

# Engineering for Restoration of Rivers and Improved Ecological Systems: Recommendations for Academic Curricula<sup>1</sup>

A Working Draft

Curriculum Working Group<sup>2</sup>  
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**Abstract** - The background required for practitioners in river restoration is interdisciplinary and includes physical, chemical, thermal, ecological, biological, and management processes in river basins. A myriad of processes (hydrological, hydraulic, geomorphic, sediment transport, thermal and chemical) provide a framework within which ecological and biological functions support life. Research and development in these areas, establishing a foundation of sound science and engineering, has intensified worldwide, as a result of widespread recognition of the importance of sustainable and environmentally acceptable use of water resources. Engineering and management of river basins demand the application of interdisciplinary knowledge, and a design philosophy, to produce environmentally sensitive and adaptive engineering works that restore river functions and values. Recognizing the need for educating and training engineers and other professionals in these interdisciplinary components is the main goal of this effort. The American Fisheries Society Bioengineering Section established a subcommittee to identify curricular needs for educating future river restoration engineers. This subcommittee consists of academics, agency personnel and private consultants active in the fields of river and ecological restoration, fish passage, and dam removal engineering. This document is a first attempt at identifying a basic curriculum through the MS degree that provides the background needed to enter the practice of river restoration and related fields. The target student is assumed to have an undergraduate degree in Civil or Environmental Engineering emphasizing water resources. An effort is made to identify where students could feasibly receive the background topics identified as desirable at either the BS or MS level.

## Introduction

The background required for river restoration practitioners is highly interdisciplinary; it requires a comprehensive understanding of the physical, chemical, ecological, biological, socio-economic, and management processes that affect river basins. The myriad of physical and chemical processes (hydrological, hydraulic, geomorphological, thermal, pollutant- and sediment-transport) provide a framework within which ecological and biological processes function to support life. All of these processes must, in turn, be considered within the context of a broad socio-economic framework, which recognizes the importance of sustainable and environmentally-acceptable use of aquatic resources.

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The practice of river restoration has flourished under increased ecological awareness, which calls into question the efficacy of current educational curricula to meet the need for educating and training engineers and other professionals in these various interdisciplinary components. While there have been many gains in the fields relating to river restoration in the last two decades, there has been no attempt to bring this learning to the academic environment in a comprehensive and certifiable way. Two unmet needs have been identified:

1. lack of academic training in fish passage resulting in a burden of extensive on the job training for the fisheries agencies (state and federal) as well as consulting firms that specialize in fish passage.
2. lack of appreciation and knowledge of the broader discipline of River Engineering resulting in frequently missed opportunities for preserving living river functions when doing engineering projects in or near the river, and the lack of a pool of academically trained experts to draw on when doing engineering for river restoration work.

At its August 2002 national meeting, the American Fisheries Society (AFS) Bioengineering Section (Section) established the Curriculum Working Group (Working Group) to identify the curricular requirements for educating future river restoration engineers. This subcommittee consists of academics, non-profit and agency personnel, and private consultants active in the fields of river and ecological restoration. Some have been teaching short and semester long courses in some of these subjects. Several are recognized (inter)national experts. Contacts were made for contributions beyond the Working Group with U.S. Geological Survey and U.S. Fish and Wildlife Service. Those personnel made valued contributions on fish passage.<sup>3</sup>

After the curriculum was drafted, it was circulated to other practitioners<sup>4</sup> and academics<sup>5</sup> in the discipline for further refinement. This effort and the need for the curriculum resonated with both groups. The Working Group met several times to consider and incorporate the comments of the academics and practitioners as well as revisions from Working Group members.

This document is an initial attempt at defining a basic curriculum through the MS degree that would provide the background necessary to enter fields related to river restoration. Suggestions for preparation at the undergraduate level needed to pursue this MS degree are included. The target student is assumed to have an undergraduate degree in Civil or Environmental Engineering, with an emphasis on water resources. The Working Group tried to identify where students could feasibly receive the desirable background topics at either the BS or MS level.

