception phase of the CBO (community based organization);
- possible avenues for developing a sustainable livelihood for the community;
- sharing and documenting indigenous knowledge, lifestyles, and cultural features;
- Setting up a Multi-stakeholder Advisory and Support Council on Sustainable Livelihood Issues;

- Supporting wealth generation activities and seeking co-financing and transfer of Seed Grant Fund to selected CBOs;
- Carrying out feasibility study and marketing.

### *3.2. Setting up a Multi-stakeholder Advisory and Support Council on Sustainable Livelihood Issues*

The establishment of community-based organizations is designed to empower the indigenous peoples through the appropriate recognition and/or establishment of CBO and strengthen community cohesiveness, which will include a sanduq and a women's committee. During the workshop, thirty-five participants from all stakeholder groups including community elders and members from Qeshm, Hormoz, Hengam, and Larak Islands, head of the Department of Environment of Qeshm Free Zone, scientific consultant of the Qeshm Free Zone, as well as facilitators from National NGOs selected the board members for the CBO and prepared a draft of the CBO's statute.

### *3.3. Carrying out Feasibility Study and Marketing*

Above this action, the sustainable livelihood group also began the marketing process for Qeshm island's handicrafts, which involve a large number of the island's female population. The sustainable livelihoods group, which includes a Qeshm community representative, were able to begin marketing and developing relations and agreements with shops at local, national and international levels for bulk orders of the island's handicrafts.

Securing contracts for the sales of the Qeshm handicrafts will significantly contribute to the livelihoods of many of the women and their families living on the island. Handicraft samples have been given to shops and organisations in Tehran, while some agreements are also underway with several traditional souvenir and handicraft shops.

### *3.4. Customary Management Systems in Qesham Island*

#### *3.4.1. Towla community*

Dokouhak area is one of the most important habitats for migratory birds on Qeshm Island. The mud flat contains lots of food for both resident and migratory birds. About 46 species of birds have been identified within this area including both resident and migratory birds.

Local communities have planted mangroves in the area with support from Qeshm free zone organization. The mangroves have been planted by the Towla people and this tree planting has increased the number of migratory birds frequenting the area, the rate of growth and reproduction of local shrimp and the honey produced in mangrove flowering season. The mangroves have even become a tourist attraction. But still the people hope to expand the mangrove forest by planting many more trees.

Indigenous people in this area are using traditional methods for fishing (Fig. 4). During the spawning season between April and May, those who have Moshta on the beach take down their nets for a month to allow the fish time to breed. Indigenous people have always done this based on their experience.

*Figure 4: Pruning the mangroves for fodder and Moshta fishing system as the sustainable traditional methods for community livelihood.*

A major threat to this important habitat is that the ships which dredge the waterfronts of the Hormozgan Province, discharge the dredged material in this area. This has led to the destruction of shrimp habitat. In the past, the annual shrimp catch was 15,000 tons. This year it was only 400 tons. Another threat to the area comes from investors eager to build residential complexes and hotels. This is due to the visual attraction of the region, as these modern designs are not appropriate for this environment. Developing projects don't care about the space that must be left between the building areas and the mangrove forested sea.

*3.4.2. Soheili community*

The people harvest the Mangrove trees for fodder for their livestock including cows, sheep and camels. This is the main source of fodder in wet and drought years, as well as winters and summers. They believe that harvesting the branches is like pruning for plants (Fig. 4). Each season has its own pruning. For example, in the summer they prune the trees near the beach, but in the winter they need to go to the middle of the mangrove, to the north. They believe that mangrove branches become sharp in the winter, and livestock do not eat them. The colder water, the further north they need to go to prone. They use sea water to moist the branches, so that livestock eat them more easily.

All villagers, anyone who has livestock make use of these branches and leaves. They believe that the right method for pruning mangrove branches is cutting them not breaking them. They say "If you break the branch, it won't grow again. Even in the following year. But when you cut the branch, it will grow the following week and you can prune it again."

They also feed the livestock bran and straw other than mangrove leaves and branches. But still, three quarters of their fodder comes from mangroves. Providing barley is not possible for them due to its high price.

*3.4.3. Pilot GEF/SGP project on artificial reefs for rehabilitation of marine resources of Qeshm Island in Salakh area*

Local communities on the coasts of Qeshm Island are highly dependent upon fisheries, however, due to population increase, pollution and destructive methods of fishing, the fisheries is in decline. During 2001-2004, a field survey was conducted to investigate the state of corals along the northern Persian Gulf, and the indigenous knowledge behind them. Salakh, an important fishing port in the southern tip of Qeshm Island was selected then as a pilot area. It was in Salakh that fishermen mentioned their fathers purposefully disposed useless objects into the sea to enhance reef building process and boost fisheries! Building upon this idea, a project was drafted on promoting "Artificial Reefs in Salakh area." Through close collaboration between local people and environmental experts, and amalgamation of indigenous knowledge and scientific methods, a modulated pyramid structure was designed and constructed using local materials (Fig. 5). Once introduced to the sea, it was protected and monitored by local fishermen (2002-2007). Later, experts found that biodiversity in these reefs was rather high (EIA study by Khoramshahr Univ. in 2007). With all rights of local community of Salakh reserved, this project has the potential to be expanded and up-scaled at coastal and regional levels [7].

*Figure 5: The participatory designed of artificial reefs for coral restoration.*

### 3.4.4. *Conservation vs. tourism, ecotourism planning for the turtle nesting site near Shibderaz Village*

To encourage the local community of Shibderaz in turtle conservation work, ecotourism was considered as a good option to provide incentives. With increasing media attention about the turtle nesting beach in Shibderaz, gradually Qeshm Island's visitors came to the site to see the turtles, especially in late March-early April as it coincides with New Year holidays in Iran. Without the necessary infrastructures in place, visitors gradually became a threat for the nesting and hatching turtles. SGP Iran in collaboration with an NGO started planning for ecotourism, aiming to reduce the impacts of tourism, while creating livelihood options for the local community. The project was successful in controlling the impacts of tourism on nesting turtles in peak season for three consecutive years (2008-2011), while also training a group of local youth as guides, and women in handicrafts production (also used as advocacy materials for marine turtles) [7].

### 3.4.5. *Promoting livelihoods for women through handicrafts*

Qeshmi women are known for tedious needle work, namely "Golabtun-douzi." To offer new livelihood options for women and also to build awareness about biodiversity of the island, Art for Conservation was initiated by an NGO with co-funding from SGP. The project was implemented in two villages, Shibderaz and Berke Khalaf, and it has expanded to many other villages now. Handicraft stores are now established in a few villages which give visitors the chance to contribute to local development. It would be interesting to see the impacts of this project on other aspects of women's life on Qeshm Island [7].

## 4. Conclusions and Recommendations

Indigenous people and local community have always had efficient ability for managing marine and coastal protected areas. So we need re-empowerment, not empowerment. We have been witness that they can communicate with governmental organizations and NGOs very well. For example one of the work groups claims that they can implement a good management system in their region but they need Intellectual support.

The experiences in Co-management Strategy and Action Plan for the natural resources have made it clear that the endangered species and habitats can only be conserved with the in-depth involvement of indigenous people and local communities in the region who are in direct contact with these ecosystems and their customary management systems have been approved over thousands of years.

As a result of this participatory action a comprehensive report was prepared of the ecological characteristics and the history of protection, as well as the current threats to the ecological integrity of the marine and coastal ecosystems of mangrove forests, with a zoning and governance plan for the protected areas. Based on the outcomes of the preliminary steps, the group has begun implementing activities and supporting the community ecological assessments and the tribal territory-based conservation and livelihood plans. The desired compromise between government, civil societies, private sectors and local communities is calling for a design in participatory governance to make a co-management model for extension and application to many other marine and coastal protected areas in the country.

### *4.1. Key Messages*

- Considering the threats to and losses of mangrove forests in Asian countries and awareness of the bio-cultural diversity significance of these habitats besides their importance in providing community livelihoods;
- To consider Indigenous and Community Conserved Areas (ICCAs) and customary management systems of natural resources as a type of protected areas, in accordance with the IUCN matrix;
- Reviewing the national management plans of protected areas with participatory approaches and also at evaluating the country's commitments to international environmental conventions;
- Aligning and updating the information, governance methods and management of Iranian protected areas with international statistics, especially on the involvement of every stakeholder groups.

## ACKNOWLEDGEMENT

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# Historical Wetland Change along the Southern California Coast: A Tool to Inform Regional Restoration Planning

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## *Abstract*

Restoration and management of resilient wetland metapopulations requires a regional perspective that can support appropriate combinations of wetlands within a defined coastal region. Historical analysis can inform regional planning by providing critical information about the composition of wetland systems, and by extension their relationship with landscape drivers, under natural conditions. In this study, we demonstrate the utility of historical information to inform regional restoration planning along the southern California coast. We acquired, digitized, georeferenced, and analyzed coastal T-sheets to provide an estimate of wetland extent and composition in the 1850 timeframe. We compared historical estimates to contemporary wetland mapping to assess losses and type conversion over the past 150 years. Total estuarine habitat declined by approximately 48% since 1850; moreover, there has been substantial type conversion, with intertidal habitats declining by over 75% and subtidal habitat increasing from approximately 35% of the total estuarine habitat to over 70%. This has been accompanied by a general consolidation of small seasonally open lagoons to larger perennially open estuaries. The understanding of historical extent and contemporary losses can be used to guide regional restoration planning and help set site-specific priorities that will contribute to a more robust and resilient system of coastal wetlands.

***Keywords: Wetland Gains and Losses, Historical Ecology, T-sheets, Regional Restoration Planning, Type Conversion***

## 1. INTRODUCTION

Restoration planning for coastal wetlands typically focuses on individual systems and the stressors most responsible for affecting the ecological quality of those systems. This is particularly true along coastlines in Mediterranean portions of the world where wetlands occur as series of relatively small, spatially disconnected systems rather than as large contiguous estuaries, as occurs in more mesic and humid regions of the world (e.g. southeastern coasts of the United States, Asia, and India/Bangladesh). In contrast, a regional perspective to restoration planning allows for the consideration of interactions between wetlands along common coastlines. This approach provides an opportunity to consider ways to improve overall resiliency by optimizing the location and type of wetlands restored to be most compatible with current and future landscape constraints. It also provides an opportunity to provide functional redundancy and connectedness among wetlands within the region.

In 2013, a coalition of southern California agencies, known as the Southern California Wetlands Recovery Project (www.scwrp.org) began an effort to develop regionally focused quantitative restoration objectives for the wetlands and watersheds along the southern California coast. The overall goal of this *Regional Strategy* is for the partner agencies to work collaboratively to reestablish a mosaic of fully- functioning and resilient wetland systems with a diversity of habitat types and connections to upland and marine communities, which preserves and recovers self-sustaining populations of species. This regional mosaic of wetlands would also provide important socio-economic values such as: sustainable habitat and food supply for fish and wildlife, including some commercially important species; improved water quality in coastal streams, beaches, and the nearshore waters; increased potential to buffer flood waters and recharge groundwater aquifers; increased opportunities for human interaction with nature – a valuable resource in a highly urbanized landscape; and increased opportunities for public education and research on the unique natural landscape features of Southern California coastal watersheds. Development of the *Regional Strategy* will consider:

1. Historic extent of wetlands;
2. Historic diversity and relative proportion of wetland types;
3. Natural processes and functions of wetland ecosystems;
4. Suite of native wetland habitats and associated species assemblages; and
5. Resilience of wetland ecosystems.

Knowledge of historical wetland extent and distribution is a key element of the *Regional Strategy* because it provides a baseline to understand past losses that can be used to guide regional planning. Understanding historical conditions provides valuable context for the relationship between landscape-scale process and wetland composition, and can inform decisions about appropriate restoration targets at different positions along the coastline. While not meant to provide a blueprint for the future, reconstructing historical patterns can provide critical information. This knowledge can inform decisions regarding restoration and management by improving understanding of both cultural and natural (i.e. geomorphic) processes that led to current conditions [1]. This is especially relevant in discussions among stakeholders with disparate restoration goals, as it provides for an educated place to initiate conversations. Furthermore, understanding historical conditions can provide insight into key drivers of change over long-time periods that should be considered during planning for long-term restoration and management [2-5].

