

Engineering for Restoration of Rivers and Improved Ecological Systems: Recommendations for Academic Curricula¹

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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.³

After the curriculum was drafted, it was circulated to other practitioners⁴ and academics⁵ 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 NH₃, 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.

Appendix A

Elective Course Outlines

To further articulate the experience and needs of the AFS Bioengineering Section, a few of the recommended graduate level courses have been further developed into course outlines. These outlines have been developed either from existing courses or for topics which section members see a specific and immediate need. This attachment is a draft document; it is hoped that all graduate level courses will eventually see this level of development by practicing academics. The following courses are currently described in outline form in this appendix: River Processes and Restoration I and II, Sustainable Watershed Management, Experimental Design, Data Collection and Field Techniques, Migration and Passage Design, Ecological Flows

A. River Processes and Restoration I

The course includes class lectures, readings, problem sets, field labs and a team project. Prerequisites include courses in surface water hydrology and hydraulics, plus an introduction to ecologic principals. The course outline follows:

1. Ecological concepts
 - A review of the literature on aquatic ecological concepts in moving waters
 - a. Niche theory
 - b. River continuum
 - c. Flood pulse effects
 - d. Patch dynamics
 - e. Natural flow paradigm
 - f. Ecological integrity
2. Regime theory and its modern evolution
 - a. Alluvial versus non alluvial channels
 - b. British Commonwealth research
 - c. Hydraulic geometry relations
 - d. USGS regional hydraulic geometry curves
 - e. Applications
3. River dynamics
 - a. Base levels and graded streams
 - b. The dynamic equilibrium concept
 - c. Hydrologic and hydro-morphic relations
 - d. Biologic community shifts
 - e. Seasonal and diurnal cycles
4. Fluvial scales
 - a. Spatial organization and patterns
 - b. Long term temporal cycles
5. Fluxes
 - a. Food chain
 - b. Biochemical

- c. Geochemical
 - d. Energy conservation and transfers
- 6. Communities
 - a. Aquatic
 - b. Riparian
 - c. Relationships
- 7. Geomorphic patterns and processes
 - a. Degradation
 - b. Aggradation
 - c. Entrenched and incised channels
 - d. Braided and anabranch channels
 - e. Bars, bedforms, deltas
- 8. Steady state stability
 - a. Threshold concepts
 - b. Critical velocity
 - c. Tractive shear stress
 - d. Stream power
 - e. Local scour at bends, constrictions, obstructions
- 9. Sediment transport
 - a. Lanes relation
 - b. Mass budgets
 - c. Steady state transport rates
 - d. Unsteady models
 - e. Trap efficiency and deposition
 - f. Typical load data
- 10. Bank stability
 - a. Cohesive versus non-cohesive characteristics
 - b. Angle of repose, internal shear strength
 - c. Mass failures; circular, block, wedge, slumps, slides
 - d. Watsons' model
 - e. Groundwater
- 11. River classification systems
 - a. Horton stream order
 - b. Hydrologic classification
 - c. Schumm's method
 - d. Rosgen system
 - e. Rapid field stability system
 - f. Fish habitat regions
- 12. Anthropogenic impacts
 - a. Deforestation
 - b. Urbanization
 - c. Channelization
 - d. Encroachments
 - e. Bridges, dams, culverts, dikes
 - f. Water quality and quantity
 - g. Aquatic habitat modifications
 - h. Climate change

B. River Processes and Restoration II

This second 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.

1. River restoration concepts
 - a. Restoration, re-creation, rehabilitation, mitigation
 - b. Micro versus macro scale
 - c. Short versus long term
 - d. Setting goals and objectives
 - e. Constraints and opportunities
 - f. Identification and inclusion of stakeholders
2. Watershed influences and management
 - a. Use of hydrologic data
 - b. Climate change
 - c. Water quality impacts
 - d. Low impact watershed uses
 - e. Erosion and sediment control
 - f. Wetland and floodplain management
 - g. Riparian buffers
3. Hydrologic management
 - a. Peak flows
 - b. Channel forming discharges, bankfull flows
 - c. Replicating natural annual flow cycles
 - d. Aquatic base flows
 - e. Tennant method
 - f. USFWS IFIM procedure
4. Application of restoration hydraulics
 - a. HEC-RAS
 - b. CORPS model
 - c. Sediment analysis model
5. Physical habitat models
 - a. Literature review
 - b. PHABSIM
 - c. Advanced models
 - d. Temperature and dissolved oxygen
6. Quantitative fluvial morphology
 - a. Determining base level and control points
 - b. Evaluating equilibrium stream profiles
 - c. Creating horizontal and vertical patterns
 - d. Estimating stable alluvial channel widths, depths, areas
 - e. Selecting channel substrates and roughness
 - f. Floodplain connectivity
7. Channel profile management
 - a. Trend forecasting
 - b. Aggradation