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Despite the substantial effort made so far, the Working Group considers this to be a living document that will be refined as the courses come to realization. It acknowledges that the current document is uneven, with some courses presented with more detail than others. The Working Group hopes to eventually have a course outline for every course and a Resource List (See Appendix B) that lecturers may draw on for course materials. However, this will be an iterative process and the need already exists. Therefore, a request for approval of this working draft document and to proceed is made in the conclusion of this document.

## **Recommendations**

### **The Bachelor's Level**

Undergraduate engineering programs are generally very prescriptive, with a single upper-level elective in a science other than engineering, and four to six upper-level engineering electives. In order to meet the earth science requirement of the Accreditation Board from Engineering and Technology (ABET), many engineering programs require that the upper-level science elective be in geology. In addition, one of the upper-level engineering electives is typically a Senior Capstone/Design Project. Allowing undergraduate students to include more science electives outside of engineering to their degree program may be desirable for some career paths.

An undergraduate student must establish a solid foundation in mathematics, physics, chemistry, biology, ecology, geology, and engineering fundamentals in order to pursue a graduate degree related to the engineering, management, and restoration of rivers. Table 1 lists courses that provide such a foundation, and should therefore be completed either as a degree requirement or as an elective. Table 1 assumes that all engineering programs include a basic Introduction to Design course and a solid foundation in engineering (Statics, etc.), science, and mathematics. These recommendations also assume the engineering electives emphasize design in assignments and course projects and that they introduce students to some of the computer models commonly used in engineering practice. Additional coursework will be desirable depending upon each student's area of specialization. Table 2 lists additional elective courses that are considered highly useful in the field of river restoration. An interdisciplinary capstone course, such as a Senior Design class, in which students from various departments work together to address actual restoration problems, is strongly recommended, as are internships that expose students to river engineering and restoration practice.

Table 1. Undergraduate subjects necessary to establish a foundation in restoration principles.

Ecology
Aquatic, Riparian and Wetland Ecology
Hydrology (including topics on climate)
Fluid Mechanics
Open Channel Hydraulics (with coverage of natural channels)
Water Resources Planning and Management (w/brief introduction to Water Law, 1-2 lectures)
General Geomorphology
Technical Communications (oral and written)
Water Chemistry
Introduction to Field Techniques (topographic surveying, basic water quality, etc. If these topics are not already being taught in laboratory sections of other courses.)

Table 2. Additional undergraduate elective course subjects considered highly useful in restoration practices (in no particular order).

Groundwater
Soil Mechanics and Foundation Engineering
Coastal Engineering
Wastewater Treatment
Construction Engineering (gaining this experience through internships or a design capstone course with construction engineering components may also be appropriate)
Fisheries Science

## Introducing Restoration Engineering

Increasing students' awareness of opportunities in the river restoration field, and of the background needed to do this work, is critical in developing competent restoration engineers. The topic of restoration engineering could be introduced into the standard undergraduate engineering curriculum in a number of courses. The following were identified as courses that could incorporate modules giving undergraduate students experience with restoration or fish passage engineering.

Introduction to Engineering. This is usually a survey course of what engineers do and what knowledge is needed to do it. Such a course would provide an excellent opportunity for initiating interest and introducing necessary courses.

Fluid Mechanics. The standard engineering fluid mechanics course should include basic open channel flow concepts. Many Fluid Mechanics courses do not include these topics because the introductory fluid mechanics course is not taught through the Civil Engineering department. Introductory culvert design, for example, can provide design examples.

Hydrology. Most engineering hydrology courses emphasize data analysis and probability, runoff modeling, flood control, and drainage design. A module dealing with flow duration curves,

flow/return period calculations and ecological water needs could be included as a special topic. The inclusion of field laboratories in hydrologic data collection further emphasizes natural system processes.

Hydraulics. A second course in hydraulics is the most likely place to introduce complex, open-channel hydraulics in natural systems, channel design, or fish passage examples into the undergraduate curriculum as design problems. Culvert hydraulics may have already been covered, and fish passage can be a special topic or additional design criteria to consider. Fish ladders and channel design are also possible topics. The inclusion of field laboratories in natural channels further emphasizes natural system processes.

