United States
Environmental Protection
Agency

EPA/600/F-11/004 | March 2011 | www.epa.gov/ord

Experimental Stream Facility
Design and Research

Providing Research Solutions to Manage Water Quality

Office of Research and Development
National Risk Management Research Laboratory

Background

The Experimental Stream Facility (ESF) is a valuable research tool for the U.S. Environmental Protection Agency's (EPA) Office of Research and Development's (ORD) laboratories in Cincinnati, Ohio. This brochure describes the ESF, which is one of only a handful of research facilities in the United States designed to conduct small stream research.

The Need for Small Stream Research

Small stream ecosystems comprise over 72% of the river miles in the U. S.; yet, the role they play in managing watershed-level water quality is uncertain. While the potential impact of naturally occurring biogeochemical functions within an individual small stream may seem minimal, the accumulated impact of the many small streams within a watershed may be significant. Small streams are largely unmapped, unregulated, overlooked in watershed models, and generally not considered in the total maximum daily load (TMDL) process or in land use regulations. As such, they are often ignored in land development plans, and are often replaced with culverts, storm sewers, or lined ditches, which eliminates any role they may play in maintaining water quality. Research is needed to increase our understanding of the relative importance of small stream ecosystems and the services they provide for effective watershed management.

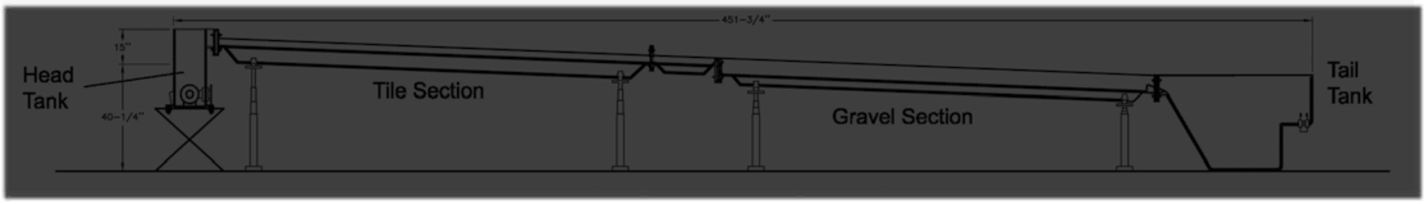
In addition to watershed management research, there is a continual need to better characterize how streams and rivers, in general, react to and process emerging contaminants and stressful mixtures. The numerous physical, chemical, and biological variables interacting under natural conditions, as aquatic ecosystems are exposed to contaminants of concern, confound the interpretation of effects on aquatic biology in receiving streams. Mesoscale studies are needed to gain a better understanding of the impact of contaminant stressors on multiple trophic levels and the levels which are the most sensitive to stress.

As a final point, biotic indicators form the basis for stream condition assessment in this Nation, but current design criteria for watershed best management practices (BMPs) are based largely on peak flow control and sediment removal. Research is needed to begin to bridge the gap between physical-based engineering design and biological-based assessment criteria.

The Need for the Stream Facility

The facility has eight stream mesocosms; a mesocosm is an experimental system designed to simulate natural conditions, often by using naturally occurring organisms and artificial

Experimental stream mesocosms



structures that simulate nature as closely as possible. Mesocosm design provides a balance between the benefits of a controlled laboratory study (e.g. controlled flow rates, solar irradiance and streambed type) and the benefits of a field study (e.g. continuous biota for colonization, and natural variability of biota and water quality). This allows researchers to study how pollutant loads interact with important characteristics of stream habitat that may or may not change as a result of anthropogenic stress. Changes to the stream ecosystem structure and function can be measured and observed in ways that are not possible in field or laboratory studies. Well designed and controlled experimental stream mesocosm studies can represent a primary tool for providing the process-level understanding necessary to move basic research and development from the laboratory bench-top to field applications.

Research Approach

ESF studies are designed to obtain information on both watershed management and the impact of contaminants of concern.