- c. Degradation
- d. Headcuts, knickpoints, and gullies
- e. In stream features, management practices
- 8. River bank stabilization
 - a. Soft versus hard approaches
 - b. Hydraulic manipulation, velocity reduction or redirection
 - c. Cross section geometry revisions
 - d. Riprap
 - e. Biotechnology
 - f. Riparian vegetation
- 9. River dechannelization
 - a. Slope and alignment modifications
 - b. Cross section revisions
 - c. Bed and bank habitat features
 - d. Aesthetics
 - e. Nature-like design concepts
 - f. Fish passage
- 10. Regulatory programs
 - a. Help or harm
 - b. USACE Section 404 regulations
 - c. Section 401 WQC
 - d. FERC hydropower regulation
 - e. FEMA flood insurance program
 - f. Typical state and local regulations
 - g. Public participation
 - h. Timing, timing, and timing
- 11. Implementation
 - a. Master plans and public input
 - b. Conceptual design
 - c. Reviews and revisions
 - d. Construction plans
 - e. Specifications
 - f. Cost estimates
 - g. Standard reference material
- 12. Case studies and class projects

C. Sustainable Watershed Management

This course covers the elements needed for strategic watershed management planning and implementation with a primary emphasis on the socio-economic function and interactions with riverine systems. Elements of project management, communication and outreach will also be incorporated into this course.

- 1. Watersheds
 - a. Watershed scale, delineation and mapping
 - b. Hydrologic unit codes
 - c. USGS monitoring programs, gauges

- d. Geology, soils, topography, vegetation, wildlife resources
 - e. Hydrology
 - f. Ecological needs, functions, and values
 - g. Watershed functions and values
2. Natural watershed processes
 - a. Stream flow dynamics
 - b. Erosion, transport, and deposition
 - c. Chemical, physical, and biologic
 - d. Ecosystem cycles and dynamics
 - e. Energy transformations
 3. Land use planning and impacts
 - a. Plan of developments, zoning
 - b. Transportation corridors and facilities
 - c. Population forecasts
 - d. Economic planning
 - e. Central business districts
 - f. Suburban sprawl
 - g. Low impact development
 4. Water supply issues
 - a. Water usage
 - b. Water demand; residential, commercial, industrial
 - c. Irrigation, agricultural needs
 - d. Supply sources, treatment, distribution
 - e. Water conservation
 5. Waste disposal practices
 - a. Subsurface disposal systems
 - b. Sanitary sewers, treatment, discharges,
 - c. Solid waste, landfills, recycling
 6. Linking land and water resources
 - a. Wetland functions and management
 - b. Groundwater recharge, yield and management
 - c. Floodplain delineation, functions, and management
 - d. Riparian corridor functions and management
 - e. Storm drainage and non point source of pollution
 7. Water resource management
 - a. Priorities
 - b. Conservation
 - c. Ecological needs
 - d. Recreation
 - e. Public access
 - f. Instream flow needs
 - g. Climate changes
 - h. Water diversions and competition
 - i. Water allocation
 - j. Water law
 8. Watershed master plans
 - a. Identify and include interested parties

- b. Public education
- c. Setting goals and objectives
- d. Consensus building
- e. Funding
- f. Implementation
- g. Monitoring and adapting

D. Experimental Design, Data Collection and Field Techniques

This course is intended to familiarize future professionals with the most relevant requirements and sources of stream and rivers related data, and to introduce the variety of field techniques for collecting these data. It should be a one- or two-semester course that includes blocks of field days devoted to the collection of above- and under-water data, lab analysis, and computer work. Cultivating observations, skills, and an intuitive understanding of running water ecosystems will be a primary objective of this course. Students will also become familiar with high-end technology, diving, boating and airborne data collection.

This course should be taught by a team, since it is unlikely that the expertise of a single person would span the entire breadth of subjects addressed. An interdisciplinary team, providing combined expertise in chemical, biological, and physical data, would therefore be ideal. The course outline follows:

1. Desktop data

This first part of the course will discuss sources of and methods used to obtain large-scale data that are available in various locations. Students will learn how to create GIS databases, which they will be able to query and use to for data interpretation.

- a. Hydrology
- b. Geology
- c. Landscape forms and use
- d. Zoogeography
- e. History
- f. Remote-sensed data
 - i. Satellite
 - ii. Airborne imagery (photography, videography, radar, laser etc.)
- g. GIS database

2. Field surveys

This second part of the course will consist of introduction and series of field data collection campaigns at various settings (e.g. small streams, large rivers). At the end the problem oriented combination surveys will be practiced.

