# LIFE (Linked Institutions for Future Earth)

## Sixth Year Report to NSF: 2017-2018

## Award Number: EAR-1737872


## Lead PI: Efi Foufoula-Georgiou (University of California, Irvine)



## Please visit the LIFE website for previous annual reports:

http://life.eng.uci.edu/

# A. ACCOMPLISHMENTS – What was done? What was learned?

## *1. What are the major goals of the project?*

The overarching goal of LIFE (Linked Institutions for Future Earth) is to create an international network of researchers, institutions, and experimental sites/field observations dedicated to advancing the quantitative predictive understanding of the Earth surface system under natural and human-induced change.

LIFE focuses its efforts on research related to Earth surface vulnerability in two key environments: (a) watersheds and (b) river deltas, and implements its goals via the following closely linked programs: (1) Researcher exchange, (2) Shared and co-mentored postdoctoral researchers, (3) International shared graduate degree programs, (4) Theme-based focused research (mainly experimental and theoretical) campaigns, (5) International summer institutes for graduate students and young researchers, (6) Data/model sharing for actionable research, and (7) science-to-public international exchange.

## *2. What was accomplished under these goals (you must provide information for at least one of the 4 categories below)?*

### *2.1. Major international collaborative and educational activities:*

During the six years of the LIFE project collaboration has been enabled and fostered between researchers in the US and researchers in several countries including Italy, UK, India, Germany, Netherlands, Japan, France, Bangladesh, Vietnam, Brazil, Norway, Canada, China, and Chile. Several students, early career scientists, and senior scientists have traveled across institutions and a large number of collaborative publications, conference presentations and joint proposals have resulted. A special issue on river deltas has been published and several special sessions at AGU, EGU and JPU have been co-organized by international teams of the project. Also students have been co-advised across institutions on their undergraduate, MS and PhD theses and have gained valuable experience for their future career development. The collective activities of the project can be found in the project website http://life.eng.uci.edu/.

In the sixth year of the project, the major activities included:

(1) A *new Summer Institute at UCI called R2R-CAL* (Ridge to Reef - Climate and Life) to be hosted at UCI on August 21-29, 2018 in which around 40 students and young scientists are expected to attend and several international and US distinguished scientists are invited to lecture on climate change and local to regional to global socio-ecological impacts.

(2) The *Summer Institute on Earth surface Dynamics* (SIESD 2018) focusing on "Earth-surface math: evolution, signals, and connections" to be hosted at the St. Anthony Falls Laboratory, University of Minnesota on July 25th-August 4th, 2018. Approximately 40 students from all over the world were accepted to the SIESD 2018 and the top 2 international applicants were offered partial travel support from LIFE as needed, to enable their participation.

(3) Continued the "*Distinguished Lecture Series on Earth-Water-Life*" that brought a cadre of international experts to the US for collaboration with researchers and student LIFE participants.

(4) A short course on "*Experiments and Modeling* of Sediment Transport and Land Building Processes", hosted by our LIFE partner Institut de Physique du globe de Paris (IPGP) in Paris in May/June 2018. Professors Paola and Voller offered a one-week short course on the IPGP campus.

(5) Preparations have started for hosting the *12th International Precipitation Conference (IPC12)* at University of California Irvine. This conference has moved around the world since 1986 and after been hosted outside the US in the past decade it is great to come back to the US. It is attended by more than 250 international participants.

(6) Continued the institutional partnerships for scientific and educational exchange established under the NSF-EU LIFE-ECOPOTENTIAL initiative spearheaded by a meeting that took place in UCI in 2016. ECOPOTENTIAL is funded by EU-Horizon 2020 and the scope of the meeting was to coordinate scientific, programmatic, observational and educational activities on ecosystems as complex systems under climate and human stressors.

(7) Completed a 5-year international collaboration between several European researchers funded under the Horizon 2020 project DRIHM (Distributed Infrastructure for Hydrometeorology) and US researchers which established the join project: DRIHM2US for hydrometeorological research of high impact weather (see the joint publication: Parodi, A., D. Kranzlmueller, A. Clematis, E. Danovaro, A. Galizia, L. Garrote, M. Llasat, O. Caumont, E. Richard, Q. Harpham, F. Siccardi, L. Ferraris, N. Rebora, F. Delogu, E. Fiori, L. Molini, E. Foufoula-Georgiou, and D. D'Agostino, DRIHM(2US): an e-Science environment for hydro-meteorological research on high impact weather events, *Bull. Amer. Meteor. Soc.*, doi:10.1175/BAMS-D-16-0279.1, 2017.)

(8) Completed a 5-year international project funded by the Belmont Forum BF-DELTAS (US PIs funded by NSF and international PIs funded by their respective federal funding agencies) on sustainability of three river deltas: Ganges-Brahmaputra, Mekong, and the Amazon. This was a collaboration among 13 PIs from 13 countries (USA, UK, India, Germany, Netherlands, Japan, France, Bangladesh, Vietnam, Brazil, Norway, Canada, China) – see website (https://delta.umn.edu/) and more than 75 international publications resulted including a policy editorial on the Sustainable Development Goals (SDGs).