Senior Design Project. These courses are designed to be open-ended, problem solving classes that emphasize the design process and team work. Therefore, if a school offers this type of course (ABET is quite persistent about requiring it), it would serve as an excellent way to introduce simple restoration design problems. A module or pre-packaged design project for restoration engineering would be appealing. The single drawback of this arrangement is that the project often has a client that works with students to define design criteria. Most engineering programs, therefore, tend to limit their projects to the local area. Local restoration engineers, restoration professionals, and resource managers could offer up potential projects to nearby schools and volunteer as "clients." This arrangement can help initiate interest and train future restoration professionals. All efforts should be made to have projects that are interdisciplinary, both in topic and through the inclusion of students from other departments.

## The Masters Level

Completing the suggested undergraduate curriculum and a Master's Program similar to the one described below would help prepare a professional engineer for a career in river restoration. The core Master's curriculum focuses on interdisciplinary, problem solving oriented coursework intended to develop advanced skills to be applied in environmental consulting, resource management, environmental policy, and research. The elective and additional courses offer a more specialized education and advanced professional skills.

A Masters of Science program generally requires 24-30 semester units. Typically, 6 of these units are thesis units, leaving approximately 8 three-unit courses for electives. Students beginning this program may need to complete courses that are either prerequisites for graduate courses, or that appear in Table 2 but not taken as undergraduates. The recommended Masters level courses (Tables 3 and 4) assume that incoming graduate students have at least the courses in Table 1 from the Bachelor's degree list. The courses in Tables 3 and 4 are described below.

Table 3. Graduate courses necessary to prepare the student for specialized careers in restoration.

River Processes and Restoration I
River Processes and Restoration II
Sustainable Watershed Management
Experimental Design, Data Collection, and Field Techniques
Practicum or Thesis

Table 4. Graduate elective courses useful to the student in specific areas of interest.

Modeling and Instrumentation for River Systems
Migration and Passage Design
Fluvial Geomorphology or River Morphology
Limnology
Environmental Economics
Environmental Statistics
River Mechanics
Assessment of Ecological Flows
Invasive Species Prevention and Control
Chemical Pollution Prevention and Control
Biogeochemistry and Fluxes
Aquatic Life Cycles and Population Dynamics
Advanced Aquatic Ecology
Technical Communication
Natural Resources Economics
Multivariate Statistics
Cultural Anthropology of Rivers

### Core Program Courses

These courses would make up the core of the program and have not been covered at the undergraduate level. Note that the first course is envisioned as the initial course in the program establishing necessary background for the other core courses. The Practicum or Thesis is the MS degree's culminating experience and would be completed near the end of the degree program. In addition to the core courses described below, any of the courses listed in Table 1 of the undergraduate degree that were not completed at the undergraduate level should be considered core courses for this Masters program. These will be needed as prerequisites to the core and elective Masters courses. Sample course outlines have been developed for some of these courses and are attached as Appendix A. An initial resource/reference list for the course topics has been developed and is attached as Appendix B.

**River Processes and Restoration I.** Natural processes and ecological interactions in running waters (see Appendix A for a sample course outline). This course studies the geophysical processes of natural rivers with emphasis on the qualitative and quantitative aspects of fluvial

morphology; addressing channel dynamics, urban rivers, human impacts on rivers, and climate change. It will focus on understanding the physical, biological, and chemical processes that drive streams and rivers, as well as on the ecological interactions within and across the ecosystems. It will underline connectivity, scales and dynamics of the processes discussed. This course also briefly introduces the consequences of human-induced alteration.

River Processes and Restoration II. Conservation and restoration engineering of streams and rivers (see Appendix A for a sample course outline). This second course in the series places more emphasis on direct application of restoration concepts to actual case studies and projects. Concurrent with this course, students are assigned one or more river sites to investigate and develop a restoration plan. The course also addresses a variety of technological mitigation and restoration measures applied in river restoration, conservation, and impact mitigation.

Sustainable Watershed Management. (See Appendix A for a sample course outline). This course will cover the elements of strategic watershed management planning and implementation with a primary emphasis on the socio-economic function and interactions with riverine systems. It will include institutional structures, socio-economical principles, resources utilization, local governances, infrastructure planning, maintenance, budgets, smart growth, sprawl, urban development, selected elements of global change and human dimension. Elements of project management, communication and outreach will also be incorporated into this course.