- a. Survey strategies and logistics
 - i. Sampling scales
 - ii. Random, systematic, topographic etc.
 - iii. Timing and seasons
 - iv. Cost estimation
- b. Biological data collection
 - i. Preservation of samples and identification procedures
 - ii. Fish

- e.g. electro-fishing, netting, trapping, lines, snorkeling, diving, underwater cameras, poisoning.
- iii. Macro-invertebrates
 - e.g. surber sampler, freeze core.
- iv. Plankton sampling
- v. Submersed aquatic vegetation
- vi. Riparian flora
- vii. Riparian and semi-aquatic fauna.
- c. Hydraulics at low- and high-flow conditions
 - i. Flow
 - ii. Velocity
 - iii. Shear stress
 - iv. Bathymetry
 - v. Acoustics
- d. Fluvial geomorphology
 - i. Channel form.
 - ii. Channel structure
 - iii. Substrate
 - iv. Sediment
 - v. Temperature
 - vi. Light
 - vii. Debris
- e. Chemical parameters
 - i. Collection and transport
 - ii. Lab analysis
- f. Habitat survey strategies

The final portion of the course will be a practical exercise in combining the above methods in order to describe aquatic habitats for different rivers and determine the management and restoration procedures best suited to these rivers.

E. Migration and Passage Design

Studies in Fishway Engineering is a series of three, one-semester courses at the graduate level. Each focuses on integral aspects of providing fish passage at barriers on waterways for species moving upstream or downstream. Public policy, fish biology, bio-engineering and field assessment are covered.⁶ A design seminar is included as a possible fourth course in the series. A subject outline for each course is provided here.

1. Public policy and fish passage biology (1 semester)
 - a. Public policy
 - i. Fish passage as a public interest
 - ii. Fishways in law (Magna Carta to present)

⁶ This draft curriculum has been developed by Alex Haro, Boyd Kynard, and John Noreika of the Conte Anadromous Fish Research Laboratory, Biological Research Division, U.S. Geological Survey in Turners Falls, MA; Ken Brownell, Alex Hoar, Curt Orvis, and Dick Quinn of the U.S. Fish and Wildlife Service in Hadley, MA; and Chris Katopodis, Freshwater Institute, Fisheries and Oceans Canada in Winnipeg, Manitoba.

- iii. Fishways in court (1700 – present)
 - iv. Fisheries management plans (state, federal, tribal)
 - v. River management plans (e.g., Kennebec River , ME)
 - b. Knowledge of the riverine environment
 - i. Definition and function of aquatic systems as a whole
 - ii. Biological description of specific ecotypes (headwater, tributary, mainstem, tidal/estuary)
 - iii. Description of general fish types (not necessarily species) associated with each ecotype
 - iv. Role and function of variation in the lotic environment (flow, temperature, productivity)
 - c. Biological basis for fish passage
 - i. Biological basis for fish movements (spawning, rearing, feeding, overwintering, growth to maturity, dispersion, migration, and seasonal use of habitat)
 - ii. Generalized life histories
 - iii. Fish migrations (anadromous, catadromous, amphidromous, and potamodromous)
 - iv. Morphology and kinematics (swimming) of generalized fish types (benthic, pelagic, etc.)
 - v. Effects of natural and manmade obstructions and velocity barriers on fish movements
 - d. Fish behavior important to fish passage
 - i. Timing of movements
 - ii. Route of movements
 - iii. Schooling
 - iv. Near-field behavior
 - v. Response to the physical environment
 - vi. Response to the chemical environment
 - vii. Response to the biological environment
 - viii. Response to structure
 - ix. Manipulation of the environment (passage and guidance)
 - e. Physiology important to passage
 - i. Hydrodynamics of fish swimming and relationships to flowing water environment
 - ii. Migration energetics
 - iii. Passage energetics
 - iv. Fish swimming performance
 - v. Water quality environment during passage
- 2. Fishway bio-engineering (1 semester)
 - a. Introduction to fish passage technology and design
 - i. Definition of “fishway” and related terms (facility, structure, device, operation, measure)
 - ii. Historic approaches to fish passage (status of state-of-the-art world-wide)
 - iii. Overview of types of fish-passage facilities and barriers to passage
 - iv. Types of dams and weirs - hydroelectric power, irrigation, water supply,