Szabo, S., R.J. Nicholls, B. Neumann, F.G. Renaud, Z. Matthews, Z. Sebesvari, A. AghaKouchak, R. Bales, C.W. Ruktanonchai, J. Kloos, E. Foufoula-Georgiou, P. Wester, M. New, J. Rhyner, and C. Hutton, Making SDGs Work for Climate Change Hotspots, *Environment: Science And Policy For Sustainable Development*, 58:6, 24-33, 2016.

Brondizio, E., E. Foufoula-Georgiou, S. Szabo, N. Vogt, Z. Sebesvari, F. G. Renaud, A. Newton, E. Anthony, A. V. Mansur, Z. Matthews, S. Hetrick, S. M. Costa, Z. Tessler, A. Tejedor, A. Longjas, J. A. Dearing, Catalyzing action towards the sustainability of deltas, *Current Opinion in Environmental Sustainability*, 19, 182-194, doi: doi:10.1016/j.cosust.2016.05.001, 2016.

(9) Several individual *visits of PIs, postdocs, and students* among LIFE participating institutions.

Some details of these activities are provided below.

**(1) A new Summer Institute at UCI called R2R-CAL (Ridge to Reef - Climate and Life) to be hosted at UCI on August 21-29, 2018.**

Renown speakers from around the world have been invited to lecture in the R2R-CAL Summer Institute and around 40 young researchers from around the world have been accepted to attend. This SI leverages the NSF-funded interdisciplinary national training program (NRT) Ridge2Reef (R2R) project at UCI for which LIFE PI Foufoula-Georgiou is a collaborator. The R2R-CAL theme will be on "Biodiversity in human-dominated landscapes" and will cover topics ranging from marine environments of urban coastlines, regional climate and hydrological projections, fragmentation and resilience of terrestrial ecosystems, and trends and patterns of human resource use and impacts on the environment. Students will not only get hands-on experience that will include spatial analysis techniques or remote sensing data including ArcGIS, machine learning algorithms, and statistical downscaling techniques, they will also

improve their professional development skills through science communication, policy and management as well as engaging in social activities that will enhance networking skills and foster long-term professional relationships.

**(2) SIESD 2018: Earth-surface math: evolution, signals, and connections. Summer Institute on Earth-surface Dynamics (SIESD) 2018 to be held on July 25th-August 4th, 2018 at the St. Anthony Falls Laboratory, University of Minnesota:** This year's Summer Institute focuses on the mathematical tools involved in earthcasting, with a particular focus on landscape connections and how signals (e.g. effects of climate change) are propagated through Earth-surface systems and recorded, whether in deposits or the current landscape. A desire to learn is essential, but training in advanced mathematics is not. The topics to be explored will include both erosional and depositional landscapes. Lectures and exercises on mathematical techniques will be complemented by experiments and observations at the St. Anthony Falls Laboratory.

**(3) The first "LIFE-ECOPOTENTIAL" Meeting on Ecosystem Management of Protected Areas, and NSF-EU cooperation meeting (University of California, Irvine).**

The meeting was organized by Lead PI Efi Foufoula-Georgiou (UCI), Antonello Provenzale (CNR, Italy), Travis Huxman (UCI), Matthew Bracken (UCI), and Kailen Mooney (UCI).

The other participants were Ghada El Serafy (DELTARES, Netherlands), Constantin Cazacu (University of Bucharest, Romania), Herman Hummel (NIOZ, Netherlands), Amy Hansen (University of Minnesota), Megan Lulow (UCI), Michael O'Connell (Irvine Ranch Conservancy), Anthony Longjas (UCI), Kristen Davis (UCI), Soroosh Sorooshian (UCI), Klaus Fraedrich (Max Planck Inst Hamburg), Ian Harrison (Conservation International), Kristin Byrd (USGS, Menlo Park), Henry (Hank) Loescher (NEON and INSTAAR), and David M. Theobald (Conservation Science Partners, USA).

The meeting brought together experts working on protected area design and management, ecosystem processes, landscape connectivity, adaptive planning, climate change, ecosystem benefit analysis, and the application of satellite information for ecosystem monitoring and biodiversity conservation.

**(4) Distinguished Lecture series on Earth-Water-Life (EWL):** This lecture series is designed to provide a forum for exchange of ideas, learning about the cutting-edge research of international groups affiliated with LIFE, and provide opportunities for students in our mutual programs to explore across-institutions research exchange visits for collaboration towards our LIFE objective of "advance discovery and actionable research in Watersheds and Deltas in a Changing Environment." The invited speakers were in residence for one week at the University of California, Irvine. They gave a seminar and met with students and researchers over extended meetings during that week.

Distinguished LIFE Speakers for 2017/2018:

1. ***Dennis Lettenmaier***, Distinguished Professor, University of California Los Angeles, Department of Geography, "*Hydrologic Change in the West*" (November 17, 2017)
2. ***Paolo Passalacqua***, Associate Professor, University of Texas Austin, Department of Civil, Architetural, and Environmental Engineering "*Connectivity in River Deltas: Observations, Modeling and Implications to Coastal Resilience*" (December 1, 2017)
3. ***Nikolaos P. Nikolaidis***, Professor, School of Environmental Engineering, Director EU-Critical Zone Observatory, Technical University of Crete, Chania, Greece, "*A platform for studying sustainable water and soil management in a Mediterranean watershed under land use and climate change*" (May 4, 2018)
4. ***Gianluca Botter,*** Associate Professor, University of Padova, Italy, "*Streamflow Regimes: Drivers, Classification & Implications*" (April 5, 2017).