In this paper, we summarize an analysis of historical conditions and change over time for coastal wetlands of southern California and discuss how this knowledge is being used to inform development of a regional recovery strategy. Because this effort is still ongoing, few details can be provided on the outcome of the *Regional Strategy*, but the general approach should be instructive for other planning efforts.

## 2. ANALYSIS OF HISTORICAL WETLAND LOSS AND CHANGE

Historical wetland losses and type conversions (i.e. changes in wetland type over time) were evaluated by comparing over 40 historical Topographic sheets (T-sheets) to contemporary mapping acquired from the National Wetlands Inventory (www.fws.gov/wetlands/). The T-sheets were produced between ca. 1850 and 1875 by the U.S. Coast and Geodetic Survey to inform coastal navigation and establishment of ports and harbors. However, T-sheet mapping also included information on wetlands and some creek and river systems occurring in the coastal zone, providing the highest quality, regionally consistent mapping of historical coastal wetlands. The National Wetlands Inventory provides nationwide mapping of wetlands using consistent methods and classification systems that is periodically updated to represent contemporary conditions. These two data layers were overlaid, aligned, rectified, and their classification systems standardized. This allowed us to compare wetlands between ca. 1850 and 2005. This analysis provides a general assessment of change. Future analyses that incorporate additional historical information will help refine our estimates of historical extent and distribution for comparison to contemporary wetlands.

The 420-km stretch of southern California coastline evaluated historically contained approximately 330 individual wetlands and river mouth lagoons, with 90% being less than 100 ha. in size. The region supported 19,591 hectares of estuarine habitat. Vegetated wetlands and subtidal water account for the majority of the historical estuarine area with 7,764 hectares and 6,914 hectares, respectively. Intertidal flats, open water, and salt flats make up the remaining ¼of the total with 4,914 hectares combined.

Individual coastal systems were relatively evenly distributed along the coast; the exception was that the northern region of the coast with rocky headlands contained fewer systems compared to the southern region. On a regional scale, larger systems occur in three areas distributed along the southern California coastline, south San Diego, along the boundary between Orange and Los Angeles Counties, and in Southern Ventura County. These three nodes were connected through strings of medium and smaller estuaries (Fig. 1).

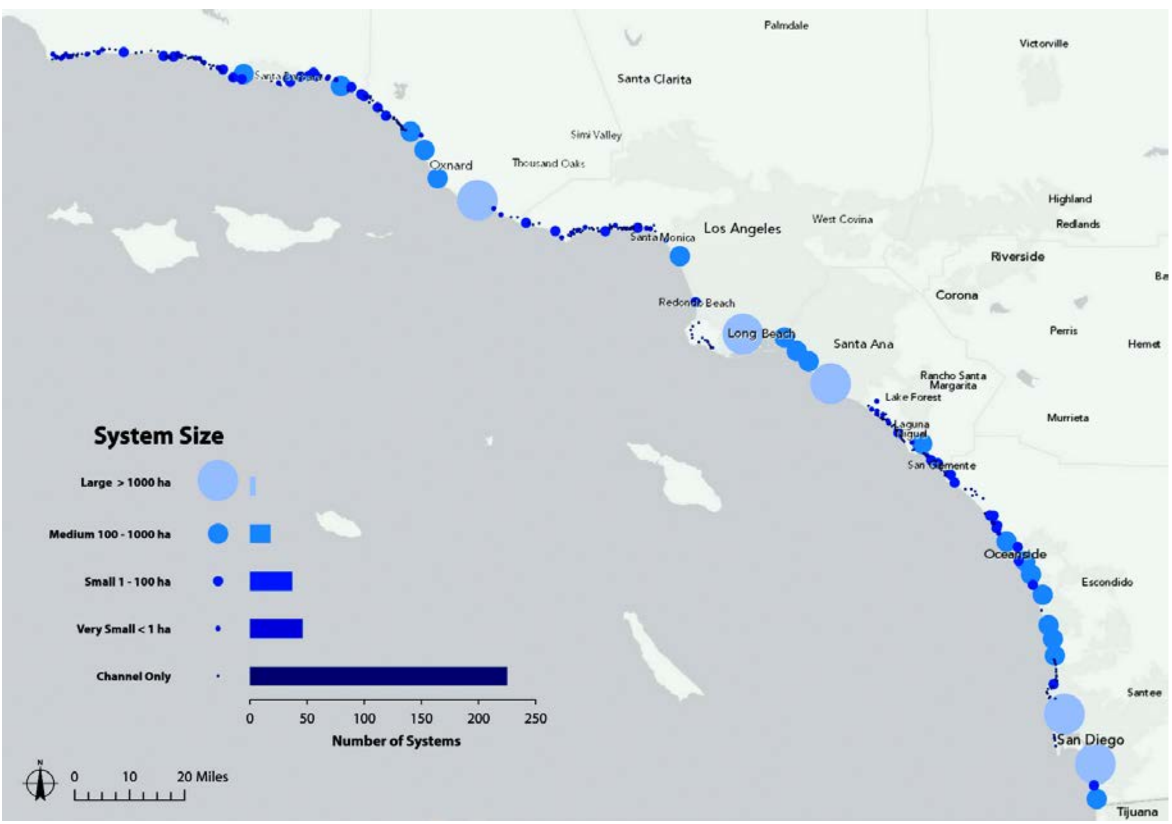


*Figure 1: Southern California coastal region showing general distribution of 330 historical wetlands. Each circle corresponds to the approximate location and relative size of a historical wetland. Inset graph shows distribution of wetland systems by size class.*

Since ca. 1850 there has been an overall loss of 9,317 hectares or 48% of historical estuarine habitats along the Southern California Coast. However, losses have not been even across the major habitat types. Estuarine vegetated habitats have experienced the greatest loss in terms of absolute area (5,819 ha, 75% loss), while estuarine unvegetated habitats have experienced the greatest proportional loss of 78% of historical extent (Fig. 2). In contrast, the contemporary landscape includes 339 ha more subtidal water, a 5% increase from historical extent. These differential losses have shifted the proportional composition of southern California estuaries. Historically there was almost an even split between estuarine vegetated (40%), estuarine unvegetated (25%), and subtidal water (35%). Currently the proportional composition is heavily weighted towards subtidal water (71%) while estuarine vegetated (19%) and unvegetated (10%) make up less than ⅓ of the total area combined.

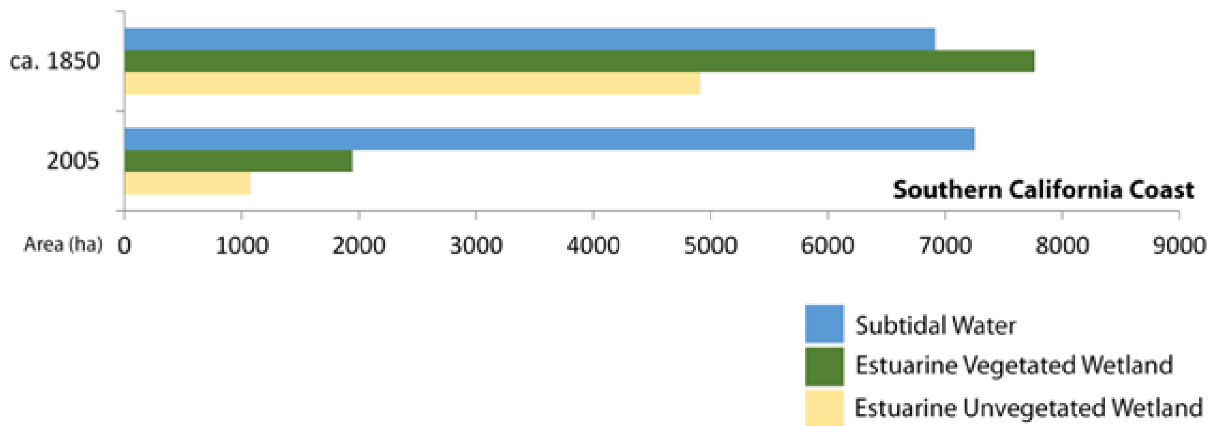


*Figure 2: Change in overall extent and composition of estuarine habitat types between ca. 1850 and ca. 2005.*

The largest type conversion experienced is the change of estuarine habitats to non-wetland features (Fig. 3). Of the 19,591 hectares of historical estuarine habitats, 8,368 hectares or 43% have been converted to non-estuarine features, i.e., developed, agricultural, or open space land uses. Thirty-four percent or 6,604 hectares of historical estuarine habitats are the same type in the 2005 mapping. However, 74% of this category is due to large subtidal water features remaining the same. In contrast, only about 1,700 hectares of historical vegetated and unvegetated estuarine habitats have remained the same type. Twenty percent (20%) of historical estuarine habitats have been converted to a different estuarine type. For example, area that was tidal flat in ca. 1850 is now tidal marsh. A lesser amount, only 880 hectares or 4% of historical estuarine habitats, have been converted to freshwater wetlands. Finally, a nominal amount of the total historical estuarine extent has been converted to marine habitats. In some areas, there has been a net increase in aquatic habitat. However, almost all of these circumstances result from deep water ports and marinas being constructed from areas that were historically either marine or intertidal wetlands. Therefore, the net area may have increased, but at the expense of converting intertidal wetlands to deep water habitat.

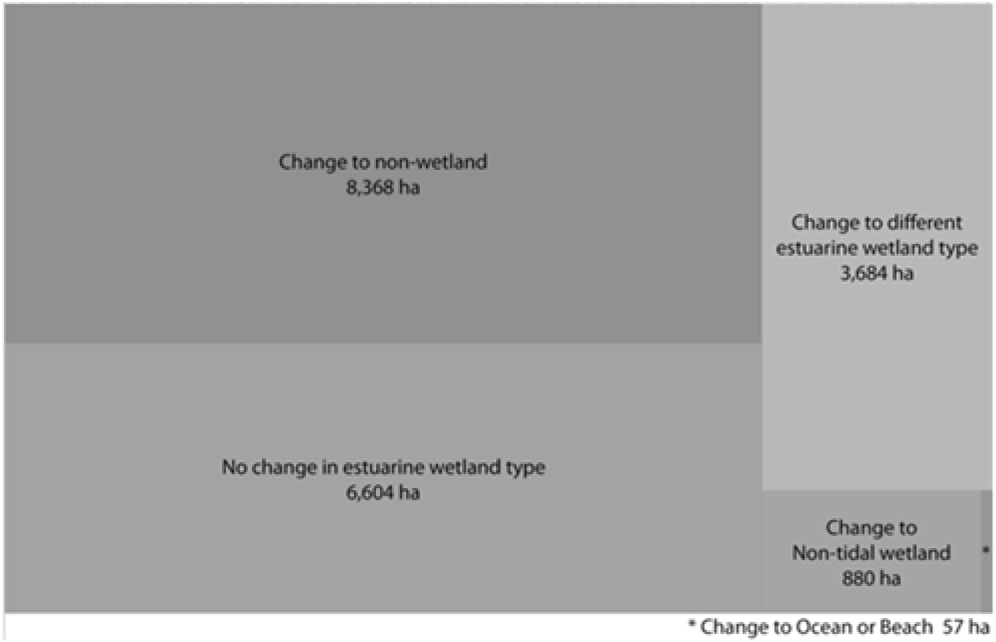


*Figure 3: Summary of type conversion of historical (ca. 1850) wetlands compared to contemporary (ca. 2005) land cover. Tree plot shows both loss (8,368 ha, darker grey box) and type conversion to other habitats (all other boxes).*

## 3. Using Historical Knowledge to Inform the Regional Strategy

Development of the *Regional Strategy* will include consideration of the results of the historical analysis. Information on historical wetlands will be combined with data on the current condition and extent of coastal wetlands, and projections of new impacts and opportunities associated with sea level rise and global climate change (Fig. 4). Various sea-level rise scenarios and consideration of future management opportunities across the region are being used to inform development of quantitative objectives that can guide future regional wetland restoration planning.