- water level control, lamprey barriers, etc
- v. Types of turbines, spillways, stilling basins, irrigation canals, and water intakes.
- vi. On-site instructional inspections
- b. Scope of design information considered
 - i. Hydrologic and hydraulic parameters for barrier (hydro/river operation, etc)
 - ii. Fluid mechanics and fish routing at barrier
 - iii. Hydrology, timing and behavior of the migratory fish community
 - iv. Hydrologic, biologic and hydraulic parameters for fish passage
 - v. Physical or numerical modeling for proposed fish passage measures
 - vi. River/Fisheries management plans - (input from policy)
 - vii. Aesthetics and visual impacts
- c. Dam removal to restore fish passage
 - i. Feasibility criteria
 - ii. Decommissioning
 - iii. Permitting issues (Sediment, head cutting, contaminants, waste disposal, etc.)
 - iv. Site restoration
- d. Guiding fish to fish passage facilities
 - i. Locations for fish passage facilities
 - ii. Flows and fish attraction
 - iii. Guiding structures
 - iv. Behavioral guidance
- e. Hybrid fish-passage structures and theory of operation
 - i. Breaches, notches, and combinations
 - ii. Obstruction height reduction
 - iii. Bypass chutes (e.g. channels, culverts)
- f. Fish passage management
 - i. Exclusion structures for invasive species (e.g. sea lamprey barriers, carp barriers)
 - ii. Exclusion structures for jumping species
 - iii. Manual and semi-manual fish sorting
 - iv. Trap and haul
 - v. Seasonal operations
- g. Introduction of upstream fish-passage facilities
 - i. Theory of operation and applicability for different species
 - ii. "Nature-like" fishways and theory of operation (bypass channels, rock ramps, boulder weirs)
 - iii. Chute (Denil, steep pass, chute with floor vanes, chute and pool)
 - iv. Pool and weir (weir, weir and orifice e.g. Ice Harbor, weir and chute, weir and notch, various weir geometries)
 - v. Vertical slot (twin jet, single jet, serpentine slot, various slot, baffle or pool geometries)
 - vi. Spiral
 - vii. Resting pools
 - viii. Mechanical (lock, lift, navigation locks)

- ix. Trap and haul / collection facilities
- x. Evaluation facilities (evaluation trap (passive/active) in fishway)
- xi. Fish sorting
- h. Introduction of downstream fish-passage facilities
 - i. Theory of operation and applicability for different species
 - ii. Spill over spillway or bypass chutes (operational constraints, shut down)
 - iii. Physical barriers (solid guide wall, screen, etc)
 - iv. Behavioral barriers (louvers, angled racks, strobes, electricity, etc)
 - v. Turbine Passage
 - vi. Trap and haul (barging/trucking/ collection facilities)
 - vii. Evaluation facilities (active/passive)
- i. Research
 - i. Guiding various species to fish passage facilities
 - ii. Experimental designs (fish friendly turbine, spillways, bypass chutes, nature mimicking and novel fishway concepts)
 - iii. Retrofits/corrections to existing structures
 - iv. Modeling (hydrologic simulation, hydraulic scale models, Computational Fluid Dynamics, controlled experiments with fish)
 - v. Field methods and research
 - vi. Latest trends/developments/professional societies/journals
- j. Design and construction
 - i. Materials
 - ii. Methods
 - iii. Conceptual and final design
 - iv. Retrofits / corrections to existing structures
 - v. Construction oversight / monitoring
- k. Operation
 - i. Timing (seasonal and daily)
 - ii. Flow control
 - iii. Constraints and shut down
 - iv. Effectiveness evaluation
 - v. Labor requirements
- l. Maintenance
 - i. Mechanical
 - ii. Structural
 - iii. Electrical
 - iv. Debris removal
 - v. Sediment
- m. Costs
 - i. Comparing design alternatives
 - ii. Methods for developing cost information
 - iii. Project cost comparisons
- 3. Field assessment (1 semester)
 - a. Fishway evaluation
 - i. Common queries that warrant evaluation
 - ii. Methods and metrics (visual/video counting, hydro acoustics, mark-recapture, telemetry)

- iii. Analyses of biological, hydrological, hydraulic passage data
- iv. Interpretation of results
- v. Evaluation of guidance and passage components
- vi. Assessment and effects of migratory delays
- vii. Field and laboratory experiments
- b. Analyses and modeling
 - i. Passage efficiency and transit time
 - ii. Estimation of variability and error in passage performance
 - iii. Individual-based models
 - iv. Survival analysis (including predation)
 - v. “Traffic rules” for migrants
 - vi. Prediction of passage success based on models or principles of behavior
- c. Integration of engineering and biology
 - i. Combination of hydraulic and biological (behavioral) datasets
 - ii. Decision-making with respect to experimental results
 - iii. Case studies of cooperative (and uncooperative?) efforts
 - iv. Constraints on design and/or modification of existing structures or their use
 - v. Fish passage engineering and biology as a scientific process
- 4. Fishway design seminar (1 semester)
 - a. Case studies (including inappropriate/dysfunctional designs)
 - b. Site instructional inspection
 - c. Team project

F. Ecological Flows

The following presents a list of topics for an Ecological Flows course that 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, biology, ecology and computer simulations. Guest speakers and case studies should supplement the basic lectures. The topics are:

- | | |
|---------------------------------|--|
| 1. Hydrologic methods | 9. Habitat-hydrodynamic simulation methods |
| 2. Hydraulic methods | 10. Time series analysis |
| 3. Geomorphologic methods | 11. Community and individual based models |
| 4. Habitat methods | 12. Ice-covered conditions |
| 5. IFIM | 13. Physiomimetic approaches |
| 6. 1-D models | |
| 7. 2-D and 3-D models | |
| 8. Statistical hydraulic models | |

Appendix B

Curriculum Resource List

This is a list of resources that lecturers may draw on for course materials. This attachment is a draft document; it is hoped that it will be further developed to include references for all graduate level courses by practicing academics.