5. ***Luigia Brandimarte***, Associate Professor, KTH Royal Institute of Technology, Sweden, "*Simple probabilistic methods for the design of hydraulic structures: Applications to bridge scour and flood protection*" (February 3, 2017).

Previous years' lecturers can be found in the annual reports (http://life.eng.uci.edu/) and include (selected international speakers):

1. ***Giuliano Di Baldassarre***, Professor Uppsala University, Sweden, "*Hydrological Extremes in the Anthropocene*" (October 28, 2016).
2. ***Alexander Densmore***, Professor, Institute of Hazard, Risk, and Resilience and Department of Geography, Durham University, *Why Fans Matter: Groundwater Abstraction and Decline in Northwestern India* (October 6, 2015)
3. ***Sebastien Castelltort***, Department of Earth Sciences, University of Geneva, Switzerland, *River basins as dynamic markers of crustal deformation* (May 22, 2015)
4. ***Sanjeev Gupta***, Professor of Earth Science, Department of Earth Science and Engineering, Imperial College, *Ancient Rivers, Ancient Civilizations, Present Water: Water and Life through Time in NW India* (Nov 18, 2014).
5. ***Cristian Escauriaza***, Assistant Professor, Department of Hydraulic and Environmental Engineering, Pontificia Universidad Catolica de Chile, *Complex Interactions of Turbulent Flows and Geochemical Processes in a High-Andean Watershed* (Sep. 9, 2014).
6. ***Francois Metivier***, Professor and Coordinator of the French Chinese International Laboratory on Sediment Transport and Landscape Dynamics, *Alluvial Fan Dynamics: Insight from Sandpiles, the Tianshan Piedmont and the Kosi River Megafan* (April 8, 2014).
7. ***Chris Keylock***, Associate Editor, Water Resources Research, Prize Senior Lecturer, Sheffield Fluid Mechanics Group, Department of Civil and Structural Engineering, University of Sheffield, *The Velocity-intermittency Structure of Ideal and Natural Turbulent Flows* (March 11, 2014).

**(5) IPG Paris short course on Experiments and Modeling of Sediment Transport and Land Building Processes (May/June, 2018):** Professors Paola and Voller continue to establish strong academic and research links with the Institut de Physique du globe de Paris (IPGP). In May/June 2018, Profs. Paola and Voller offered a one-week short course on the IPGP campus. The title of the course was "Experiments and Modeling of Sediment Transport and Land Building Processes." This course involves a relatively unique blend of real time experiments and modeling activities. Our hope is that this course will become a regular offering in the IPGP curriculum and that its format might provide a template for similar courses elsewhere in the LIFE network.

**(6) PI exchanges and Web collaboration ideas:** PI Foufoula-Georgiou presented at the AGU 2017 and EGU 2018 meetings and met with LIFE partners. As part of the LIFE supported research, PI Foufoula-Georgiou was invited to present a talk at UCLA, Caltech, EGU, and Stockholm University. PIs Chris Paola and Vaughan Voller visited IPGP for the short course in May/June 2018.

Postdoc Alejandro Tejedor visited several collaborators in Europe to advance our work on modelling river deltas using network theory and information-based methodologies (part of the Theme 2 of LIFE):

1. May 16-19: Second workshop on information theory and the earth sciences (http://swites.ihcantabria.com/).

This workshop is the 2nd in the series and gathers around 30 (mostly young) researchers for an intense exchange of theoretical and applied concepts on Information Theory and their use in problems of hydroclimatology and quantifying dependences among variables in complex systems. This is an educational component of the LIFE grant.

2. May 22 – Visit Alvaro Corral at CRM (Centre de Recerca Matematica) (http://www.crm.cat/en/About/People/Researchers/ACorral/Pages/PersonalInformation.aspx).

Extreme value theory under non-stationarity is an emergent topic of research and the visit of Alejandro Tejedor to CRM will initiate some new ideas related to hydroclimatic extremes.

3. May 24-26 – Visit Prof. Yamir Moreno at University of Zaragoza (http://cosnet.bifi.es/ ).

We have started a collaboration with Prof. Yamir Moreno on the newly emerging topic of multilayer directed graphs motivated by our interest to model the dynamics of delta river networks as they exchange fluxes with surrounding islands. Two papers are under review; one in *Physical Review X* and the other in *Geophysical Research Letters*.

The following international student visited PI Foufoula-Georgiou at UC Irvine for two months:

1. ***Nicola Durighetto***, University of Padova (Italy): "A stochastic view of the impact of flow regimes on mussel population dynamics: the Redwood River (US) case study". Sept 1 - Nov 29, 2017. He was co-advised by LIFE PI Foufoula-Georgiou and Professor Gianluca Botter (University of Padova, Italy).