Watershed Perspective

The ESF sits at the downstream end of the watershed of the East Fork of the Little Miami River (1295 km^2 / 500 mi^2), and experiments are designed with watershed scale management as one focus of the studies. Studies at the ESF afford EPA the opportunity to collect and analyze data on in-stream process-level biological, chemical, and physical interactions. Each ESF study is designed to provide information on small stream ecosystem structure and function that can be used for the development and testing of: new indicators of ecological stress; water quality monitoring technologies; watershed monitoring strategies; and water quality management methods and models. Characteristics of small stream sub-watersheds in the East Fork watershed provide information for the design of ESF experiments, and the results of ESF experiments are subsequently incorporated into a multi-spatial scale watershed research plan designed to characterize, track, and model changes to water quality

associated with the National Pollutant Discharge Elimination System (NPDES) and the Safe Drinking Water Act -associated BMP implementation projects. Hence, an overarching goal is to develop numerical descriptions of these stressor-biotic linkages for watershed models used as decision support in TMDL and TMDL-like analyses of watershed management.

Contaminant Perspective

The ESF mesocosms are especially useful for studying the impacts of contaminants of concern (e.g. endocrine disruptors, pharmaceuticals, pesticides) on the natural stream biota. Contaminants can be added at environmentally relevant levels; levels observed in natural ecosystems and reported in the literature. Exposure at these levels lets researchers observe more subtle changes (e.g. gene and protein expression) in stream biota as well as changes in biotic communities and ecosystem structure and function. This approach provides additional information to laboratory studies which commonly use lethal effects (e.g. LC_{50}) as the endpoint. The post-dose recovery period built into each experiment provides additional information on the ability of the biota to recover when the contaminant is removed from the ecosystem. The relative importance of specific changes in stream habitat (e.g. sediment load, flow rates) on contaminant impact can be simulated and are often included as interacting variables. Additional biotic indicators can be studied through the use of emergent traps, fish deployments, in-stream invertebrate exposures, and real time biomonitoring. Interactions and effects observed in the ESF setting help identify important assessment endpoints, and inclusion functions for field-scale models of the fate and transport.

Experimental Framework

Natural river water flows through the ESF, which allows studies to be conducted when stream biota are most abundant and active, approximately mid-March through late October. Typically two experiments are conducted per year, with each experiment running for about 12-15 weeks: 4-6 weeks for colonization of the streams by natural biota; 4-6 for applying a stressor(s) such as a chemical dose or flow manipulation; and 3-4 weeks for stream recovery after the stressor period ends.

Base Analytical Endpoints

The baseline analytical endpoints for each experiment include: sediment size fractions; carbon, nitrogen, and phosphorus in sediments; inter-gravel water nutrient species concentrations; surface water temperature, conductivity, pH, dissolved oxygen, oxidation/reduction potential, and turbidity; stored organic matter; invertebrate community structure; periphyton (a gelatinous matrix, also known as a biofilm, that may consist of attached algae, bacteria, fungi, trapped fine sediment and deterital material, and microinvertebrates that use it both as a food source and habitat); per capita invertebrate drift emigration rates; periphyton chlorophyll-a concentrations; carbon, nitrogen, and phosphorus in periphyton; surface water nutrient species concentrations; and algal community structure. These data are acquired and managed across all ESF studies, and are likewise a part of the associated field research. They serve as a basis for meta-analyses, scaling ESF results to the field, or comparing against novel indicators of exposure and stress.

The Research Team

National Risk Management Research Laboratory (NRMRL) is responsible for the operation, maintenance, and facilitation of the experiments at the ESF. However, the experimental designs are developed and implemented by a multi-disciplinary team of research scientists and engineers, and technical support personnel from across EPA's ORD laboratories. The lead for each experiment can be a researcher from any of the EPA laboratories. Using the combined expertise of the multi-disciplinary team members optimizes coordination, leverages resources, and encourages collegiality in the integration of both risk assessment and risk management objectives into novel experiments.

Scientist and engineers

The Experimental Stream Facility

The facility, located in Milford, Ohio, was originally built by the Proctor & Gamble Company, and was well known as a premier laboratory in the area of mesocosm research in ecotoxicology and risk assessment. The facility is currently owned by Clermont County, and became available to EPA in 2005, through a lease with the County (some lab and office space is used by the Clermont County Sewer District Water Quality Testing Laboratory). Since taking occupancy, EPA has made several modifications to the facility which make it a unique small stream research laboratory. The capabilities of the facility have been extended for research applications in the fields of ecohydrology/sedimentology, biogeochemistry, and risk management.