Aquatic Biology

Fisheries Techniques 2nd edition (Editor) Murphy and Willis AFS 1996
ISBN 1-888569-00-X

Dams

USGS report on dam impacts
<http://ks.water.usgs.gov/Kansas/pubs/reports/wrir.99-4147.html#HDR0>

Aspen/Berkeley Clearinghouse on Dam Removal
<http://www.lib.berkeley.edu/WRCA/damremoval/>

Education

Degrees of Belief: Subjective Probability and Engineering Judgement by Steven Vick ASCE
2002 ISBN 0784405980

Fish Passage

Advances in Fish Passage Technology, Editor Mufeed Odeh AFS 2000 ISBN 1-888569-20-4

Innovations in Fish Passage Technology, Editor Mufeed Odeh AFS 1999 ISBN 1-888569-17-4

Fisheries Handbook of Engineering Requirements and Biological Criteria, by Milo Bell, US
Army Corp of Engineers 1991

Fish Migration and Fish Bypasses, Editor Jungwirth, Schmutz and Weiss Fishing News Books
(Blackwell Science distributor) 1998 ISBN 0-85238-253-7

Design of Fishways and Other Fish Facilities, 2nd edition by Charles Clay CRC 1995
ISBN 1-56670-111-2

New Concepts in Fish Ladder Design Part 1-4, by John Osborn Bonneville Power
Administration 1984

Fish Passage (Cont.)

Symposium on Small Hydropower and Fisheries, Editor Olson, White, Hamre AFS 1985
ISBN 0-913235-37-7

Fisheries BioEngineering Symposium, Editor Colt, White AFS 1991 ISBN 0-913235-72-5

Fish Passage Policy and Technology, Editor Ken Bates AFS 1993

Fish Passage Technologies: Protection at Hydropower Facilities, OTA 1995OTA-ENV-641
ISBN 0-16-048342-5

Behavioral Technologies for Fish Guidance, C. C. Coutant, editor. American Fisheries Society Symposium 26, Bethesda, Maryland (2001).

Introduction to fishway design, Katopodis, C. 1992b. Working Document, Freshwater Institute, Fisheries and Oceans Canada, Winnipeg, Man. 67 p.

Field studies of fishways in Alberta, Rajaratnam, N., C. Katopodis and R. Paccagnan. 1992. Canadian Journal of Civil Engineering, Vol.19(4): 627-638.

Advancing the art of engineering fishways for upstream migrants, Katopodis, C. 1990. Proceedings International Symposium on Fishways, (invited lecture), October 8-10, 1990, Gifu, Japan, p. 19-28.

Structures assisting the migrations of non-salmonid fish, Pavlov, D.S. 1989. U.S.S.R. FAO Fisheries Technical Paper 308, Rome, Italy, 97p.

Nature-mimicking fishways

Katopodis, C. 2002c. Nature-mimicking fishways: concepts and practical applications. Keynote lecture, Proceedings of 2nd Nordic International Symposium on Freshwater Fish Migration and Fish Passage, Evaluation and Development, Sept. 20-22, 2001, Reykjavik, Iceland, p. 87-93; Environmental Sciences and Technology, P.O. Box 7300, FIN-90014 University of Oulu, Finland.

Katopodis, C., J.A. Kells, and M. Acharya. 2001. Nature-like and Conventional Fishways: Alternative Concepts? Canadian Water Resources Journal, 26(2): 211-232 (invited paper for special issue edited by C. Maule and M. Conly).

Wang, P.D., and C. Katopodis. 1999. Fishway studies for the Lower Churchill River Water-Level Enhancement Project in Manitoba. 3rd International Symposium on Ecohydraulics, Salt Lake City, July 13-16, 1999.

Fish Passage (Cont.)

Vertical slot fishways

Wu, S., N. Rajaratnam, and C. Katopodis. 1999. Structure of flow in vertical slot fishway. *Journal of Hydraulic Engineering*, ASCE Vol. 125 (4): 351-360.

Rajaratnam, N., C. Katopodis and S. Solanki. 1992. New designs of vertical slot fishways. *Canadian Journal of Civil Engineering*, Vol.19(3): 402-414.