Long-term international collaborators include:

1. ***Gianluca Botter*** (University of Padova, Italy) visited to finalize work on "Reducing Aggregation Bias of Water and Solute Travel Times in Heterogeneous Catchments via a Time-Variant Lagrangian Transport Formulation". The work was eventually published in Geophysical Research Letters.
2. ***Stefano Lanzoni*** (University of Padova, Italy) visited to discuss new ideas on proposing a new metric for Braiding Index based on entropy.
3. ***Jean-Louis Grimaud*** (MINES ParisTech, France) visited and discussed on precipitation driven knickpoints.
4. ***Diogo Bolster*** (University of Notre Dame) visited PI Voller at the St. Anthony Falls Laboratory, University of Minnesota last March 2017 to discuss work on flows in heterogeneous porous media.

## *2.2. Significant results:*

International research collaborations have been extensive as reported in Years 1-5 reports. Examples from Year 6 include:

(1) Collaboration with University of Zaragoza, Spain (Prof. Yamir Moreno).

### *a. Diffusion Dynamics and Optimal Coupling in Directed Multiplex Networks*

Multiplex networks have been intensively studied during the last few years as they offer a more realistic representation of many interdependent and multilevel complex networked systems. However, even if most real networks have some degree of directionality, the vast majority of the existent literature deals with undirected versions of multiplex networks. Here, we study the dynamics of diffusion processes acting on directed multiplex networks, i.e., coupled multilayer networks where at least one layer consists of a directed graph. We reveal anew and unexpected signature of diffusion dynamics on directed multiplex networks, namely that differently from their undirected counterparts, they can exhibit a non-monotonic rate of convergence to steady state as a function of the degree of coupling, resulting in a faster diffusion at an intermediate degree of coupling than when the two layers are fully coupled. We use synthetic multiplex examples and a real-world topology to illustrate the characteristics of the directed dynamics that give rise to a regime in which an optimal coupling exists. We further provide analytical

evidence to demonstrate that this new phenomenon is solely a property of directed multiplex, and more specifically in directed multiplex consisting of at least of one layer that exhibits large-scale directionality. Given the ubiquity of both directed and multilayer networks in nature, our results have important implications for studying the dynamics of multilevel complex systems.

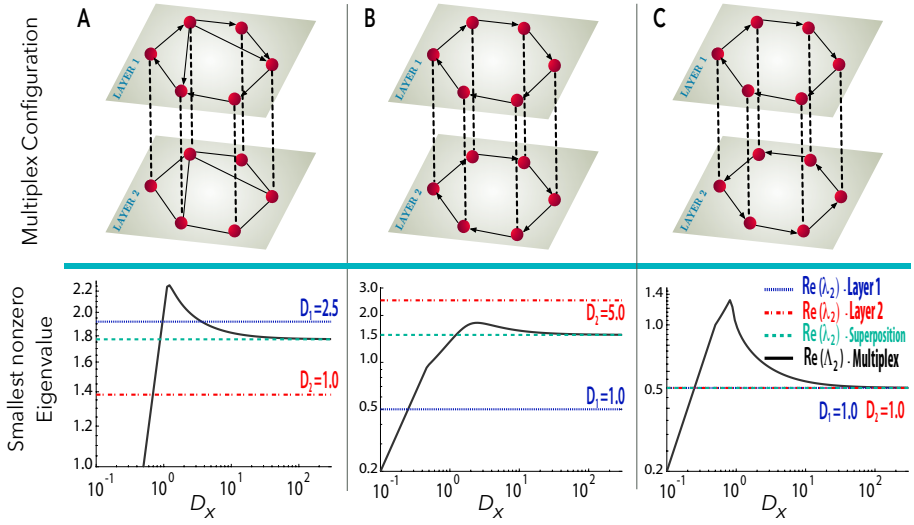


**Figure 1.** The top panels depict the three synthetic multiplex networks with two coupled layers: (a) corresponds to Multiplex-1; (b) to the Multiplex-2 configuration; and (c) to the Multiplex-3 architecture. Bottom panels show the behavior of the smallest (in terms of its real part) nonzero eigenvalue Re($\Lambda_2$) of the supra-Laplacian $L^{out}$ as a function of interlayer coupling, $D_X$.