Ultimately this process will be used to develop quantitative objectives at the regional and subregional scales that will provide targets for the amount, composition, and distribution of coastal wetlands (Fig. 5). In addition to quantitative restoration targets, the *Regional Strategy* will include recommendations to encourage long term resiliency of coastal wetlands, such as:

1. Provide upland transition zones for marsh transgression with sea level rise and to improve ecological linkages
2. Ensure broad representation of historical wetland types in proportions informed by both historical composition and contemporary constraints
3. Incorporate concepts of dynamism into restoration design and long-term management
4. Incorporate functional redundancy by ensuring that critical habitat types occur in multiple locations in the region.
5. Maintain landscape connections with adjacent uplands, marine resources, and nearby wetlands

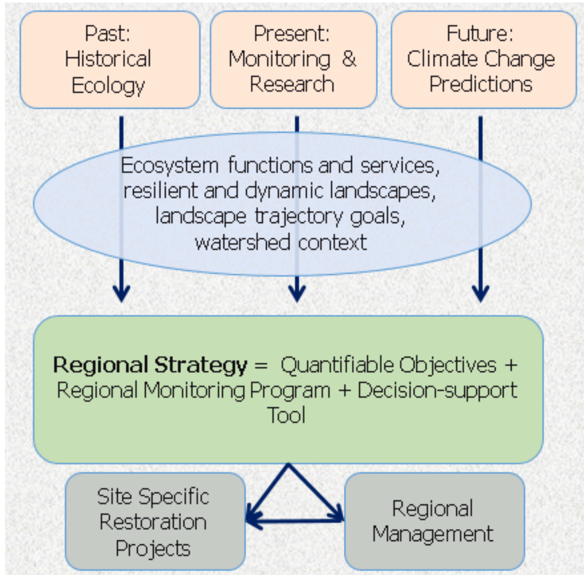


*Figure 4: Overview of process used to develop the southern California Regional Strategy for coastal wetland restoration and management.*

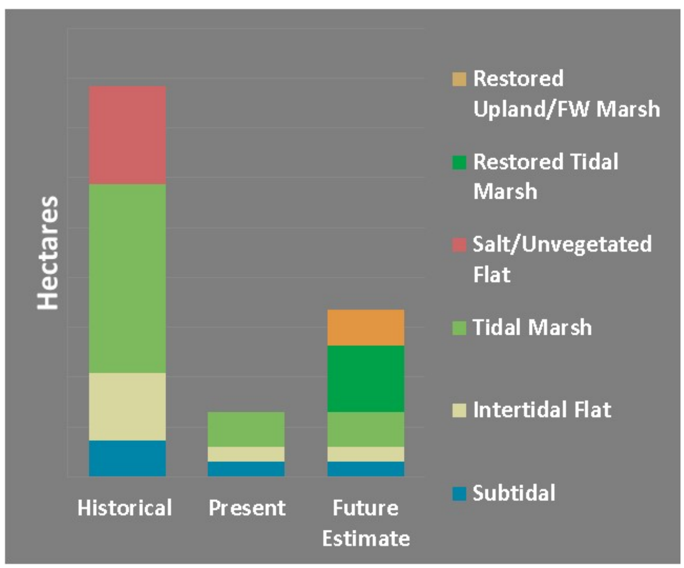


*Figure 5: Hypothetical representation of regional quantifiable objectives. In this example, the desired extent and composition of the future wetlands is informed by historical composition.*

We envision that future decisions regarding prioritizing, funding and designing individual restoration projects will be done in the context of these regional objectives. This will allow individual project planning to look beyond the constraints and opportunities of the specific site they are focused on, and consider how each project relates to nearby wetlands and contributes to a regionally resilient landscape. This will not only improve planning, but should also provide for a more efficient use of limited resources by allowing each project to take advantage of the regional analyses and recommendations. Finally, this will facilitate development of a regionally consistent monitoring program that can ultimately be used to track progress toward achieving the agreed upon goals and quantitative objectives of the *Regional Strategy.*

**ACKNOWLEDGEMENTS**

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**U.S.-Iran Symposium on Wetlands**

March 28-30, 2016

Irvine, California

# Phytoremediation: A Green Approach for Wetlands Management

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## *Abstract*

Wetlands are important ecosystems in the world which should be maintained and protected from natural and anthropogenic threats. Although there are several methods for wetlands management, nature-based solutions (e.g. phytoremediation and bioremediation) having minimum environmental side-effects are the most efficient approaches. Since pollution prevention is considered as one of the main issues of wetland and integral component of sustainable management, phytoremediation, specially using native plants, can be a great choice in this regard. Besides, plants can be used in buffer zones of natural wetlands. Meanwhile, vegetated buffers protect wetlands by filtering sediments, contaminants and bacteria and maintain water quality and provide a high quality wildlife habitat. Therefore, finding native plants for phytoremediation of environmental pollutants in wetland ecosystems which seems specifically fragile in Iran is an important issue. Furthermore, enhancing plant efficiency to tolerate, accumulate and degrade pollutants would be a way to enhance feasibility of using them in wetland buffer zones. The efficiency of *Festuca arundinacea* in accumulation of heavy metals (e.g. Pb and Ni and As) and also enhancing degradation of petroleum hydrocarbons in the rhizosphere has revealed its potential in phytoremediation process. Furthermore, the results have shown that endophytic fungi associated with this grass can enhance its tolerance to grow in contaminated media and consequently increase its remediation potential. Therefore, *Festuca* species together with their associated fungi or bacteria have a high potential to be used in vegetative buffer zone of wetlands and help their protection. However, field experiments and screening the suitable plants and their associated microorganisms for protection of wetland ecosystems are needed.

***Keywords: Phytoremediation, Buffer Zone, Environmental Pollution, Wetland Restoration***

## 1. INTRODUCTION

Wetlands are crucial and valuable ecosystems providing numerous ecological services including a range of social, economic and environmental benefits [1,2]. However, they are influenced and threatened by various factors which the most common are water scarcity, changing biodiversity and human intervention [3]. Industrial and agricultural activities could increase the entrance of organic and inorganic pollutants into the wetland ecosystems and consequently affect their performance [1]. Therefore, protection of wetlands from environmental stressors is an important issue that supports and retains ecological balance and biodiversity of these ecosystems.

Constructed wetlands have been introduced as environmental friendly approaches which help preserving wildlife habitats and biodiversity at local and global scales [4]. Plants play the main role in constructed wetlands by remedying various pollutants from the growth media. In fact, phytoremediation is a green technology that uses plants and their associated microorganisms to remove, degrade and/or stabilize environmental pollutants of soil, sediment and water [5]. This technique categorized in several parts depending on the type of pollutants and the mechanism of plants in response to toxic organic and inorganic compounds. Phytoextraction/rhizofiltration and phytostabilization are the mechanisms which are generally used to remove and stabilize heavy metals and non-degradable pollutants in the environment, respectively [5,6]. Plant can also enhance microbial degradation of organic pollutants in the plant tissue and in the rhizosphere (the area close to the plant roots) through the phytodegradation/phytotransformation and phytostimulation (i.e. rhizoephere-enhanced degradation or rhizosphere bioremediation) processes, respectively [5,6]. Furthermore, either organic and inorganic pollutants or their modified forms and constitutes may transfer to the atmosphere and react with the free radicals through the phytovolatilization process [5,6]. Using the mentioned mechanisms, plants actually act as a green leaver to detoxify environmental pollutants [5].

Phytoremediation in engineered wetlands can be a promising alternative method to treat pollutants [7]. Engineered wetland phytoremediation as a solar-driven promising technique is a semi-passive kind of constructed wetland which has been modified through the design modification, process additions, vegetative changes and using advanced operation methods [7]. However, the performance of engineered wetlands depends on various factors including plant characteristics and physicochemical properties of wetland and contaminants (e.g. pollutant initial concentration, loading rate, pH, temperature, dissolved oxygen, salinity etc.) [7]. Among the mentioned factors, selection of plant species may be the best way to maximize pollutant removal [8]. Planting a diverse macrophyte community has been proposed to improve the constructed wetland efficiency in removing organic and inorganic materials [9,10] but the selection of their species is a limiting factor in research and feasibility studies [8]. Because of the time limitation in selecting the best plants and the limited number of tested species, it is considered rather costly [8].

Constructed wetlands are mostly planted with proliferative species (e.g. *Phragmites australis*) that originate from nurseries and that could be a risk for biodiversity of downstream ecosystems [11]. Thus, selection of wild plant species and native macrophytes, especially those grown at the short distances from industrial discharges, could be a good choice [11]. The selected plants should be tolerant, produce a high shoot biomass and develop a healthy root system [11]. Use of diverse macrophyte communities should be considered rather than monotype stands in constructed wetlands [10]. In addition to the type of plants, the source of wastewater can also affect the efficiency of constructed wetlands. The results of 400 horizontal sub-surface flow constructed wetlands from 36 countries around the world have revealed the highest and lowest efficiency in municipal wastewater and landfill leachate, respectively [9]. Considering the importance of wetlands management in Iran, this study was carried out i) to find some suitable plants for phytoremediation of environmental pollutants and ii) to investigate the effect of plant-fungi symbiosis on tolerance, accumulation and degradation of pollutants which would be a way to enhance feasibility of using plants in wetlands management.

## 2. STATUS OF SOME WETLANDS IN IRAN

Wetlands in Iran are important ecosystems providing habitats for more than 140 migratory and indigenous bird species comprising 30% of bird population in the country [12]. About 30 Iranian wetlands are listed in Ramsar Convention. Since the country is located in an arid environment, the drought of wetlands can be a source of dust storms. Therefore, water management of wetlands is an important way to protect the environment.

### *2.1. Shadegan Wetland*

This wetland with more than a half million hectare area is one of the biggest in Iran and is located in the southwest of the country and northwest of the Persian Gulf in Khozestan Province where most oil and chemical industrial activities are taking place. Water scarcity and environmental pollutants such as heavy metals and petroleum hydrocarbons are the major threats to the Shadegan Wetland. Considering that the mean annual rainfall is up to 153 mm, the changes of water quantity and adjusted land use are shown in Fig. 1.

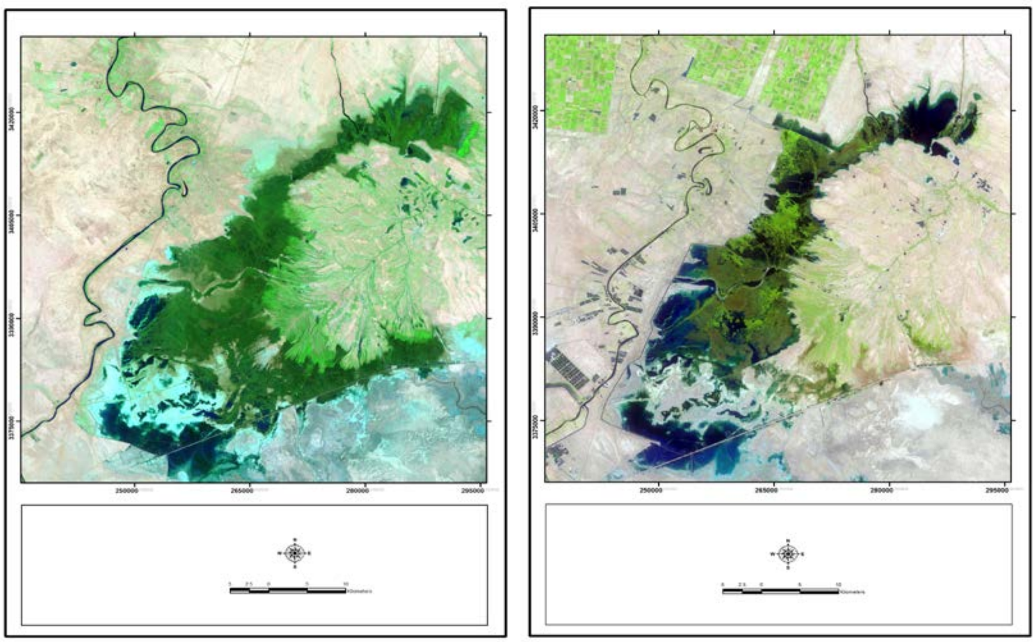

*Figure 1: Landsat images of water area (light and dark blue) and adjucent agricultural land use (light green) changes in Shadegan Wetland (April 1990, left; April 2015, right).*

The shallow and deep water areas, shown respectively by light blue and dark blue colors, and also agricultural land use have significantly decreased from 1990 to 2015. High amounts of Mn, Ni, Zn, V, Cd and Pb in sediments of this wetland have been reported that mostly were bioavailable and had a high potential to transfer to food chain [13]. Meanwhile, accumulation of metals in aquatic plants (*Phragmites australis* and *Typha australis*) grown in the wetland showed that they were mostly in plant roots rather than shoot, stem and leaf [13]. The main source of heavy metal pollution is entering through industrial and agricultural wastewater discharge to the wetland. Oil seepage from pipelines passing by the wetland and rainfall carrying petroleum hydrocarbons after the Iraq-Kuwait war together with the pesticides and herbicides of adjacent agricultural lands are considered the main sources of organic pollutants of the region.