Pool and weir fishways

Rajaratnam, N., C. Katopodis and A. Mainali. 1988. Plunging and streaming flows in pool and weir fishways. *Journal of Hydraulic Engineering*, ASCE, Vol. 114 (8): 939-944.

Denil fishways

Katopodis, C, N. Rajaratnam, S. Wu, and D. Tovell. 1997. Denil fishways of varying geometry. *Journal of Hydraulic Engineering*, ASCE, Vol. 123 (7): 624-631.

Rajaratnam, N., C. Katopodis, S. Wu, and M.A. Sabur. 1997. Hydraulics of resting pools for Denil fishways. *Journal of Hydraulic Engineering*, ASCE, Vol. 123 (7): 632-638.

Rajaratnam, N., and C. Katopodis. 1991. Hydraulics of steppass fishways. *Canadian Journal of Civil Engineering*, Vol.18(6): 1024-1032.

Katopodis, C., A.J. Derksen and B.L. Christensen. 1991. Assessment of two Denil fishways for passage of freshwater species. *American Fisheries Society Symposium* 10: 306-324.

Blackett, R.F. 1987. Development and performance of an Alaska steppass fishway for sockeye salmon (*Oncorhynchus nerka*). *Can. J. Fish. Aquat. Sci.* 44: 66-76.

Culvert fishways

Ead, S.A., N. Rajaratnam and C. Katopodis. 2002. A generalized study of the hydraulics of culvert fishways. *Journal of Hydraulic Engineering*, ASCE, p. 1018-1022.

Ead, S.A., N. Rajaratnam, C. Katopodis, and F. Ade. 2000. Turbulent open-channel flow in circular corrugated culverts. *Journal of Hydraulic Engineering*, ASCE, 126(10): 750-757.

Katopodis, C. 1993. Fish passage at culvert highway crossings. *Highways and the Environment*, Charlottetown, May 17-19, 1993. 26 p.

Fish Passage (Cont.)

Rajaratnam, N., C. Katopodis, and M.A. Sabur 1991. Entrance region of circular pipes flowing partly full. *J. of Hydraulic Research, International Association for Hydraulic Research, IAHR*, 29(5): 685-698.

McKinnon, G.A. and F.N. Hnytka 1985. Fish passage assessment of culverts constructed to simulate stream conditions on Liard River tributaries. *Can. Tech. Rep. Fish. Aquat. Sci.* 1255:vi+121p.

Katopodis, C., P.R. Robinson, and B.G. Sutherland. 1978. A study of model and prototype culvert baffling for fish passage. *Can. Fish. Mar. Serv. Tech. Rep.* 828: v + 78 p.

Fish screens

Katopodis, C. 1992a. Fish screening guide for water intakes. Working Document, Freshwater Institute, Fisheries and Oceans Canada, Winnipeg, Man. 5 p.

Fish swimming performance

Colavecchia, M., C. Katopodis, R. Goosney, D.A. Scruton, and R.S. McKinley 1998. Measurement of burst swimming performance in wild Atlantic salmon (*Salmo salar* L.) using digital telemetry. *Regulated Rivers: Res. Mgmt*, 14: 41-51.

Katopodis, C. 1994. Analysis of ichthyomechanical data for fish passage or exclusion system design. *Proc. International Fish Physiology Symposium*, July 16-21, 1994, Vancouver, B.C. American Fisheries Society and Fish Physiology Association, p. 318-323.

Fluvial Geomorphology

A Primer on Stream and River Protection for the Regulator and Program Manager, Tech. Ref. Circular WD 02 - #1 by Ann Riley SF Bay Region Water Quality Board

River Engineering for Highway Encroachments, Hydraulic Design Series Number 6 FHWA NHI 01-004 2001

Geomorphic Processes and Riverine Habitat, Editor Dorava, Palcsak, Fitzpatrick AGU 2001 ISBN 0-87590-353-3

Rapid Evaluation of Sediment Budgets, by Reid & Dunne Catena Verlag GMBH 1996 ISBN 3-923881-39-5

Fluvial Forms & Processes, by David Knighton Oxford University Press 1998 ISBN 0-340-66313-8

Fluvial Geomorphology (Cont.)