Experimental Stream Configuration

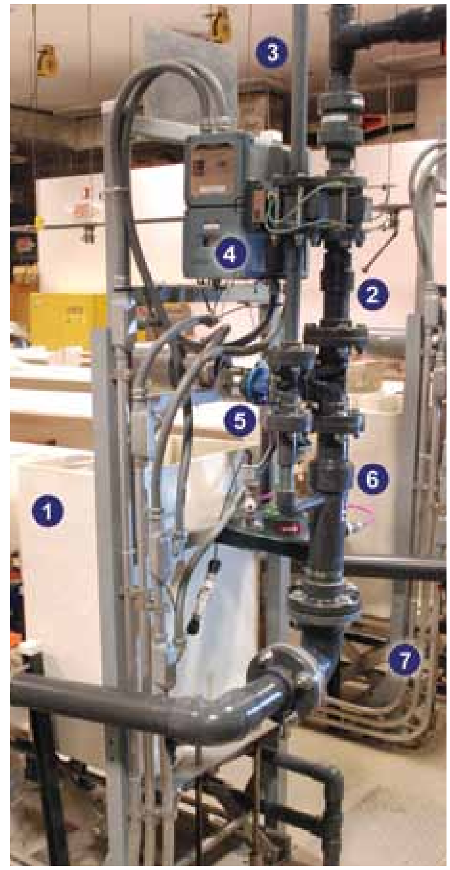
Each stream mesocosm includes a head tank, an upper biotic colonization channel, a lower biotic colonization channel, a tail tank, and a water recirculation system (see figure, page 4), and is 12 meters (m) long, or 39 feet (ft). The upper channel typically has a tile streambed, and the lower channel usually has a gravel streambed, but the channels can be interchanged. A small pool section can be added between the upper and lower channels. Plastic or stainless steel mesocosms are available, depending upon the physiochemical properties of the contaminant under study. A removable baffle to subdivide the channel sections into like units is optional for increasing statistical replication.

Head Tank

All source water, chemical dose, and recirculated water flows pass through an in-line mixer into the bottom of the 126 liter (L), or 33 gallon (gal), head tank. Water flows over a rectangular weir into the upper channel section. The head tank is mounted on a jacking system which can raise or lower the head tank, which allows the channel slope to be varied between 0 and 4.3% to simulate different stream flow conditions.

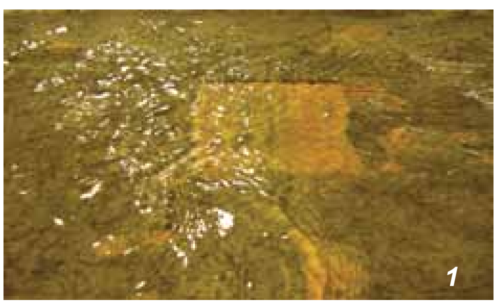
Head Works

1) Head Tank
2) Main River Water Influent
3) Alternate Water Source Influent
4) Flow Meter-Transmitter
5) Actuator
6) Chemical Dose Influent
7) Scissor Jack-Slope Control



Tile Section

The upper channel is usually configured to simulate large, flat rocks in a glide reach of a natural stream where periphyton attach and grow. The channel is approximately 30 centimeters (cm), or 12 inches (in), wide; 9 cm (3.5 in) deep; and 4.5 m (14 ft) long. It is usually lined with 47 rows of unglazed ceramic tiles, with 3 tiles per row. The tiles provide a defined surface area, as well as a removable substrate for the growth of periphyton. Water moves through this section in a more laminar flow at a depth of 2.5 cm (1 in). The tiles are sampled randomly during an experiment to derive several measurements, such as algal biomass, stored nutrients, and periphyton community structure.