### *2.2. Gavkhooni Wetland*

The Gavkhooni wetland is located in the east of Isfahan city, central Iran. Having an arid environment (about 125 mm annual rainfall) and an area of 43,000 ha, water scarcity is the main problem of this wetland which is presented in Fig. 2. Since wind direction in summer is from east to west of Isfahan, drought of the wetland is considered as a potential source of dust and air pollution in the region. Recently (June, 2015) water was seen streaming again into the wetland after 10 years (http://www.doe.ir) using primary treated municipal wastewater which should be fully treated to prevent probable environmental side effects. The wetland provides numerous ecological services including vital habitats for animals and birds, prevention of dust storms as well as cultural value and tourist attraction.

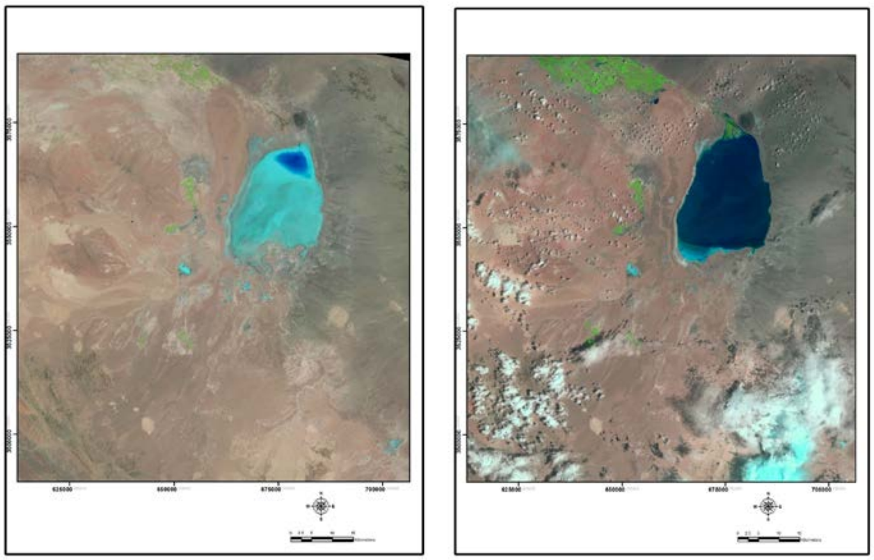

*Figure 2: Landsat images of water area (light blue=shallow water area, and dark blue=deep water area) and adjucent agricultural land use (green) changes in Gavkhoni Wetland (May 1993, left; May 2013, right).*

### *2.3. Anzali Wetland*

The Anzali wetland is located in north of Iran and on the southern coast of the Caspian Sea connected to Anzali port. The basin of the wetland has an area of 374,000 hectare. Because of the humidity (mean annual rainfall of 1,830 mm), water scarcity is not considered a main threat of the wetland in comparison to other Iranian wetlands. However, discharge of domestic, agricultural and industrial wastewater into the wetland has increased heavy metal content in the water and sediments. Bioavailability of some elements increases the potential risk of entering the food chain [14]. Additionally, Azolla is an invasive plant species and a serious threat that comes from the irrigated farmlands [12]. The excess of nitrogen and phosphorous in the wetland may trigger eutrophication and enhanced growth of algae and ferns (such as Azolla) and decreased dissolved oxygen content, adversely affecting aquatic animals. It seems that during past years the amount of algae and ferns on surface water of the wetland has increased (Fig. 3). Although a wetland management master plan has been formulated for this wetland by collaboration of Iran's Department of Environment and the Japan International Cooperation Agency (JICA), prevention of pollution at this wetland is still an important issue.

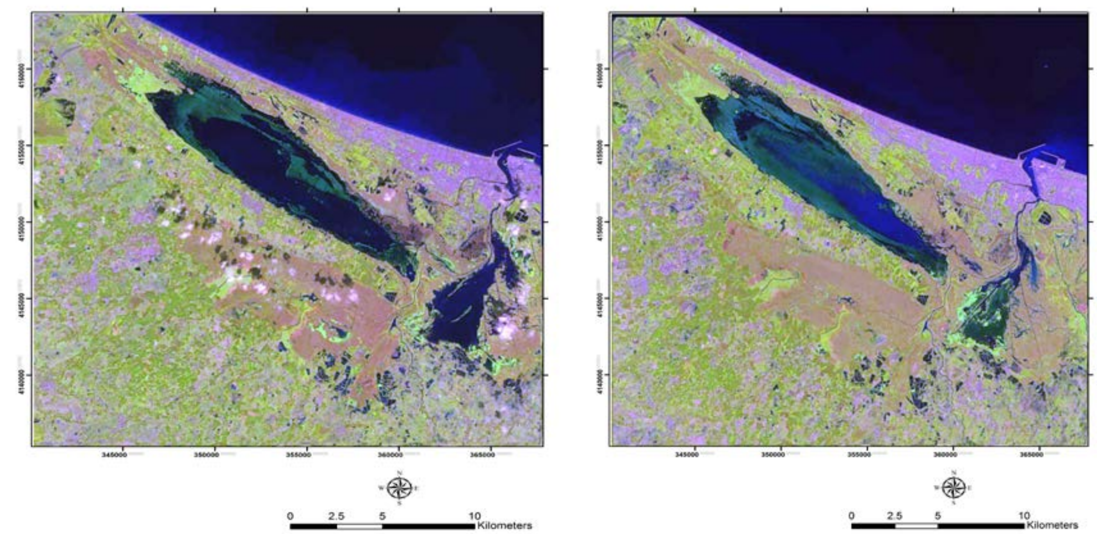

*Figure 3: Landsat images of Anzali Wetland (Sep. 2013, left; Sep. 2015, right) showing the agricultural lands around the wetland and increasing fern and algae on water surface.*

## 3. Wetlands Management, Buffer Zone and Plants

Although plants can be used in constructed wetlands for water quality management, they also have a high potential to be used in buffer zones around natural wetlands. Wetland buffers are the transition zone between the wetland ecosystems and surrounding area and help protect and support the wetland functions and environmental values [2]. Vegetative buffers can be used for water management and reduction of nonpoint source pollution [15].

Buffer zones are comprised of two parts including separation and support areas. The former part protects the wetland against negative impacts of external pressures by trapping and filtering sediments, acting as a physical barrier against pesticides and herbicides and providing an attractive visual barrier and the latter part maintains and supports the wetland environmental values including hydrological processes, food webs, physical habitat, nutrient cycling, water supply, etc. within the wetland [2,16] The efficiency of buffers depends on various factors including buffer physical properties (e.g. width, slope, soil and vegetation type) and characteristics of pollutants, as well as placement and proximity of the buffer to pollutant sources [15,17]. Generally, wider and forested buffers are more efficient than narrow and grass ones, respectively [18]. Wetland function and values, land use of surrounding area, and buffer characteristics (e.g. soil type and slope) are considered as the main factors in selecting the width of buffer zones [16].

## 4. Enhanced Phytoremediation in Retaining Wetlands

Plants, particularly those which have the ability to tolerate pollutants, play a key role in phytoremediation approach. Our previous research revealed that *Festuca arundinasea* as a grass had a potential to accumulate Pb and Ni when grown in sediments of the Shadegan wetland [19]. However, more strategies are needed to increase the tolerance and accumulation potential of the plant and subsequently enhance the efficiency of the green method (i.e. phytoremediation). Although several approaches have been proposed in this regard (e.g. using chemical chelates and genetically-modified plants) [6], it seems that they are not the most environmental friendly. Therefore, finding a native-based approach can obviously help to overcome the problem. Symbiosis relationships between plants and microorganisms (e.g. bacteria and fungi) can be an effective approach to reduce environmental pollutants [6]. *Neotyphodium* endophytic fungi located in shoots of tall fescue species can enhance degradation of petroleum hydrocarbons and accumulation of Cd by the host plant [20,21]. The fungi not only give host plants the ability to tolerate environmental stressors but also increase the biomass production of plants as well as increase drought tolerance [20,21]. The effect of endophytic fungi on tolerance and phytoremediation of pollutants might depend on host genotype and endophyte-host interaction [22].

The 2-month growth of seedlings of *Festuca arundinacea* infected and non-infected by *Neotyphodium* endophytes in hydroponic media containing 0, 1, 2, 3, 10, 20 and 40 mg $L^{-1}$ arsenic (As0, As1, As2, As3, As10, As20 and As40) showed that the fungi could reduce translocation of As from root to shoots (Fig. 4). The same results were obtained from plants grown in contaminated soils with As and Cd separately. Using infected plants as a phytostabilization technique could be a valuable approach to reduce risk of pollutant transfer into the wetland food chain. Highly tolerant plants that can accumulate pollutants in their roots could be considered as good choices in buffer zones of wetlands where the risk of pollution transfer to animals and birds should be minimized. Furthermore, efficient plants having the capability to grow in arid conditions (like most of wetlands in Iran) and could decrease the time of remediation process. In addition to fungi, endophytic bacteria associated with various plants could give the pollutant tolerate ability to the hosts and increase efficiency of in-situ phytoremediation [23,24].

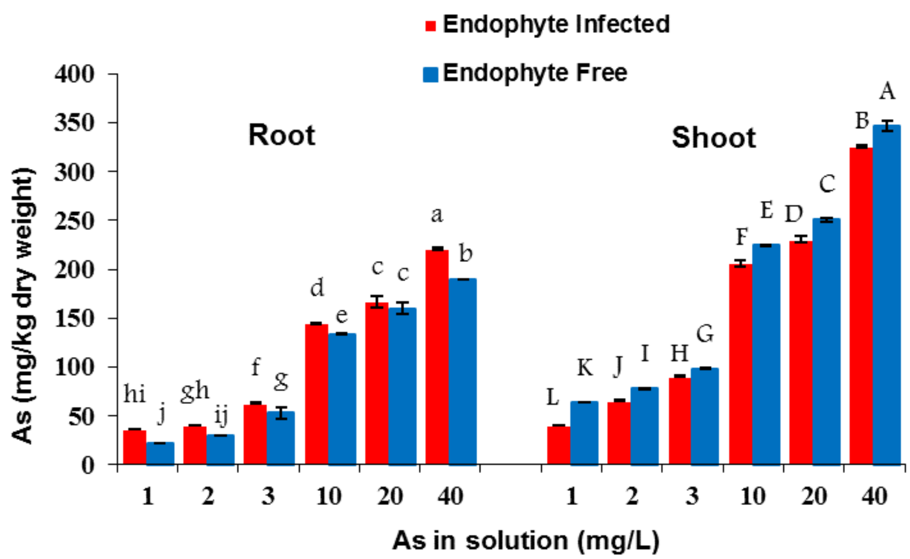


*Figure 4: Arsenic accumulation in shoot and root of Festuca arundinacea (infected and non-infected by endphytic fungi) grown in hydroponic systems. Different letters at top of columns (capital and small ones seperately) are showing significant difference between means using Tukey test (P<0.05).*

## 5. Conclusion

Phytoremediation is a green approach to decrease environmental pollutants in various media including constructed wetlands and buffer zones of natural wetlands. To enhance the method efficiency, not only do we need to screen new plants to be used in various environmental conditions, but we also need to increase the efficiency of plants using native-based approaches. Tall fescue and their associated microorganisms showed a high capability to accumulate inorganic contaminants and in bio-stimulation of organic pollutants. Use of this plant could be an important and green management approach for protection of wetlands in arid conditions against environmental stressors. Using endophyte-infected species not only could increase their efficiency in remediation of pollutants but also could enhance their tolerance against other growth limiting factors such as drought, nutrients and pests. Finding new plants, particularly halophytic species, and new symbiosis interactions (e.g. between endophytic fungi/bacteria and plants) and also investigating plant removal efficiency in field conditions should be considered in future wetland research in Iran.