River morphology : a guide for geoscientists and engineers
by J. Mangelsdorf, K. Scheurmann, F. Weiss. Springer-Verlag, c1990. ISBN-35405114083

Incised River Channels, Editor Darby, Simon Wiley 1999 ISBN 0-471-984469-9

Applied Fluvial Geomorphology for River Engineering and Management, Editor Thorne, Hey, Newson Wiley 1997 ISBN 0-471-96968-0

Fluvial Processes in Geomorphology, by Leopold, Wolman, Miller Dover 1992
ISBN 0-486-68588-8

Fluvial geomorphology : in memoriam J.N. Jennings. Gebr. Brontreager ASIN 3443210554

River morphology / edited by Stanley A. Schumm., Stroudsburg, Pa. : Dowden, Hutchinson & Ross, 1972. Van Norstrand Reinhold (trade) June 1982 ASIN 0879330015

Incised Channels : Morphology, Dynamics, and Control, by Stanley Alfred Schumm, Water Resources Pubns 1994 ISBN 0918334535

Stream Reconnaissance Handbook : Geomorphological Investigation and Analysis of River Channels, by Collin R. Thorne (Paperback - October 1998) John Wiley and Sons ISBN 7471968560

Natural and Anthropogenic Influences in Fluvial Geomorphology : The Wolman Volume (Geophysical Monograph, Vol 89) by John E. Costa (Editor), et al (Hardcover - May 1995) ISBN 0875900461

The role of profile disturbances in channel morphology, by David Alexander. Department of Geography University College London ASIN 090481310x

Streams: Their Dynamics and Morphology, by Marie. Morisawa (Paperback - June 1968) McGraw Hill Text ASIN 007043213x

Federal DOT river environment manual,
www.fhwa.dot.gov/bridge/hire1990.pdf

Article on stream classification,
<http://www.stream.fs.fed.us/PDFs/GOODWIN.PDF>

Forestry Service manual on reference reaches,
www.stream.fs.fed.us/PDFs/RM245.PDF

Stream Team morphology references,
<http://www.stream.fs.fed.us/pointers.html#fluvial>

Fluvial Geomorphology (Cont.)

Corps manual on channel stability,

<http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-1418/toc.htm>

Federal DOT stream stability and morphology manual,

<http://isddc.dot.gov/OLPFiles/FHWA/010008.pdf>

General

Corps of Engineers Manuals,

www.usace.army.mil/inet/usace-docs/eng-manuals/cecw.htm

USGS maps and photos, <http://www.terraserver.com/>

USGS software, <http://water.usgs.gov/software/>

Hydraulics

Hydraulics of River Channel Closure by S. V. Izbash ASIN 0408700009

River Hydraulics (Technical Engineering & Design Guides As Adapted from U.S. Army Corps of Engineers, 18) (Paperback - March 1996) ISBN 0784401294

Hydrology

Stream Hydrology: An Introduction for Ecologists by Gordon, McMahon, Finlayson Wiley 1992 ISBN 0-471-93084-9.

USGS Home Page-hydrology, <http://water.usgs.gov/>

Ichthyology

Fishes 4th edition by Moyle and Cech Prentice Hall 2000 ISBN 0-13-011282-8

Modeling

Practical Aspects of Computational River Hydraulics, by J. A. Cunge (Textbook Binding - November 1980) ASIN 0273084429

River Processes

The Realities of Floods: A Multi-Disciplinary Review of Flood Management Issues US Committee on Irrigation and Drainage ISBN 0-887903-00-3

River Processes (Cont.)

Mountain Rivers by Ellen Wohl AGU 2000 ISBN 0-87590-318-5

Inland Flood Hazards: Human, riparian and aquatic communities Editor Wohl Cambridge University Press ISBN 0-521-62419-3

Chang, Howard. "Fluvial Processes in River Engineering," John Wiley & Sons, New York 1988. ISBN 1575242125

Dynamics of Gravel-Bed Rivers by P. Billi, et al (Paperback - June 1992) John Wiley and Sons ASIN 047192976x

Changing River Channels by A. M. Gurnell (Editor), Geoffrey Petts (Editor) (Hardcover) John Wiley and Sons 1995 ISBN 047957275

Fluvial Processes in Dryland Rivers (Springer Series in Physical Environment, Vol 3) by William L. Graf (Hardcover - April 1988) Springer Verlag 0387175911

Gravel-Bed Rivers : Fluvial Processes, Engineering and Management by R. D. Hey (Editor) (Hardcover - October 1982) John Wiley and Sons 0471101397

International Conference on River Regime by W.R. White (Editor) (Hardcover - September 1988) John Wiley and Sons ISBN 0471919551

Mechanics of Alluvial Channels by K. Mahmood, et al. Water Resources Pubns. ISBN 0918334632

River Channels : Environment and Process (Institute of British Geographers Special Publications Series, Vol 18) by Keith Richards (Editor) (Hardcover - December 1987) ASIN 063114577x

River Mechanics by Pierre Y. Julien (Hardcover - May 2002) Cambridge University PR ISBN 0521529700

Rivers: Form and Process in Alluvial Channels by Keith Richards (Hardcover - February 1983) Rutledge Kegan and Paul ISBN 0416749003

Rivers over Rock : Fluvial Processes in Bedrock Channels (Geophysical Monograph Series, 107) by K. J. Tinkler (Editor), Ellen E. Wohl (Editor) American Geophysical Union November 1998 ISBN 0875900909

River Restoration

Leopold, Luna. "A View of the River," Harvard University Press, 1994. ISBN 0674937325

River Restoration (Cont.)