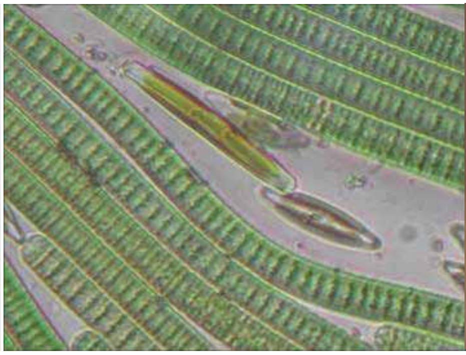


1. Tiled sampled in low light channel 2. Tiled sampled in highlight channel 3. Cyanobacteria in tile section

Gravel Tray Section

The lower channel is usually configured to simulate a riffle in a natural stream where small rocks and gravel provide both substrate for periphyton and shelter for aquatic invertebrates. The channel is approximately 50 cm (21 in) wide, 17 cm (6.5 in) deep, and 4.5 m (14 ft) long. It contains an array of gravel-filled plastic trays in 15 rows, with 3 trays per row (mesh baskets can be used instead of plastic trays to allow interflow between sampling units.). Gravel (small river rock) ranging in size from 1.5 to 4 cm (0.6 to 1.6 in) diameter has been used to date, but substrates ranging from fine silt/clays to smaller gravel could be used depending on experimental objectives. Each gravel tray provides a removable substrate of defined volume and area, which can be used to quantify many of the base analytical endpoints.

Water moves through this section in a more turbulent flow at a depth of 5 cm (2 in), and water jets can be configured in this section to simulate peak flow velocities during storm events. Gravel trays are also sampled randomly during an experiment. Similar gravel trays are used at several field sampling locations in the East Fork Watershed, and provide the same base analytical endpoint data. Standard operating procedures have been written for sampling, processing, and analyzing all variables obtained from the gravel trays and the tiles.



1. Trays at the start of experiment 2. Trays with accumulation & recently replaced trays 3a-c. Gravel biota 4. Samplers are buried in gravel 5. Sampled tray

Drift Measurements

Invertebrate drift responses can be measured by positioning drift nets to isolate the gravel section. The upstream net secludes influent drift, while the downstream net catches all organisms drifting from the gravel during the measurement period. Per capita emigration is determined as the number of individuals captured by the downstream net divided by their respective density counted in the gravel section.

Upstream Drift Net

Tail Tank

A 222 L (59 gal) tail tank at the end of each mesocosm simulates conditions of a pool in a natural stream channel. The tail tanks house continuous clam-based behavioral biomonitoring and real-time water quality sensing equipment, and can be configured for exposing larger stream biota (i.e., fish). Side-streams are plumbed in-line with the discharge from each mesocosm to supply flow to additional small tanks for other biotic exposure options. The biomonitors allow behavioral responses to be tracked in relation to the measured changes in stream structure and function. Outflow from the tail tank can be discharged under an NPDES permit or sent to the neighboring wastewater treatment plant. A new version of clam biomonitors is currently being tested.