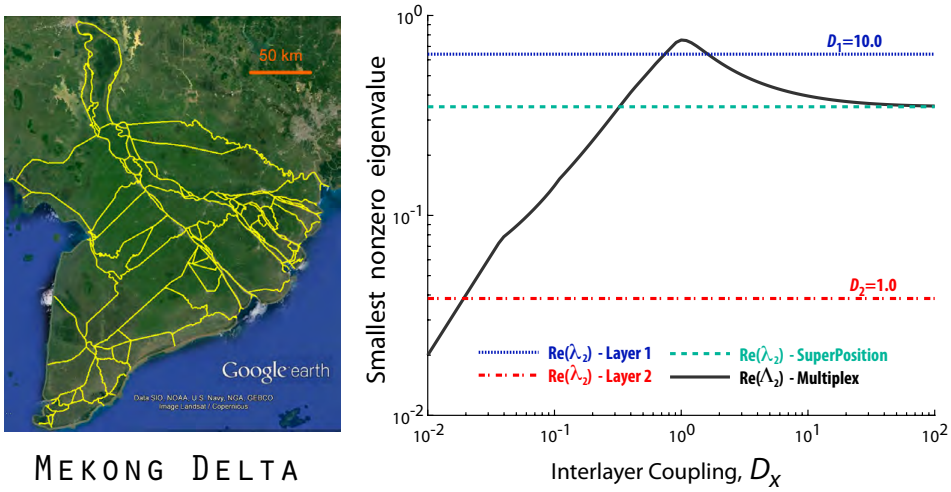


**Figure 2.** The Mekong delta Multiplex. The left panel shows the extracted channel network of the Mekong delta at 50 m resolution. The right panel shows the behavior of the smallest (in terms of its real part) nonzero eigenvalue Re($\Lambda_2$) of the supra-Laplacian $L^{out}$ corresponding to the Mekong delta multiplex as a function of $D_X$. For intermediate coupling rates, $D_X \sim 1$, maximum Re($\Lambda_2$) is observed.

Publication:

1. Tejedor, A., A. Longjas, E. Foufoula-Georgiou, T. Georgiou, and Y. Moreno, Diffusion Dynamics and Optimal Coupling in Directed Multiplex Networks, *Physical Review X*, in revision, 2018.

### *b. River deltas as Multiplex networks: A framework for studying multi-process multi-scale connectivity via coupled-network theory*

Transport of water, nutrients or energy fluxes in many natural or coupled human-natural systems occurs along different pathways that often have a wide range of transport timescales and might exchange fluxes with each other dynamically (e.g., surface-subsurface). Understanding this type of transport is key to predicting how landscapes will change under changing forcing. Here, we present a general framework for studying transport on a multi-scale coupled-connectivity system, via a multilayer network, which conceptualizes the system as a set of interacting networks, each arranged in a separate layer, and with interactions across layers acknowledged by interlayer links. We illustrate this framework by examining transport in river deltas as a dynamic interaction of flow within river channels and overland flow in the islands, when it is controlled by the flooding level. We show the potential of the framework to answer quantitatively questions related to the characteristic timescale of response in the system.

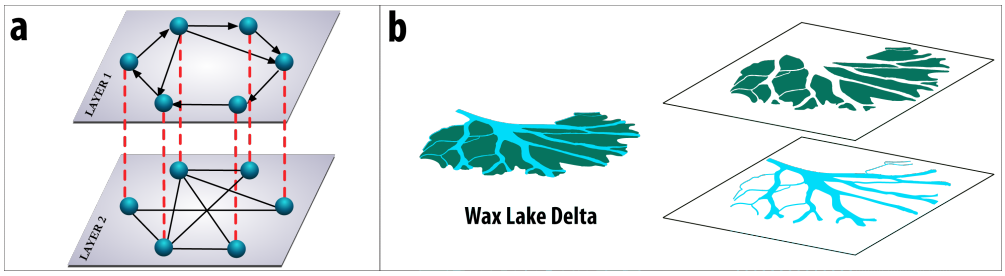


**Figure 3.** Delta Multiplex (a) *Illustration of a multiplex:* Multiplex are coupled multilayer networks where each layer consists of the same set of nodes but possibly different topologies (set of links) and layers interact with each other only via replica nodes in each layer (dashed lines) (b) *Wax Lake Delta Multiplex*. Illustration of the Wax Lake delta in the Louisiana coast (USA). The delta multiplex consists of two layers: Layer 1 (Bottom) accounts for the channel connectivity, and Layer 2 (Top) represents the connectivity that arises from overland flow on islands.

Publication:

1. Tejedor, A., A. Longjas, P. Passalacqua, Y. Moreno, and E. Foufoula-Georgiou, River deltas as Multiplex networks: A framework for studying multi-process multi-scale connectivity via coupled-network theory, *Geophysical Research Letters*, in revision, 2018.

(2) Collaboration with Prof. Gianluca Botter and Nicola Durighetto (University of Padova, Italy)

### *A stochastic view of the impact of flow regimes on mussel population dynamics: the Redwood River (US) case study*

The main goal is to investigate how streamflow regimes, as derived from the stochasticity of precipitation and the runoff generation processes, may affect the dynamics of riverine species. This is done by applying a model for mussel population on top of a stochastic rainfall-runoff model, to the Redwood River catchment closed at the USGS measuring station near Marshall. The agricultural conversion of the catchment from small grains to soybeans and corn and the related installation of subsurface drainage tiles dictated a subdivision of the streamflow data into two periods, separated by the hydrologic transition that occurred in 1983. The rainfall-runoff model was able to reproduce the streamflow regime of each season both before and after the hydrologic transition, reconstructing a pdf of the specific discharge that closely follows the probability distribution of the observed streamflows. The snowmelt water that drives the hydrology after the winter season is responsible of an increase in both the average streamflow and the persistency index that lasts until the summer, when hydrology becomes forced only by rainfall.