## ACKNOWLEDGEMENT

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**U.S.-Iran Symposium on Wetlands**

March 28-30, 2016

Irvine, California

# The Constructed Ecosystems Research Facility: A Treatment Wetland in Arizona

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## *Abstract*

The Constructed Ecosystems Research Facility (CERF) was a demonstration-scale wetland project in continuous operation from 1989 through 2006. Located in the City of Tucson in southern Arizona, CERF was a cooperative effort of Pima County and The University of Arizona's Office of Arid Lands Studies. The project was initiated in 1983 to determine the feasibility of aquatic wastewater treatment in Tucson's hot arid environment. Capital and operational funding, approximately $3M, was provided by the Pima County Wastewater Management Department. CERF was comprised of six wetland raceways that were utilized in multiple configurations during three phases of operation. In Phase 1, water hyacinth was studied in surface flow water wetlands that received either primary or secondary effluent. During Phases 2 and 3, raceways were operated as subsurface flow wetlands that contained a variety of vegetation species, and received either secondary effluent or municipal tapwater. Research studies conducted at CERF examined vegetation effects (growth rates, plant uptake) and water quality changes (organics, nutrients, heavy metals, pathogens). The multi-year period of subsurface flow operation permitted evaluation of seasonal variations in wetland treatment performance and as well as changes occurring over the timespan.

***Keywords: Constructed Wetland, Water Hyacinth, Subsurface Flow, Organics, Nutrients***

## 1. INTRODUCTION

In many parts of the world, natural wetlands have received wastewaters for many years. Information on the quality of water exiting these natural wetlands led scientists and engineers to realize the potential benefits of wetlands in wastewater management systems. Thus, increasingly over the past 40 years, natural and constructed wetlands have been engineered for wastewater treatment [1-7]. The idea of using constructed wetland technology in the arid southwestern United States for urban and peri-urban wastewater treatment and habitat creation developed in the early 1980s [8-10]. Several demonstration, research and operational facilities have been created in Arizona and over 40 systems from small residential on-site systems to large operational facilities have been built or are planned. These systems have demonstrated significant benefits in improved water quality and habitat creation, but have also encountered some problems.

Constructed wetland technology includes systems with open water surface flow (SF), subsurface flow (SSF) through a gravel or soil media, or aquatic systems with deeper water and floating aquatic plants. These systems have been designed to treat municipal, industrial and/or agricultural wastewater and stormwater. Municipal wastewaters, including domestic and commercial wastewaters pretreated in lagoons, septic tanks, or conventional primary and secondary processes (screening, primary settling, trickling filters and activated sludge) are the primary sources for these systems. Industrial wastewaters discharged to wetlands for advanced treatment include food processing wastes, textile wastes, chemical facility and refinery wastes, cooling tower blow-down waters, landfill leachates, and pulp and paper effluents. Agricultural wastewaters include dairy wastes, feedlot and hog-farrowing wastewaters, and runoff from many agricultural practices.

The Constructed Ecosystems Research Facility (CERF) was a demonstration-scale wetland site in continuous operation over 17 years from 1989 through 2006. Located in the City of Tucson in southern Arizona, CERF was a cooperative effort of Pima County and The University of Arizona's Office of Arid Lands Studies. The project was first initiated in 1983 to determine the feasibility of aquatic wastewater treatment in Tucson's hot arid environment. Tucson is located at an elevation of 792 m (2,600ft) ASL with an annual average precipitation of 30 cm (11.9 in) and a (reference) evapotranspiration of 201 cm (79 in). The facility was constructed in 1989 on a 1.2 ha (3 ac) site adjacent to Pima County's Roger Road Wastewater Treatment Plant on the west side of the City of Tucson. Capital and operational funding for the facility, approximately $3M, was provided by the Pima County Wastewater Management Department.

Three phases of research were conducted at CERF. In Phase 1 (1989-1993), research focused on the efficacy of using water hyacinth (*Eichhornia*) in the treatment of wastewater in surface flow wetlands. CERF was the first wetland facility to test water hyacinth under colder (freezing) weather conditions. During Phase 2 (1994-2003), raceways were operated as subsurface flow wetlands containing mixed tree and other plant species. Potable water and secondary effluent were compared on a variety of native, locally tolerant plants representative of the arid west and selected biological and chemical constituents and pathogens were examined. In the third phase of research at CERF (2003-006), the existing vegetation (shrubs, trees) in raceways 2-5 was removed. Raceways 2 and 3 remained as unplanted controls and raceways 4 and 5 were replanted with sedges, permitting direct evaluation of the role of plants on water quality improvement.

CERF provided numerous opportunities for education and research. In total, 19 University of Arizona graduate students completed MS or PhD projects based on studies conducted at CERF. The purpose of this paper is to summarize the history of CERF and to provide an overview of research findings from this facility.

## 2. CERF CONSTRUCTION AND SETUP

CERF was constructed on the west side of the City of Tucson, near the Roger Road Wastewater Treatment Plant (RRWTP), in 1989 as a cooperative effort between The University of Arizona's Office of Arid Lands Studies and Pima County Wastewater Management Department. The facility consisted of six pilot-scale hypalon-lined ponds (raceways) with an array of pumps and monitoring stations and a trailer that served both as a sample and data collection facility and as an on-site laboratory (Fig. 1). Construction of the raceways is illustrated in Fig. 2. Five of the raceways measured 61 m × 8.2 m × 1.4 m (200 ft × 27 ft × 4.6 ft). The sixth raceway was somewhat larger in area and was 2.6 m (8.5 ft) deep. This facility provided a unique, controlled setting for evaluating water quality-related impacts on vegetation species of the regional ecosystem and also for assessing water quality improvements during wetland treatment.

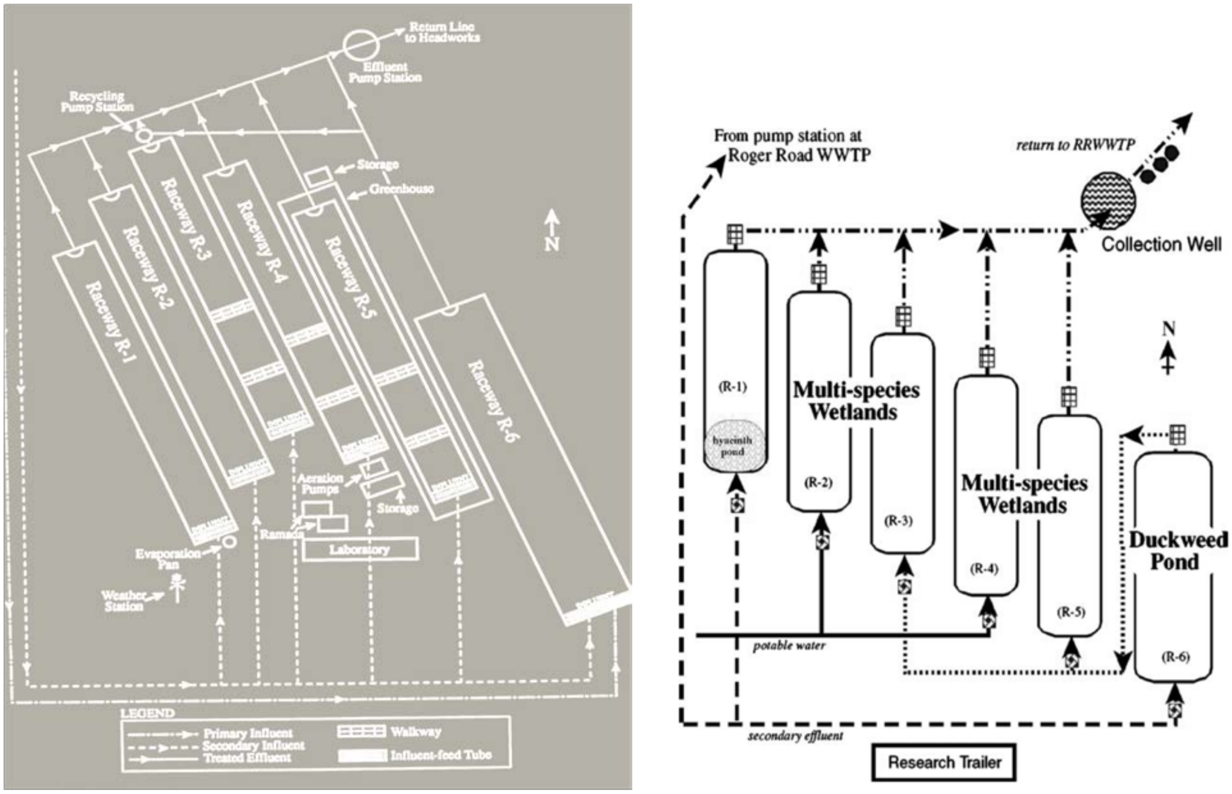


*Figure 1: Schematic layout of CERF facility during Phase 1 operation as a water hyacinth facility (a) and Phase 2 operation as subsurface flow wetlands (b).*

*Figure 2: Construction of CERF wetland raceways in 1989.*

## 3. PHASE 1: WATER HYACINTH TREATMENT SYSTEMS, 1989-1993

The first phase of research at CERF (1989-1991) focused on the use and survival of water hyacinth (*Eichhornia crassipes*) in the six aquatic raceways (Fig. 1a). The source waters were primary effluent and unchlorinated secondary effluent from the nearby Pima County wastewater treatment plant at Roger Road.

During Phase 1 studies at CERF, independent variables included sourcewater quality (primary vs secondary effluent) and the type of control system used to protect the water hyacinth plants from wintertime freezing temperatures (Fig. 3). Protection methods that were studied at individual wetland raceways included a greenhouse structure, a fogging system, sprinklers, tarps, and a negative control that did not receive any protection measures. Dependent variables during Phase 1 included: plant survival rates, and a variety of water quality measurements including biochemical oxygen demand, total nitrogen, coliform bacteria, and enteric viruses. Water samples were collected weekly using 24-hr composite samplers positioned at the outlet of each raceway.

*Figure 3: Water Hyacinth raceways at CERF, circa 1990, showing some of the various techniques studied to protect water hyacinth plants from wintertime freezing temperatures.*

### *3.1 Results: Water Hyacinth Survival*

Water hyacinth (*Eichhornia crassipes*) was the first species selected for study at CERF as a biological filter. During the first years of operation (1990-92), research focused on winter survival of hyacinths and their year-round performance in enhancing water quality. Although Duckweed (*Lemmna* species) was found to be more frost-tolerant, water hyacinth plants were mostly able to survive the winter and to provide treatment benefits year-round in the Tucson climate. There were no significant differences found in survival rates by the various protection measures studied. Duckweed, unlike water hyacinth, was found to be readily consumed by some of the avian visitors to CERF such as mallard ducks.

### *3.2 Results: Organics and Nutrients*

The CERF surface wetlands containing water hyacinth were found to be effective in cleaning the water during the Phase 1 operation. Representative water quality data for biochemical oxygen demand (BOD) and total suspended solids (TSS) are provided in Table 1.