Tail tank with exposure cage

Clam biomonitor housing in tail tank

Clams in biomonitor; plunger moves proportional to shell gape

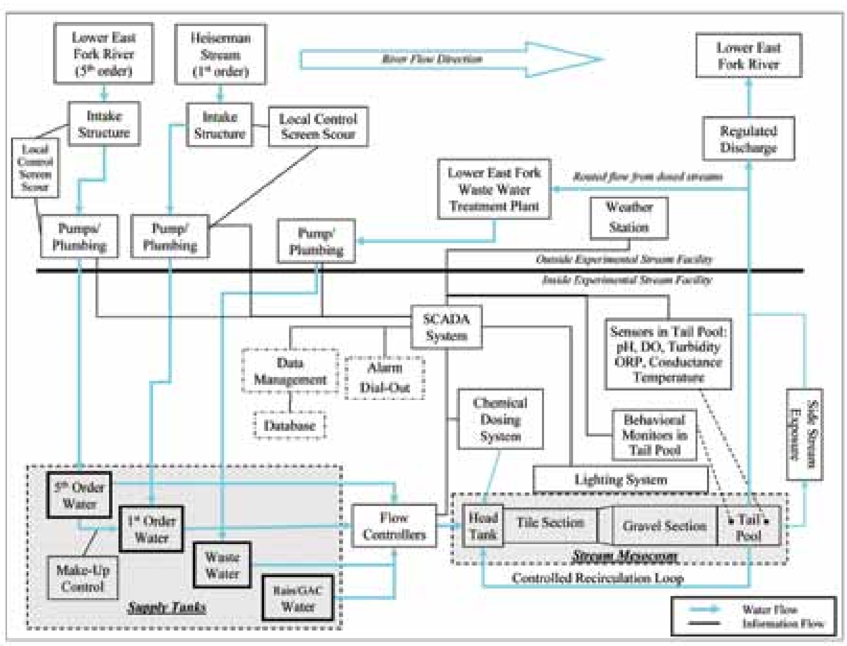
Recirculation System

Recirculation loops with pumps can return water at a constant pre-set flow rate from the tail tank to the head tank for each mesocosm, which allows residence time to be manipulated while maintaining velocities and turbulent features for the biotic colonization sections. This can be important for studies considering the fate and transport of stream solutes. The recirculation flow can also be diverted to the head tank of an adjacent mesocosm so that the effluent of one mesocosm can serve as influent to another, allowing up to eight streams to be studied in series.

1. Tail tanks 2. Recirculation line from tail tank to pump 3. Flow meter on recirculation loop

Unique ESF Features

There are several unique features that make the ESF a one-of-a-kind facility for conducting controlled, flow-through, meso-scale simulation studies of stream ecosystems. The process flow diagram below depicts the key components and linkages of the process-controlled systems.



Multiple Water Sources

Water is pumped into four ESF supply tanks from several sources, and flows by gravity from the supply tanks to each mesocosm. Each mesocosm has two sets of piping, flow meters, and computer-controlled valves to allow water from two supply tanks to flow to the head tank of each mesocosm. Flow through one set can be controlled within 0.38 liters/minute (L/min), or 0.1 gallons per minute (gpm), in the range of 19 to 190 L/min (5 to 50 gpm). Flow though the other set can be controlled within the range of

East Fork River intakes

East Fork River main channel

ESF water supply tanks

0 to 57 L/min (0 to 15 gpm). This flow control, along with the ability to adjust the mesocosm slopes, allows for a range of controllable in-stream velocities.

Natural water flow can be supplied from two nearby sources: Heiserman Stream, a relatively unimpacted headwater stream, or the East Fork, a 6th order river channel. The East Fork water has two to three times the carbon and nutrient concentration of the Heiserman water. The availability of water from such different stream sources expands the natural simulation horizon of ESF experiments.

Tertiary wastewater effluent (oxidation ditches followed by clarification and sand filtration) from the adjacent Lower East Fork Wastewater Treatment Plant (WWTP) is pumped to an ESF supply tank which can be aerated to avoid stagnation. Excess wastewater is routed back to the WWTP. The availability of wastewater allows the effects of emerging contaminants in wastewater to be studied alone or in combination with other variables. Finally, carbon-treated tap water is also available for experiments.

Grow lights - low light channels

Variable Simulated Solar Irradiance

High intensity grow lights provide simulated sunlight to fuel primary production in ESF mesocosms. The ceiling mounted lights provide daily-integrated irradiance of approximately 12% of unshaded (open-field) photosynthetically active radiation (PAR), which is similar to that experienced by a forested stream where leaves in the tree canopy shade the channel. Additional lights can be configured to provide daily-integrated irradiance of approximately 100% of unshaded (open-field) PAR to simulate a stream flowing through an agricultural field or developed area without a forested riparian buffer. The lights are programmed to run on a 24-hour cycle based on the ESF's geographical location.

High light channel

Continuous Water Quality and Climate Monitoring

Each mesocosm has sensors in the tail tank that measure the surface water quality base analytical endpoints listed previously. The sensors continually transmit the water quality data for each mesocosm at five minute intervals to the data acquisition system. A complementary set of these sensors monitors the influent waters to the facility. The ESF has an outdoor weather station and indoor sensors to continuously monitor PAR, air temperature, and humidity. Precipitation is continuously tracked by the outdoor station as well.