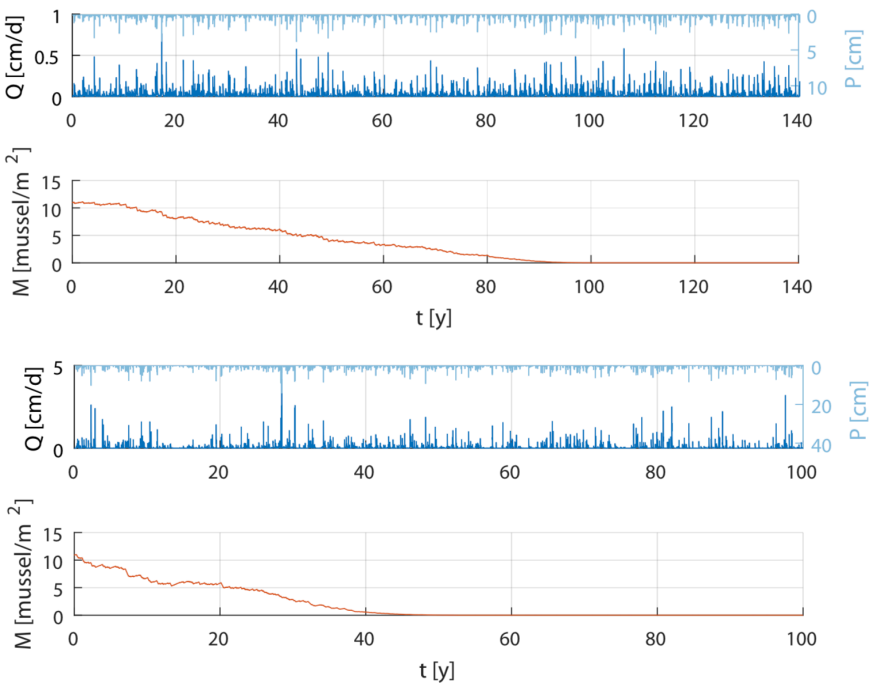


**Figure 4.** Generated streamflow and mussel population series for the basin before (top) and after (bottom) hydrologic transition, considering the whole simulated year.

The streamflow regime before the hydrologic transition was erratic and characterized by almost linear recessions. The strong engineering of the landscape that causes the hydrologic transition is responsible of an increase of both the mean streamflow and the non-linearity of the recessions. This shift leads to higher streamflow peaks after rainfall events that last for a shorter period of time, decreasing the persistency index and increasing the coefficient of variation of specific streamflow. The results of the coupled ecological-hydrological model show how an *increase* in mean streamflow and in its degree of erraticism (i.e. higher coefficient of variation) creates *detrimental* ecological conditions that eventually lead to a faster extirpation of the mussel population.

Publications:

1. Nicola Durighetto, University of Padova (Italy): "A stochastic view of the impact of flow regimes on mussel population dynamics: the Redwood River (US) case study".

2. Danesh-Yazdi, M., G. Botter, and E. Foufoula-Georgiou, Time-Variant Lagrangian Transport Formulation Reduces Aggregation Bias of Water and Solute Mean Travel Time in Heterogeneous Catchments, *Geophysical Research Letters*, 44, doi:10.1002/2017GL073827, 2017.

## *3. What opportunities for training and professional development has the project provided?*

In Year 6, Training has been provided via all LIFE activities, in the following categories:

(1) One-to-one mentoring of students and post-docs by LIFE participating institutions and PIs.
(2) Engagement of students, post-docs, and young PIs into interdisciplinary international research via working group meetings, international visits, short courses, and the Summer Institute on Earth surface Dynamics (SIESD).

(3) Mentoring of the next generation of students not only in research but also in broader impacts is accomplished via including into the SIESD program visits to the Science Museum of Minnesota, joint poster programs with the REU students hosted at the same time at the University of Minnesota (most of them minority students), and lectures on broader impacts and science communication.
(4) Providing travel funds from LIFE to young researchers for participation in the SIESD, R2R-CAL, and in international conferences (AGU, EGU etc).

## *4. How have the results been disseminated to communities of interest?*

The SIESD was announced in *Gilbert Club* mailing list as it was targeting the whole international community. It was also announced in the *Geomorphology* and *abouthydrology* mailing lists.

Annual progress reports and LIFE activities are posted in the http://life.eng.uci.edu/ website.

Annual reports of the international BF-DELTAS project are posted in the BF Deltas website: https://delta.umn.edu/content/publications.

The LIFE-sponsored Science-on-a-Sphere videos as part of the Great Cities Initiative are posted in the LIFE (http://life.eng.uci.edu/) and in the National Oceanic and Atmospheric Administration (NOAA) websites (http://sos.noaa.gov/Datasets/dataset.php?id=480). The videos are both in Spanish and English versions and are immediately available for download.