TABLE 1. SUMMARY OF WATER QUALITY IMPROVEMENT DURING TREATMENT IN CERF WATER HYACINTH RACEWAYS

| sourcewater | Primary effluent (6 d detention time) | | Secondary effluent (3d detention time) | |
|---|---|---|---|---|
| | in | out | in | out |
| BOD (mg/L) | 91 | 33 | 20 | 7 |
| TSS (mg/L) | 39 | 6 | 23 | <5 |

## 4. PHASES 2 AND 3: SUBSURFACE FLOW WETLANDS, 1993-2006

### *4.1 Setup*

In 1992, five of the aquatic ponds were converted into subsurface-flow multi-species wetland ecosystems (Fig. 4). The Water Hyacinth plants were removed and coarse gravel was added to the raceways to a depth of 0.5m. The gravel-filled raceways were then planted with an array of vegetation species including cottonwood, willow, ash, sycamore, desert willow, cattail, bulrush and other plant species. As the vegetation matured, a natural habitat for wildlife, including mammals, reptiles, birds and insects, was created. In an effort to duplicate the most natural environmental conditions, the presence of animals was encouraged and, as much as possible, wildlife drawn to the facility were not interfered with.

Secondary effluent began flowing into the first subsurface flow system (Raceway 1) in August 1992. Raceway 6, planted with *lemna* sp. (duckweed), continued to receive secondary effluent during Phase 2. Potable municipal (tap)water was provided to the remaining raceways until planting was completed in July 1994. At that point, Raceways 2 and 4 continued to receive municipal tapwater and Raceways 3 and 5 began receiving effluent from Raceway 6 (Fig. 1b), a duckweed pond receiving secondary effluent from the Roger Road Wastewater Treatment Plant. Raceway 6 was used as a pre-treatment step to reduce the suspended solids content of the secondary effluent before it was delivered to the subsurface flow wetlands (Raceways 2-5), reducing the potential for clogging. Detention time in the SSF raceways was about 4 days.

*Figure 4: Conversion of CERF raceways to SSF wetlands.*

Vegetation planted in the subsurface flow raceways began with two tree species, black willow (*Salix nigra*) and cottonwood (*Populus fremontii*), in Raceway 1 along with selected herbaceous species. Raceways 2-5 were planted with Black willow, cottonwood, various shrubs as well as cattail (*Typha domingensis*), bulrush (*Scirpus olneyi*), and giant reed (*Arundo donax*) (Fig. 5). Desert shrub species included seep willow (*Baccharis glutinosa*) and desert willow (*Chilopsis linearis*) and the tree species were coyote willow (*Salix exigua*) and sycamore (*Platanus wrightii*). Black walnut (*Juglans major*) and ash (*Fraxinus* sp.) were planted in Raceways 4 and 5.

*Figure 5: Subsurface flow wetland raceways at CERF.*

Independent variables during Phase 2 included sourcewater quality (secondary effluent vs municipal tap water) and the types of emergent vegetation planted in the subsurface flow raceways (Fig. 4 and 5). Water quality dependent variables during Phase 2 included: biochemical oxygen demand, dissolved organic carbon, total nitrogen, heavy metals, coliform bacteria, enteric viruses, Giardia, and Cryptosporidium. As in Phase 1, water samples were collected weekly using 24-hr composite samplers located at the outlets of the raceways.

During the third phase of research at CERF (2003-006), the existing vegetation (shrubs, trees) in raceways 2-5 was removed. Raceways 2 and 3 remained as unplanted controls and raceways 4 and 5 were replanted with sedges. The raceways continued to be operated as SSF wetlands and the effect of sourcewater quality was compared to the role of plants on water quality improvement.

### *4.2 Results: Vegetation*

The research conducted at CERF during Phase 2 showed that secondary effluent stimulated the growth of most plant species. Cottonwood and willow trees were observed to grow over 3 m (10 ft) during the first year following planting in raceways that were supplied with either potable municipal water or with secondary effluent.

### *4.3 Results: Organics and Nutrients*

Treatment performance of the subsurface wetlands for removal of organics and nutrients is summarized in Table 2. Monthly-averaged reductions of BOD and total nitrogen in the two SSF raceways receiving secondary effluent ranged from 44-82% and 15-35%, respectively, during the first year of operation in 1995. It is important to note that these percent reductions reflect only the performance of the SSF raceways; secondary effluent was first pre-treated in Raceway 6 (duckweed pond) to reduce TSS. The monthly-averaged reductions across the two raceway "system" for BOD and total nitrogen ranged from 68 -93% and 12-34%, respectively. Note that BOD was efficiently reduced in both the duckweed pond and the SSF raceway, whereas reduction of total nitrogen occurred mainly during passage through the SSF raceways.

TABLE 2: MONTHLY AVERAGED CONCENTRATIONS OF CHEMICAL PARAMETERS AT CERF RACEWAYS IN 1995 (DATA FROM [11]).

| Multi-species wetland systems (Raceways #3 and#5) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | pH | | BOD (mg/L) | | | Total N (mg/L) | | |
| | in | out | in | out | % red. | in | out | % reduced |
| July | 7.7 | 7.5 | 9 | 5 | 44 | 11.7 | 7.6 | 35.0 |
| August | 8 | 7.5 | 14 | 5 | 64 | 14.9 | 10.7 | 28.2 |
| September | 7.9 | 7.5 | 15 | 6 | 60 | 18.4 | 15.7 | 14.7 |
| October | 7.7 | 7.5 | 12 | 5 | 58 | 19.6 | 16.4 | 16.3 |
| November | 7.8 | 7.5 | 11 | 2 | 82 | 17.2 | 13.7 | 20.3 |
| December | 7.7 | 7.5 | 17 | 8 | 53 | 25.2 | 20.8 | 17.5 |

| Duckweed system (Raceway #6) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | pH | | BOD (mg/L) | | | Total N (mg/L) | | |
| | in | out | in | out | % red. | in | out | % reduced |
| July | 7.8 | 7.7 | 19 | 9 | 53 | 11.6 | 11.7 | -0.86 |
| August | 7.9 | 8.0 | 23 | 14 | 39 | 16.0 | 14.9 | 6.88 |
| September | 7.7 | 7.9 | 26 | 15 | 42 | 18.1 | 18.4 | -1.66 |
| October | 7.9 | 7.7 | 32 | 12 | 63 | 18.9 | 19.6 | -3.70 |
| November | 7.8 | 7.8 | 31 | 11 | 65 | 20.2 | 17.2 | 14.9 |
| December | 7.8 | 7.7 | 42 | 17 | 60 | 25.4 | 25.2 | 0.79 |

[1] negative value indicates a percent increase

The continuous multi-year period of SSF raceway operation permitted evaluation of seasonal differences in water quality treatment performance and the opportunity to reveal any changes in treatment efficiency over time. Fig. 6 shows quarterly-averaged BOD reductions across Raceways 3 and 5 over an eleven year period of operation, 1995-2005. Comparison of data from the first quarter (Jan through March) and the third quarter (July through September) permits evaluation of differences in treatment performance within an annual period and also over a multi-year timespan. During cooler winter months (Fig. 6a), BOD removal was about 80% or greater. In the hotter summer months (Fig. 6b), BOD removal was similarly efficient in the first three years of operation but then became much more variable (larger error bars) and generally less efficient for the remainder of the eleven year period of monitoring.

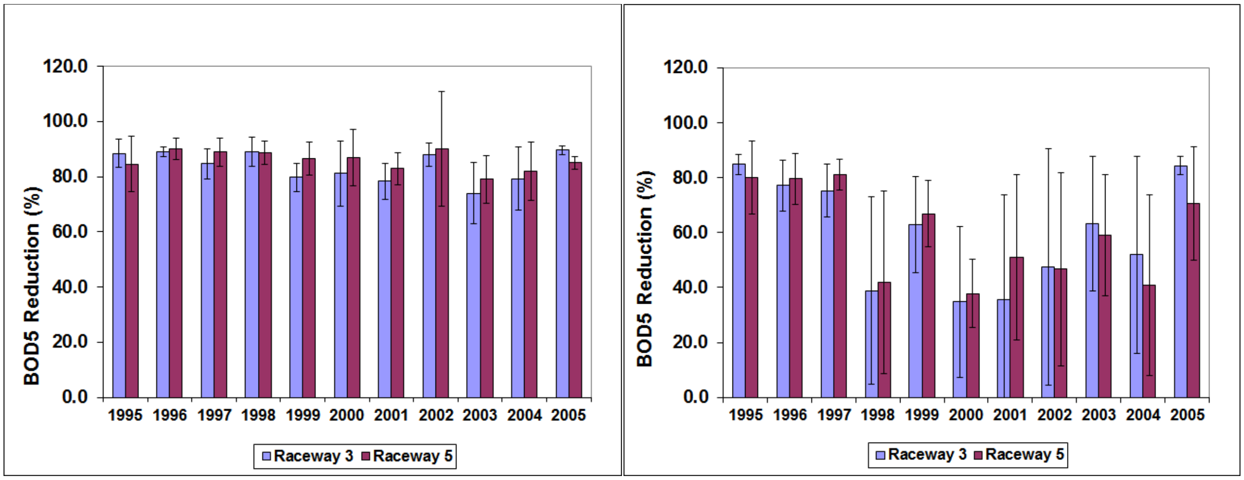


*Figure 6: Quarterly-averaged $BOD_5$ removal efficiencies over a 10-year monitoring period for January through March (a) and for July through September (b).*

Mechanisms responsible for seasonal variability of organics removal efficiency were further investigated by Quanrud et al. [12]. The parallel setup of raceways at CERF receiving secondary effluent or municipal tapwater enabled examination of the effects on effluent quality due to season-dependent processes of evapotranspiration (ET) and wetland-derived organics production. Organics of wastewater and wetland origin were evaluated in terms of their contributions to dissolved organic carbon (DOC) in wetland effluent. Higher temperatures and associated biochemical activities during summer months resulted in increased DOC concentrations in wetland effluent. In other words, DOC removal efficiency was negatively correlated to temperature. The contributions of ET and wetland-derived organics to elevation of DOC in wetland effluents during summer were roughly comparable. One management implication of this work is that the elevation of organic carbon concentration during wetland polishing of wastewater effluent may promote higher production of disinfection by-products when treated waters are chlorinated prior to reuse.

The fate of dissolved organic matter (DOM) during subsurface wetland treatment at CERF was examined by Quanrud et al [13]. The study objectives were to (1) discern changes in the character of dissolved organics as consequence of wetland treatment (2) establish the nature of wetland-derived organic matter, and (3) investigate the impact of wetland treatment on the formation potential of trihalomethanes (THMs). Subsurface wetland treatment produced little change in DOM polarity (hydrophobic–hydrophilic) distribution. Biodegradation of labile effluent organic matter (EfOM) and internal loading of wetland-derived natural organic matter (NOM) together produced only minor changes in the distribution of carbon moieties in hydrophobic acid (HPO-A) and transphilic acid (TPI-A) isolates of wetland effluent. Aliphatic carbon decreased as a percentage of total carbon during wetland treatment. The ratio of atomic C:N in wetland-derived NOM suggests that its character is determined by microbial activity. Formation of trihalomethanes (THMs) upon chlorination of HPO-A and TPI-A isolates increased as a consequence of wetland treatment. Wetland-derived NOM was more reactive in forming THMs and less biodegradable than EfOM. For both HPO-A and TPI-A fractions, relationships between biodegradability and THM formation potential were similar among EfOM and NOM isolates; the less biodegradable isolates exhibited greater THM formation potential.

Seasonal differences and changes in treatment efficiency over time for total nitrogen were also examined at CERF. Fig. 7 shows quarterly-averaged reductions of total nitrogen across Raceways 3 and 5 over the eleven year period of operation, 1995-2005. Comparison of data from the first quarter (Jan through March) and the third quarter (July through September) permits evaluation of differences in treatment performance within an annual period and also over a multi-year timespan. Similar to the results for BOD (Fig. 6), total nitrogen removal was higher during cooler winter months (Fig. 7a). In the hotter summer months (Fig. 7b), removal of total nitrogen was highly variable (large error bars) and less efficient than during winter months. Negative removals (net increase of total nitrogen) occurred in four out of the eleven years of data collection.