Continuous water quality monitoring equipment

Chemical Dosing System

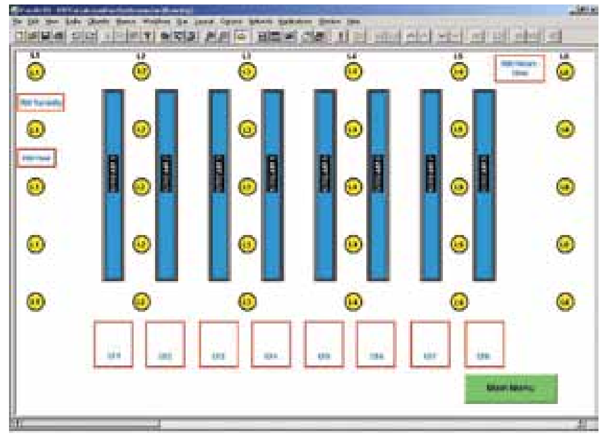
Chemical doses of stressors/pollutants can be metered into the head of each mesocosm from the chemical delivery system. Doses are continuously mixed in 570 L (150 gal) stainless steel tanks. The chemical feed pumps are accurate to within 0.5 milliliters/minute (ml/min), or 0.2 gallons per day (gpd), within the range of 25 to 150 ml/min (9.5 to 57 gpd), and are integrated with pressure transducers to ensure even pumping and fail safe operation. They work together with meters and valves on the river flow lines to provide constant in-stream dose concentration over extended dosing periods (e.g. 30 days, typically).

Chemical dosing tanks

Supervisory Control and Data Acquisition

A supervisory control and data acquisition (SCADA) system performs several functions:

- monitors/controls natural river, wastewater, and recirculation flows;
- activates/controls the timing of the simulated solar irradiance;
- monitors/controls the chemical delivery system;
- acquires data from all the continuous water quality and behavioral monitoring sensors; and
- initiates phone calls to the operators in case of any system failure (e.g. low water flow).



Screenshot of SCADA System

Data files generated within the SCADA system are transferred to a data storage device, in which data management functions are housed. An effort is underway to make data accessible to all collaborators via email or the web.

Programmable Environmental Triggers

Logic control algorithms can be written for the SCADA system that trigger changes in flow rate, chemical dosing, or flow distribution (river inflow vs. recirculation) in response to natural changes in climate or water quality. Some examples include mesocosm flow regimes that can be programmed to change at the onset of a rain event, as detected by the weather station, or a change in water quality, as detected by one of the real-time sensors in the tail tank. The timing and proportion of flow that is recirculated can be used to manipulate sediment accumulation, colonization rates, and/or discharge rate from each mesocosm. Contaminant dosing can be programmed to be continuous or intermittent and triggered by a rain event.

Significance

Understanding the impact of contaminants on small streams, and reducing the loading of stressors to watersheds, is of concern to environmental stakeholders, including local and state governments, utilities, developers, and homeowners. Knowing how contaminants of concern affect aquatic biota will help determine which stressors are most important for the consideration of environmental regulators. Adoption of the watershed approach and best management practices to control both urban and rural sources of waterborne pollutants is helping to reduce contaminants at the watershed level. The chief beneficiaries are the environmental decision makers who will use the ESF data in watershed models to better characterize how streams react to, and process, emerging contaminants and stressful mixtures, and to quantitatively link known stressors in stream flow with the structure and function of stream ecosystems.

Contacts

Technical Contact

Christopher Nietch PhD
Systems Ecologist
U.S. Environmental Protection Agency
Office of Research & Development
National Risk Management Research Laboratory
Water Suppy & Water Resources Division
(513) 569-7460 nietch.christopher@epa.gov

Communications

Michelle Latham
Biologist/Communications Specialist
U.S. Environmental Protection Agency
Office of Research & Development
National Risk Management Research Laboratory
Water Supply & Water Resources Division
(513) 569-7601 latham.michelle@epa.gov

EPA Scientist leading a tour at the Experimental Stream Facility.

Resources

Website

Experimental Stream Facility
http://www.epa/nrmrl/wswrd/wqm/esf/esf.html

Video

U.S. EPA (2009) Experimental Stream Facility - Design and Research
http://www.youtube.com/user/USEPAgov#play/uploads/5/jwOlYv7heE4

Fact Sheet

Experimental Stream Facility
(EPA/600/F-08/006)
http://www.epa.gov/ord/NRMRL/pubs/facilities/600f08006.pdf

United States
Environmental Protection
Agency

Office of Research and Development
National Risk Management Research Laboratory
Cincinnati, Ohio 45268

Official Business
Penalty for Private Use
$300

PRESORTED STANDARD
POSTAGE & FEES PAID
EPA
PERMIT NO. G-35

Printed with vegetable-based ink on paper that
contains a minimum of 50% post-consumer fiber
content and processed chlorine free.