## *5. What do you plan to do during the next reporting period to accomplish the goals?*

In Year 7 we will plan the following major activities:

(1) The International Precipitation Conference (IPC) is an international conference that started in 1986 in Caracas, Venezuela. It was supported in the past by NSF but this support has not materialized in the past decade as the conference has moved to international hosting (Netherlands, Paris etc.). This international forum (attended by more than 200 scientists) comes back to be hosted in the US in 2019 and LIFE is undertaking this effort. LIFE will also sponsor young scientists to attend the 12$^{th}$ IPC.
(2) Continue the new Summer Institute at UCI called R2R-CAL (Ridge to Reef: Climate And Life) where we expect more than 40 young researchers from around the world to attend. This SI leverages the NSF-funded national training program Ridge2Reef (R2R) at UCI for which LIFE PI Foufoula-Georgiou is a collaborator.
(3) Organize the *"Stochastic Transport and Emergent Scaling on the Earth Surface"* (STRESS 5) workshop, which is 5$^{th}$ in a series of workshops aiming to increase international collaboration on a focused topic. The topic is on connectivity in earth surface dynamics, vulnerability assessment in coupled earth surface processes, and exploration of climate networks for identifying change climate modes and change.
(4) Continue the "*Distinguished Lecture Series on Earth-Water-Life*". This lecture series was introduced four years ago to provide a forum for exchange of ideas, learning about the cutting-edge research of international groups affiliated with LIFE, and provide opportunities for students in our mutual programs to explore across-institutions research exchange visits for collaboration towards our LIFE objective of "advance discovery and actionable research in Watersheds and Deltas in a Changing Environment."

(5) Short and long-term visits of research collaborators. For the following year we plan visits of several researchers, including: *Chris Keylock* (Prize Senior Lecturer, University of Sheffield) to advance joint work on landscape evolution using the extensive data we have collected on the eXperimental Landscape Evolution (XLE) facility where different uplift and precipitation rates were applied and high resolution scanned topographies recorded*; Remko Uijlenhoet* (Professor, Hydrology and Quantitative Water Management Group, Department of Environmental Sciences, Wageningen University, Netherlands); *Andreas Langousis* (Assistant Professor in Hydrology and Water Resources, University of Patras, Greece); and *Andrea Rinaldo* (Professor, Ecole Normale Polytechique de Lausanne, EPFL).

## B. PRODUCTS – What has the project produced?

Products for Years 1-5 can be found in the LIFE website: life.eng.uci.edu.

For Year 6, these products include:

### *1. Dissertations*

Mohammad Danesh-Yazdi (2017), "Inferring the Impacts of Anthropogenic Changes and Catchment Spatial Heterogeneity on the Water Cycle Dynamics and Transport Time Scales", University of Minnesota, http://hdl.handle.net/11299/185617. Supervised by LIFE PI Foufoula-Georgiou.

Zeinab Takbiri (2018), "Multi-satellite remote sensing of land-atmosphere interactions: Advanced data-driven methodologies for passive microwave retrievals of precipitation and flood," University of Minnesota. Supervised by LIFE PI Foufoula-Georgiou.

Nicola Durighetto (2018), "A stochastic view of the impact of flow regimes on mussel population dynamics: the Redwood River (US) case study", University of Padova (Italy). He was co-advised by LIFE PI Foufoula-Georgiou and Prof. Gianluca Botter (University of Padova, Italy).

### *2. Publications*

Mamalakis, A., J.-Y. Yu, J.T. Randerson, A. AghaKouchak, and E. Foufoula-Georgiou, A new interhemispheric teleconnection increases predictability of winter precipitation in southwestern US, *Nature Communications*, 2018.

Czuba, J. A., A. T. Hansen, E. Foufoula-Georgiou, and J. C. Finlay, Contextualizing Wetlands Within a River Network to Assess Nitrate Removal and Inform Watershed Management, *Water Resources Research*, doi:10.1002/2017WR021859, 2018.

Papalexiou, S. M., A. AghaKouchak, K. E. Trenberth, and E. Foufoula-Georgiou, Global, Regional, and Megacity Trends in the Highest Temperature of the Year: Diagnostics and Evidence for Accelerating Trends, *Earth's Future*, doi:10.1002/2017EF000709, 2018.

Belmont, P., and E. Foufoula-Georgiou (2017), Solving water quality problems in agricultural landscapes: new approaches for these nonlinear, multiprocess, multiscale systems, *Water Resources Research, 53*, 2585-2590, doi: 10.1002/2017WR020839

Czuba, J.A., E. Foufoula-Georgiou, K. Gran, P. Belmont, and P. Wilcock, Interplay between Spatially-Explicit Sediment Sourcing, Hierarchical River-Network Structure, and In-Channel Bed-Material

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## *3. Presentations*

Tejedor, A., A. Longjas, and E. Foufoula-Georgiou (2017), Modeling multi-process connectivity in river deltas: extending the single layer network analysis to a coupled multilayer network framework, EP52A-06, AGU Fall Meeting, New Orleans. **(INVITED)**

Singh, A., A. Tejedor, J.-L. Grimaud, and E. Foufoula-Georgiou (2017), Experimental evidence of rainfall driven knickpoints, EP51C-1664, AGU Fall Meeting, New Orleans.

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Papalexiou, S.M., E. Foufoula-Georgiou, and A. AghaKouchak (2017), Spatial coherence of extreme precipitation trends in the contiguous United States, H53D-1488, AGU Fall Meeting, New Orleans.

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Papalexiou, S.M., A. AghaKouchak, K.E. Trenberth, and E. Foufoula-Georgiou (2018), Global, Regional, and Megacity Trends in the Highest Temperature of the Year, EGU2018-11975, EGU General Assembly, Vienna, Austria.

## *4. Technologies or techniques*

Not applicable.

## *5. Inventions, patent applications, and/or licenses*

Not applicable.