Experimental Design, Data Collection, and Field Techniques. (See Appendix A for a sample course outline.) This course will cover desktop, field and remote-sensed data collection methods for stream assessment. The first part of the course will focus on the creation of geographic computer models of riverine systems and queries using large-scale hydrological, meteorological and biological data. The second part of the course, field data collection, will include: sampling strategies, rapid assessment techniques, fish (electro-fishing, netting, underwater and surface observations etc.), and macro-invertebrate (e.g., surber, freeze cores) survey techniques, plankton collections, aquatic and riparian vegetation, water chemistry, collection of temperature, light penetration, turbidity, sedimentation, shear stress, flow, velocity, depth, river morphology, fish habitat, seepage, subsurface flow, groundwater, aerial and satellite imagery, field safety.

Practicum or Thesis. The practicum or thesis would allow students to complete a project analysis or design applying the concepts learned in the course work. The practicum could take the form of an internship in a resource agency, consulting firm, non-profit organization, or local government, or a more traditional thesis project. The thesis would be a standard Masters thesis with research emphasizing the design or analysis of processes relevant to a river restoration topic.

## Elective Courses

The Working Group proposes the following examples of elective courses that serve to further the degree of specialization, but were not included in the core graduate education. Many students interested in becoming restoration engineers will need additional specific skills in Biology/Ecology/Engineering that the following courses might provide.

Modeling and Instrumentation for River Systems. This course will prepare students for the extensive modeling of rivers and watersheds. It will build upon advanced hydraulics (open-channel and local), hydrology, river mechanics, ecology, statistics, and computing. The laboratory techniques for creation of physical models, scaling, construction and calibration of measuring instruments, sensors and probes will be a core part of lab work. Creation of conceptual and computer models, simulations and validation of results will also be an important component of the study. Sensitivity analysis and application of common models in practice should be included.

Migration and Passage Design (3-4 courses). (See Appendix A for sample course outline.) This series of 3-4 courses covers the biological basis for aquatic organism and small mammal passage, fish behavior and physiology important to fish passage, biological evaluation of fishways, and the integration of engineering and biology. It also includes an advanced engineering portion, introducing fish passage technology and design, design criteria for passage, dam removal and modification to restore passage, nature-like fishways, exclusionary fish passage structures, fish friendly turbines, etc. Interdisciplinary instructors are needed for these courses.

Fluvial Geomorphology or River Morphology. An advanced course or current topics seminar in fluvial geomorphology would allow further study for students interested in this area of research.

River Mechanics. A classic river mechanics course emphasizing channel formation processes and water and sediment transport measurement and modeling would provide a student more in-depth experience with river processes.

Assessment of Ecological Flows. (See Appendix A for a sample course outline.) An Ecological Flows course is intended to have broader coverage than an instream flow course. The course presents different approaches used to estimate instream, environmental or ecological flows, and draws on hydrology, hydraulics, geomorphology, habitat metrics, and biology, ecology and computer simulations.

## Additional Elective Courses

The following elective courses and topics were identified as examples of relevant courses depending on a student's area of interest.

### Invasive Species Prevention and Control

Impacts of invasive species  
Physical and chemical invasion control  
Biological control agents  
Distribution control

### Chemical Pollution Prevention, Fate and Transport in Natural Systems

Detection and compliance control  
Municipal pollutants NH<sub>3</sub>, BOD modeling  
Toxics and acid rain

Organic chemistry and organic chemical pollutants  
Endocrine disruptors, PCB's, Dioxin etc.

Biogeochemistry and Fluxes

Stable isotopes  
Nitrogen, phosphorus, and carbon fluxes  
Tracing organisms and their environment.

Aquatic Life Cycles and Population Dynamics

Species and life stages  
Quantitative population analysis  
Physical and chemical cycles (disturbances and scales)

## **Conclusion**

The Working Group has completed a major phase of its charge and respectfully requests that this draft be approved by the Section. The Working Group will then set about the task of contacting and working with selected universities to find how best to gradually weave this into their course offerings. It will keep the Section posted of this progress, as well as substantial revisions to the document. Section members are encouraged to make suggestions to the Working Group for improvement of this document and cooperation with universities.