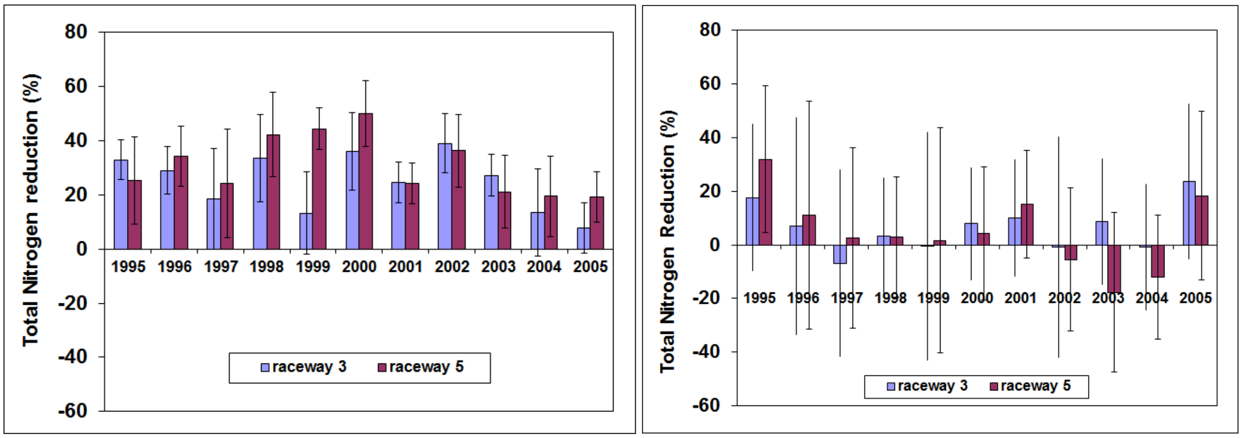


*Figure 7: Quarterly-averaged total nitrogen removal efficiencies over a 10-year monitoring period for January through March (a) and for July through September (b).*

### *4.4 Results: Plant Uptake of Nutrients and Heavy Metals*

One of the major issues that has been identified in the use of constructed wetland technology is plant nutrient uptake and tissue storage of nutrients as well as heavy metals. Karpiscak et al. [14] examined plant uptake and storage in the CERF SSF raceways and background concentrations in natural systems. Plant tissues were collected and analyzed from natural systems and from the CERF raceways receiving either wastewater effluent or municipal water. Plants investigated included the herbaceous species *Anemopsis californica* (Yerba mansa), *Scirpus* spp. (bulrush) and *Typha domingensis* (cattail), and tree species *Fraxinus velutina* (ash), *Populus fremontii* (cottonwood) and *Salix* spp. (willow). Data indicate that uptake varies not only among plant species, but also among chemical species, depending upon water quality within the wetlands. Leaf tissues of *Fraxinus, Salix* and *Populus*, contained the lowest amounts of nutrients and heavy metals studied (Na, P, K, Cu, Pb and Zn), while the root tissues of the herbaceous plants generally had the highest concentrations.

### *4.5 Pathogens*

The fate of pathogens was studied in two multi-species SSF wetlands at CERF, one receiving secondary sewage effluent and the other potable (disinfected) tapwater by Thurston et al. [15] and Karim et al [16]. Each wetland had a retention time of approximately 4 days. The objectives of the studies were (1) to evaluate the ability of multi-species subsurface wetlands to physically remove Giardia cysts; Cryptosporidium oocysts, total and fecal coliforms, and coliphages; and (2) to determine the likely impact of local wildlife on the occurrence of these indicators and pathogens. In the wetland receiving secondary effluent, total coliforms were reduced by an average of 98.8% and fecal coliforms by 98.2%. Coliphage were reduced by an average of 95.2%. Giardia cysts and Cryptosporidium oocysts were reduced by an average of 87.8 and 64.2%, respectively. In the “control” wetland receiving disinfected tapwater, an average of $1.3 \times 10^2$ total coliforms/100mL and 22.3 fecal coliforms/100mL were found in the wetland outflow and were most likely contributed by both flora and fauna; no parasites or coliphages were detected.

## 5. Conclusion

The Constructed Ecosystem Research Facility was a highly successful long-term wetland project that demonstrated the benefits of utilizing wetlands for treatment of wastewater in an arid environment. The six raceways at this facility permitted evaluation of multiple operational configurations, including surface flow and subsurface flow wetlands and with a variety of different plant species and sourcewater qualities. The facility supported several graduate student research projects on a variety of wetland research topics including plant growth, organics, nutrients, heavy metals, and pathogens.

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# Application of Vetiveria Zizaniodes in Nutrient Reduction from Agricultural Runoff by Constructed Wetland

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## *Abstract*

Nitrate and phosphorous of agricultural runoff has destructive effects on water resources. Nitrate is of concern because of its potential impacts on both public health and ecosystem function, and because of the widespread use of nitrogen in modem agriculture. In this research reduction of nitrate of an agricultural runoff in constructed wetland with surface flow and Vetiveria Zizaniodes cultivation was studied. Strategically targeting sites that intercept high nitrate loads and sizing the wetlands according to the characteristics of their watersheds can maximize wetland efficiency while minimizing costs and maintaining productive agriculture. Nitrate removal in a wetland takes place by plant uptake, denitrification and microbial processes. A number of factors affect the rate of nitrate and phosphorous removal, including hydraulic loading rate/hydraulic retention time, concentration of nitrate in the inflow water, temperature of the water, soil conditions, vegetation processes, and flow characteristics in the wetland. The main objective of this study was to examine the efficacy and capacity of using constructed wetlands. Three parallel pilot-scale modified free water surface (FWS) constructed wetland systems were installed including blank system, root cultivated system and floating cultivation with fixed dimensions and effects of hydraulic retention time, nitrate concentrations ,temperature, were monitored. Results showed that the efficiency of nitrate removal in highest retention time with root cultivation of Vetiveria Zizaniodes was more than 50%.

***Keywords: Constructed Wetland, Nitrate, Removal, Vetiveria Zizaniodes***

## 1. INTRODUCTION

Wetland can effectively remove or convert large quantities of pollutants from point sources (municipal, industrial and agricultural wastewater) and non-point sources (mines, agriculture and urban runoff), including organic matter, suspended solids, metals and nutrients. The focus on wastewater treatment by constructed wetlands is to optimize the contact of microbial species with substrate, the final objective being the bioconversion to carbon dioxide, biomass and water.

Wetlands are characterized by a range of properties that make them attractive for managing pollutants in water [1]. These properties include high plant productivity, large adsorptive capacity of the sediments, high rates of oxidation by microflora associated with plant biomass, and a large buffering capacity for nutrients and pollutants. Moreover, use of constructed wetlands is now recognized as an accepted eco-technology, especially beneficial to small towns or industries that cannot afford expensive conventional treatment systems [2-4]. The wetland system is energetically sustainable because it uses only natural energy to reduce pollutants. Compared with the conventional wastewater treatment system currently in use, it only requires low construction and low operational costs [5-7]. The constructed wetland known as free water surface (FWS) system mimics natural systems as the water flows over the bed surface and is filtered through a dense stand of aquatic plants [8,9]. An alternative system, known as the subsurface flow wetland, is also a constructed system consisting of an excavated but usually lined shallow basin containing gravel media and emergent aquatic plants [10-12]. There are currently thousands of constructed wetlands worldwide receiving and treating a variety of municipal, industrial, and urban runoff wastewaters [13-15]. Nitrogen processes in wetland soils include: nitrification (in aerobic zones), denitrification (in anaerobic zones) – releasing $N_2$ and $N_2O$ gases, plant uptake, sedimentation, decomposition, litterfall, ammonia volatilization and accretion/accumulation of organic N in peat because of redox potential of hydric sediment conditions. Although constructed wetland technology is well established, its application for treating specific industrial effluents has not been well documented [14,16,17]. To minimize the operational and maintenance cost of conventional wastewater treatment utilities, some medium- and small-scale factories have been found to illegally dump untreated wastewater directly into water bodies causing more serious environmental problems while reducing the costs of wastewater treatment.

There are six major biological reactions involved in the performance of constructed wetlands, including photosynthesis, respiration, fermentation, nitrification, denitrification and microbial phosphorus removal [18]. Photosynthesis is performed by wetland plants and algae, with the process adding carbon and oxygen to the wetland. Both carbon and oxygen drive the nitrification process. Plants transfer oxygen to their roots, where it passes to the root zones (rhizosphere). Respiration is the oxidation of organic carbon, and is performed by all living organisms, leading to the formation of carbon dioxide and water. The common microorganisms in constructed wetlands are bacteria, fungi, algae and protozoa. Fermentation is the decomposition of organic carbon in the absence of oxygen, producing energy-rich compounds (e.g., methane, alcohol, volatile fatty acids). This process is often undertaken by microbial activity. Nitrogen removal by nitrification/denitrification is the process mediated by microorganisms. The physical process of volatilization also is important in nitrogen removal. Plants take up dissolved nutrients and other pollutants from the water, using them to produce additional plant biomass. The nutrients and pollutants then move through the plant body to underground storage organs when the plants senesce, being deposited in the bottom sediments through litter and peat accretion when the plants die. Wetland microorganisms, including bacteria and fungi, remove soluble organic matter, coagulate colloidal material, stabilize organic matter, and convert organic matter into various gases and new cell tissue [18]. Many of the microorganisms are the same as those occurring in conventional wastewater treatment systems. Different types of organisms, however, have specific tolerances and requirements for dissolved oxygen, temperature ranges and nutrients. Metals can precipitate from the water column as insoluble compounds. Exposure to light and atmospheric gases can break down organic pesticides, or kill disease producing organisms. The pH of water and soils in wetlands exerts a strong influence on the direction of many reactions and processes, including biological transformation, partitioning of ionized and un-ionised forms of acids and bases, cation exchange, solid and gases solubility. Sedimentation and filtration are the main physical processes leading to the removal of wastewater pollutants. The effectiveness of all processes (biological, chemical, physical) varies with the water residence time (i.e., the length of time the water stays in the wetland). Longer retention times accelerate the removal of more contaminants, although too-long retention times can have detrimental effects.

The main objectives of this study were to (1) examine the efficacy and capacity of using a constructed wetland system on wastewater treatment for agricultural runoff wastewater, (2) determine the appropriate plant species for this type of wastewater treatment and (3) evaluate the optimal design factors, e.g., plant species.

## 2. MATERIALS AND METHODS

Availability of a sewage transportation system and electrical power to transfer sewage to a reservoir tank are the most important factors for site selection to construct wetland pilot. After site selection, dimensions are determined in order to designate the area of constructed wetland with surface flow model K-C* is applied to reduce pollution from inlet wastewater with initial concentration $C_i$ to reduce it to $C_o$:

$$A = \frac{Q}{Ka}.\ln\left[\frac{Ci - C*}{Co - C*}\right] \tag{1}$$

$C_o$, $C_i$, and $C^*$ are nitrate concentrations in discharge flow from wetland, inlet flow and background concentrations. $K_a$ is process constant of area unit in first order equation, Q is average flow rate in outlet and inlet, and A is wetland area in $m^2$. Considering extensive data for constructed wetland for nitrate removal $C^*= 0$ and $K_a= 0.096$ were estimated. Inlet concentration of nitrate 19 mg/l, outlet 9 mg/l, removal efficiency 60% and average flow rate 400 L/day and area of each wetland was about 3 $m^2$. Three parallel pilot-scale modified free water surface (FWS) constructed wetland systems were installed. In the present study, three constructed wetlands with the same dimensions were considered, including a blank system, a root cultivated system and a floating cultivation system, and effects of hydraulic retention time, nitrate and phosphorous concentrations were monitored.

As ratio of length to width (L:W) is 2:1 to 4:1 and even 10:1 in some references, the ratio of 3:1 was arranged for current study. Length 3m, width 1m and depth 0.65m, flow rate 400 L/day and HRT of 3, 5, and 7 days were assumed.

As the volume of each wetland was constant, variation of retention time was possible with flow rate adjustment. At a height of 0.65 m in each wetland, one aqueduct was installed for outlet flow. Polluted water was collected with a centrifuge pump and 1" pipe in a tank. In each wetland, porous media soil was settled at 0.4 m depth and Vetiveria plants were cultivated in two rows with 20 cm distance apart. pH was monitored using a Qispro Lineplus pH meter. Nitrate concentration in the inlet and outlet flow was determined by water and wastewater standard methods [19] and using a spectrophotometer Chromtech model CT2201 at 420 nm wavelength. Efficiency of nitrate removal was calculated by:

$$R = \left[1 - \left(\frac{Ce}{Ci}\right)\right] \times 100 \tag{2}$$

In this study three types of wetlands with three HRTs were studied and results were analyzed by SAS and Excel software.