## *6. Websites*

We have revamped our project web site, which we will update regularly and populate with our publications, presentations and products. The project website is currently hosted at the University of California, Irvine (transferred from University of Minnesota): http://life.eng.uci.edu/.

The web site of the international BF-DELTAS deltas, leveraged by the LIFE project, includes an extensive list of international activities during the five year duration of the project: https://delta.umn.edu/.


## *7. Other products, such as data or databases, physical collections, audio or video products, software or NetWare, models, educational aids or curricula, instruments, or equipment*

The data produced by LIFE will be handled in the same way as the NCED data, that is, stored in an easy to access format in the NCED web site and available to the research community at large and the public. Currently, discussions are taking place with SEAD (Sustainable Environment- Actionable Data) at the University of Michigan to mainstream and improve the storage and retrieval of the NCED2 and LIFE data and use them as demonstration case studies. A preliminary such case study with NCED data has already been developed.

## C. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS – Who has been involved?

### *1. What individuals have worked on the project?*

People that have contributed to the LIFE project by exchanging research ideas:

Efi Foufoula-Georgiou (University of California, Irvine)

Chris Paola (University of Minnesota)

Vaughan Voller (University of Minnesota)

William Dietrich (University of California, Berkeley)

Paola Passalacqua (University of Texas, Austin)

Praveen Kumar (University of Illinois, Urbana-Champaign)

Patrick Hamilton (Science Museum of Minnesota)

Vladimir Nikora (University of Aberdeen, UK)

Liam Reinhardt (University of Exeter, UK)

Francois Metivier (IPGP, France)

Antonio Parodi (CIMA Research Foundation, Italy)

Daniel Conde (Universidad de la Republica, Uruguay)

Cristian Escauriaza (Pontifica Universidad Catolica de Chile)

Rina Schumer (Desert Research Institute, Reno)

Lauren Larsen (University of California, Berkeley)

Chris Keylock (University of Sheffield, UK)

Stefano Lanzoni (University of Padova, Italy)

Gianluca Botter (University of Padova, Italy)

David Mohrig (University of Texas, Austin)

Arvind Singh (University of Central Florida)

Barbara Burkholder (University of Minnesota)

Diana Dalbotten (University of Minnesota)

Antonello Provenzale (CNR, Rome, Italy)

## *2. What other organizations have been involved as partners?*

None entered.

## *3. Have other collaborators or contacts been involved?*

Yes.

**D. IMPACT – What is the impact of the project? How has it contributed?**

## *1. What is the impact on the development of the principal discipline(s) of the project?*

LIFE Research advances understanding of deltas and watersheds that spans the disciplines of geomorphology, hydrology, river biology, ecology, water resources engineering, and socio-economic sciences. The researches of the PIs have contributed original ideas to (1). *Optimal Coupling in Directed Multiplex Networks*, (2) *Studying multi-process multi-scale connectivity via coupled-network theory*, and (3) *Impact of flow regimes on mussel population dynamics.*

## *2. What is the impact on other disciplines?*

The two research themes of LIFE (quantifying vulnerability and resilience of watersheds, coastal areas, and deltas in a changing environment) are by nature multi-disciplinary (hydrology, geomorphology, ecology, engineering, social sciences). The quantitative frameworks developed by life PIs can be used for analysis in other disciplines.

## *3. What is the impact on the development of human resources?*

The LIFE project is a collaboration of several, international and diverse teams of specialists with expertise in the geosciences and engineering. Students and young researchers are exposed to an interdisciplinary approach to scientific research and a combination of theoretical approaches, models, fieldwork and survey-based analyses. Special emphasis on broader impacts and in bridging research, education, and science-policy that affects society is embedded in all activities of LIFE.

The Science Museum of Minnesota (SMM), a LIFE partner, is featuring an exhibit called "Future Earth" where the impacts of humans on the future of our resources are explained for the public. With financial support from LIFE, SMM produced four "Science-on-a-Sphere" films as part of the Great Cities Initiative. The videos are both in Spanish and English versions and are immediately available for download.

## *4. What is the impact on physical resources that form infrastructure?*

LIFE uses extensively the experimental laboratories in the U.S. and abroad (the St. Anthony Falls Laboratory at the University of Minnesota and the laboratory facilities at IPGP, France) for both education and research. In subsequent years more facilities will be engaged in the projects both in collaborative research and training.

## *5. What is the impact on institutional resources that form infrastructure?*

Not applicable.

### *6. What is the impact on information resources that form infrastructure?*

Not applicable.

### *7. What is the impact on technology transfer?*

Not applicable.

### *8. What is the impact on society beyond science and technology?*

Delta and watershed research is immediately relevant to the livelihood of people that live there and the goods that they produce. Our research findings are expected to play a major role in informing management and policy decisions in watersheds and deltas undergoing change.

## E. CHANGES/PROBLEMS

### *1. Changes in approach and reasons for change*

None

### *2. Actual or Anticipated problems or delays and actions or plans to resolve them*

None

### *3. Changes that have significant impact on expenditures*

None

### *4. Significant changes in use or care of human subjects*

None

### *5. Significant changes in use or care of vertebrate animals*

None

### *6. Significant changes in use or care of biohazards*

None

## SPECIAL REQUIREMENTS

None