The River Book : The Nature and Management of Streams in Glaciated Terranes (Dep Bulletin, 28) by James Grant MacBroom (Hardcover - September 1998) National Resources Center
ISBN 094208506x

California Rivers and Streams –The Conflict between Fluvial Process and Land Use by Jeffery Mount University of California Press 1995 ISBN 0-520-20250-3

ASCE 1999 International Water Resources Engineering Presentation Summaries ASCE

Strategies for Restoring River Ecosystems: Sources of Variability and Uncertainty in Natural and Managed Systems ed Wissmar, Bisson AFS 2003 ISBN 1-888569-46-8

Rehabilitation of rivers for fish : a study undertaken by the European Inland Fisheries Advisory Commission of FAO / edited by Ian G. Cowx and Robin L. Welcomme.

Published: Oxford ; Malden, MA : Published by arrangement with the Food and Agriculture Organization of the United Nations (FAO) by Fishing News

Books : distributor, Blackwell Science, 1998 ISBN 0852382472

Channelized Rivers: Perspectives for Environmental Management by Andrew Brookes (Hardcover) John Wiley and Sons, March 1989 ISBN 0471919799

Engineering Approaches to Ecosystem Restoration :Wetlands Engineering & River Restoration Conference 1998 by Donald F. Hayes (Editor) (CD-ROM - December 1998) Society of Civil Engineers (CD ROM) ISBN 0784403821

Land, Water and Development : Sustainable Management of River Basin Systems by Malcolm Newson (Hardcover - September 1997) Routledge 2nd Edition ISBN 041515507x

Rehabilitation of Rivers: Principles and Implementation by Louise C. De Waal (Editor), et al (Hardcover) John Wiley and Sons, January 1995 ISBN0471957534

River and Lake Ice Engineering, by George D. Ashton (Editor) (Hardcover - August 1986)Water Resource Pubns. ISBN 0918334594

River Channel Restoration: Guiding Principles for Sustainable Projects by Andrew Brookes (Editor), F. Douglas Shields (Editor) (Hardcover) John Wiley and Sons August 1996
ISBN 0471961396

River Engineering-Part 1, Design Principles (Water Practice Manuals) by Thomas W. Brandon (Textbook Binding - December 1987) Water Environment ISBN 9998720257

River Restoration (Cont.)

River Projects and Conservation : A Manual for Holistic Appraisal by John L. Gardiner (Editor) (Hardcover - May 1991) John Wiley and Sons ISBN 0471926434

River Quality : Dynamics and Restoration by Antonius Laenen (Editor), David A. Dunnette (Contributor) (Hardcover - January 1997) Lewis Publisher Inc. ISBN 1566701384

River Restoration : Selected Extracts from the Rivers Handbook by Geoffrey Petts (Editor), Peter Calow (Editor) (Paperback - July 1996) Blackwell Science Inc. ISBN 0865429197

The Restoration of Rivers and Streams: Theories and Experience by James A. Gore (Editor) (Textbook Binding - April 1985) Butterworth and Heinman ISBN 0250405059

Water Bioengineering Techniques : For Watercourse, Bank and Shoreline Protection by Hugo M. Schiechl, R. S. Stern (Contributor) (Hardcover - December 1996) Blackwell Science Inc. ISBN 0632040661

Wetlands Engineering and River Restoration by Donald F. Hayes (Editor) (Hardcover - June 2001) American Society of Civil Engineers ISBN 0784405816

Inter agency Stream Restoration Manual,

http://www.usda.gov/stream_restoration/ www.usda.gov/stream_restoration/

Sediment

Manual of Bioassessment of Aquatic Sediment Quality by Alena Mudroch (Editor), et al (Hardcover - September 1998) Lewis Publishers ISBN 1566703433

Sediment Transport in Gravel-Bed Rivers by J.C. Bathurst, et al (Paperback - September 1987) John Wiley and Sons ISBN 0471909149

USGS sediment discharge program,

<http://water.usgs.gov/software/seddisch.html>

Statistics

Elementary Statistics - Picturing the World, 2nd Edition, Ron Larson & Betsy Farber, published by Prentice Hall. March 2002 ISBN 013655953

Design and Analysis of Experiments, 5th Edition, Douglas C. Montgomery, published by John Wiley and Sons. June 2000 ISBN 0471316490

Water Management

USGS Circular on water use, <http://water.usgs.gov/watuse/pdf1995/html/>

Water Management (Cont.)

Cadillac Desert by Mark Reisner 1987 Penquin ISBN 0140104321

Water Quality