## 3. Results

The applied nitrate concentration in the inlet flow is shown in Table 1. As it is understood in this agricultural runoff, nitrate concentrations in autumn and winter, which is simultaneous with rainfall period, is higher in comparison with its quantity in spring.

Also, as soil surface is washed by rain storms and runoff is transported to lower layers and conveyed to drains, nitrate concentration increases. After the rainfall period (HLR), hydraulic loading rate of nitrate was decreased. The average nitrate concentration of inlet flow was 20 mg/L and standard deviation was 3.76 mg/L. Average temperature and pH are shown in Table 2.

TABLE 1: NITRATE CONCENTRATION IN INLET FLOW TO CONSTRUCTED WETLANDS IN DIFFERENT HRT

| HRT=7 day | | HRT=5 day | | HRT=3 day | |
|---|---|---|---|---|---|
| $C_i$ (mg/l) | Starting date[1] | $C_i$ (mg/l) | Starting date[1] | $C_i$ (mg/l) | Starting date[1] |
| *20.86* | *03/10/2014* | *22.46* | *28/09/2014* | *23.00* | *18/09/2014* |
| *22.59* | *21/11/2014* | *24.93* | *16/11/2014* | *27.14* | *02/11/2014* |
| *25.12* | *12/12/2014* | *23.31* | *17/12/2014* | *21.38* | *02/12/2014* |
| *18.45* | *25/01/2015* | *18.13* | *20/01/2015* | *17.19* | *15/01/2015* |
| *18.13* | *12/02/2015* | *17.72* | *07/02/2015* | *18.25* | *02/02/2015* |
| *14.81* | *29/02/2015* | *14.65* | *24/02/2015* | *15.21* | *19/02/2015* |

| HRT=7 day | | | HRT=5 day | | | HRT=3 day | | |
|---|---|---|---|---|---|---|---|---|
| pH | T | Starting date[1] | pH | T | Starting date[1] | pH | T | Starting date[1] |
| *7.1* | *9.8* | *03/10/2014* | *7.3* | *10.0* | *28/09/2014* | *7.1* | *8.9* | *18/09/2014* |
| *7.2* | *12.5* | *21/11/2014* | *7.1* | *9.0* | *16/11/2014* | *7.1* | *12.8* | *02/11/2014* |
| *6.9* | *20.0* | *12/12/2014* | *7.0* | *17.0* | *17/12/2014* | *7.0* | *15.3* | *02/12/2014* |
| *7.4* | *26.4* | *25/01/2015* | *7.2* | *25.0* | *20/01/2015* | *7.0* | *18.3* | *15/01/2015* |
| *7.0* | *28.6* | *12/02/2015* | *7.0* | *27.0* | *07/02/2015* | *7.0* | *27.3* | *02/02/2015* |
| *7.1* | *31.2* | *29/02/2015* | *7.2* | *28.0* | *24/02/2015* | *7.0* | *31.0* | *19/02/2015* |

[1] dates are given as: day/month/year

TABLE 2: AVERAGE PH AND TEMPERATURE IN DIFFERENT RETENTION TIME

| HRT=7 day | | HRT=5 day | | HRT=3 day | |
|---|---|---|---|---|---|
| $C_i$ (mg/l) | Starting date | $C_i$ (mg/l) | Starting date | $C_i$ (mg/l) | Starting date |
| *20.86* | *18/9/2014* | *22.46* | *18/9/2014* | *23.00* | *18/9/2014* |
| *22.59* | *18/9/2014* | *24.93* | *18/9/2014* | *27.14* | *02/11/2014* |
| *25.12* | *18/9/2014* | *23.31* | *18/9/2014* | *21.38* | *02/12/2014* |
| *18.45* | *18/9/2014* | *18.13* | *18/9/2014* | *17.19* | *15/01/2015* |
| *18.13* | *18/9/2014* | *17.72* | *18/9/2014* | *18.25* | *02/02/2015* |
| *14.81* | *18/9/2014* | *14.65* | *18/9/2014* | *15.21* | *19/02/2015* |

[1] dates are given as: day/month/year

At the end of each retention time, nitrate concentration was examined and removal percentage was determined. It was observed that the highest efficiency of nitrate removal occurred in the root cultivation system. For a 3 day retention time (Fig. 1), the efficiencies of removal in the cultivated root (emergent), floating root, and blank system (unplanted) were 37.52%, 22.11% and 14.24%, respectively. For a 5 day retention time (Fig. 2), removal efficiencies were 41.27%, 25.69% and 16.32%, respectively. For 7 days retention time (Fig. 3), removal efficiencies were 50.51%, 37.29% and 16.42%, respectively.

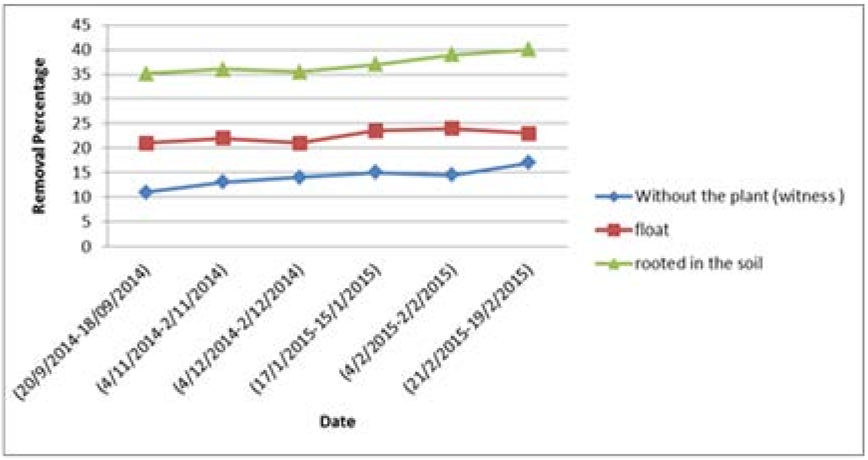


*Figure 1: Nitrate removal efficiency after 3 day retention time.*

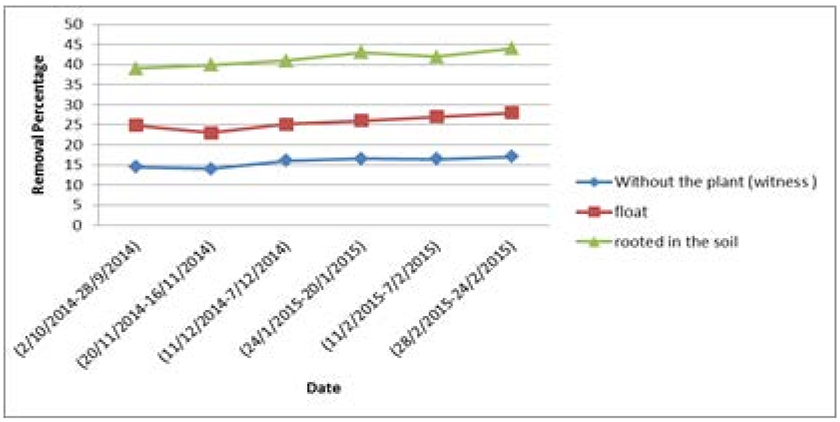


*Figure 2: Nitrate removal efficiency after 5 day retention time.*

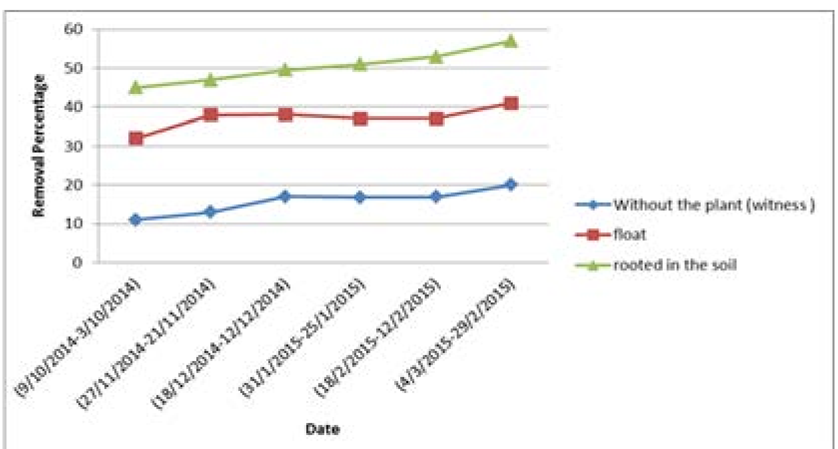


*Figure 3: Nitrate removal efficiency after 7 day retention time*

By comparing the average of results of wetland system type, retention time, temperature and their bilateral effects on nitrate removal it was obvious that the effect of system type and retention time was statically significant in difference, but system type and temperature and temperature and retention time did not have significant difference. Table 3 shows the effect of wetland type on nitrate removal efficiency.

TABLE 3. EFFECT OF WETLAND TYPE ON NITRATE REMOVAL EFFICIENCY

| | **Type of wetland** | | |
|---|---|---|---|
| | **blank** | **Floated root** | **Cultivated root** |
| **Removal efficiency (%)** | *15.66c* | *28.36b* | *43.09a* |

In all 3 systems there was 95% of significant difference on nitrate removal, as the highest removal efficiency was on root cultivated wetland. Table 4 shows retention time effect on nitrate removal, as it can be seen there is a significant difference of 95% between different retention times. Highest removal efficiency was achieved after 7 days.

TABLE.4: COMPARISON OF DIFFERENT RETENTION TIMES ON NITRATE REMOVAL EFFICIENCY

| | **Retention time** | | |
|---|---|---|---|
| | 3 days | 5 days | 7 days |
| **Average percent removal** | *24.62* | *27.76* | *34.73* |

Table 5 shows the average nitrate removal percentage on different dates. As it is seen there is a significant difference of 95% in nitrate removal except two dates.

TABLE 5: AVERAGE NITRATE REMOVAL PERCENTAGE ON DIFFERENT DATES

| | **Sampling dates** | | | | | |
|---|---|---|---|---|---|---|
| | **6th May-June** | **5th May** | **4th April** | **3rd March** | **2nd Feb.** | **1st Dec.-Jan.** |
| **Average temperature** | *30.1* | *27.6* | *23.2* | *17.4* | *11.5* | *9.6* |
| **Average % removal** | *31.94* | *30.23* | *29.96* | *28.86* | *27.20* | *26.03* |

## 4. DISCUSSION

Constructed wetlands with surface flow are a sufficient treatment choice for agricultural, industrial and urban wastewater treatment and a complement option for mine runoff and leachate waste [20]. In the current research application, constructed wetlands with surface flow was studied for agricultural runoff treatment. In constructed wetlands, the denitrification mechanism depends on pH and dissolved oxygen concentration as well as available organic carbon and nitrate concentration [21]. Chemical and biological water characteristics rely on pH and many bacteria are unable to survive outside of the range of $4.5<pH<9.5$. The best pH for denitrifying bacteria is about 7.2 and higher [22]. In this study inlet flow pH ranged from 6.9-7.4, which is adjusted to mentioned limits for denitrification. Biological treatment processes like nitrification and denitrification also depend on temperature [20]. When water temperature is less than 15°C or more than 30°C nitrifying bacteria growth is critically decreased and therefore denitrification becomes limited [23]. Moreover because of decrease in available DO in the months with lower temperature nitrate removal also decreased, thus by increasing microbial activity the best efficacy of treatment will be achieved.

## 5. Conclusion

According to the results, increasing the wetland retention time will increase nitrate removal efficiency, also root cultivated wetlands are more sufficient. Cultivation of Vetveria is relatively easy and economical with regard to temperature and rich sunlight resource in the country and remarkable treatment efficiency of constructed wetlands can be considered as an adequate option for small urban communities, rural, agricultural and industrial wastewater treatment.


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