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The Uncertainties of Ecosystems with the Fluvial Hydrodynamics LUO Ching-Ruey (Edward)

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--***ABSTRACT***--

Fluvial ecosystems, a colorful platform of the interactions between human being and environment. The hydrologists and the geomorphologists summarize the idea of relevant factors of regional context, which including watershed hydrology, watershed geomorphology, water quality, stream and riparian ecology and stream/river hydraulics, such as water depth, width of channel, flow velocity, bed material and slope of stream/river, to transport nutrient and thermal regimes changing temporally and spatial, make the ecosystem alive. And they are obviously important of watershed management on decision support for the necessities to manage water resources in environments, fluvial ecosystem diversity, explaining watershed processes and the effects of disturbances across different regions including the human behaviors. Turbulence as a scalar quantity is a useful descriptor of turbulence in complex 3D flows characterized by non-zero vorticity. There is no general rule on when, why and which hydraulic model should be applied for eco-hydraulic studies but fundamentally the accurate topographical survey at the resolution of the scale of the processes investigated is more essential. All of them own uncertainties. Understanding the fundamental associations and relationships between hydraulic forces and floral and faunal communities, species, and their habitats, modelling them and using this information to provide management recommendations continues to be important and challenging goals for river scientists, managers, and other end users. In this paper, the characteristics of fluvial ecosystem with its variable factors will be illustrated and then the functions of fluvial ecosystem are following. Finally, the impact mechanisms resulting uncertainties on the platform are emphasized with their conceptual solving strategies.

KEYWORDS: *Fluvial Ecosystems; Hydraulics; Turbulence; Geomorphology; Hydrology; Uncertainty.*

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I. INTRODUCTION

Fluvial ecosystems vary in many additional features. Rivers that still have an intact floodplain exchange organic matter and nutrients with the adjacent land, and all fluvial ecosystems high connectivity laterally, longitudinally, and vertically. Frissell et al. (1986)〔13〕took the view of river systems as a hierarchically arranged nested series of units provides a powerful organizing framework in which to examine the patterns and processes of fluvial ecosystems. The hydraulic characteristics of flow through channels are an important component of aquatic habitat evolving in stream systems in which water velocity and flow depth vary spatially within the watershed and temporally on a daily, seasonal, and annual basis. Spatial variability enhances species diversity by creating a variety of habitats within stream reaches. Velocity may often be the factor limiting available habitat space. Hawkins, et al. (1996〔14〕mentioned "channel componentssuch as pools, riffles, steps, cascades, and plane beds provide important habitat for many organisms. The difference is an estimate of all the nutrients removed by ecosystem processes or stored within soils and sediments, and this can be viewed as a measure both of the services provided by an ecosystem and of their limitations. Streamflow in channels moves materials, including organic particles and dissolved nutrients as well as large particles of mineral substrate. The need for interdisciplinary research and collaborative teams to address research questions that span traditional subject boundaries to address these issues has been increasingly recognized (Dollar et al, 200〔11〕 and has resulted in the emergence of new 'sub-disciplines' to tackle these questions. Eco-hydraulics is one of these emerging fields of research that has drawn together biologists, ecologists, fluvial geomorphologists, sedimentologists, hydrologists, hydraulic and river engineers and water resource managers to address fundamental research questions that will advance science and key management issues to sustain both natural ecosystems and the demands placed on them by contemporary society. More recently, there has been a shift towards greater interdisciplinarity, with teams of scientists, engineers, water resource and river managers and social scientists working together in collaborative teams towards clearly defined common goals (Porter and Rafols, 2009)〔27〕. The growing world-wide interest in eco-hydraulics can be demonstrated by increasing participation in the international symposia on the subject.

II. PERFORMANCES OF FLUVIAL ECOSYSTEMS

Fluvial ecosystems exhibit tremendous variability in the quantity, timing, and temporal patterns of river flow, and this profoundly influences their physical, chemical, and biological condition. Vast quantities of fresh water are extracted to meet agricultural, municipal, and industrial demands, yet freshwater ecosystems also need enough water, of sufficient quality and at the right time, to remain ecologically intact and provide economically valuable commodities and services to society. The hydrologic cycle describes the continuous cycling of water from atmosphere to earth and oceans, and back to the atmosphere. The characterization of streamflow has practical application for the design of flood-control structures, evaluation of channel stability, and in determining whether sufficient water is available at the appropriate time to meet the needs of both people and the ecosystem. The river ecosystem includes its hydrology, diversity of channel and habitat types, solutes and sediments, and biota (see Fig.1). "Rivers are not only important links in the hydrologic cycle" and ''the gutters down which run the ruins of continents, but also ecosystems that use and reuse biologically reactive elements".

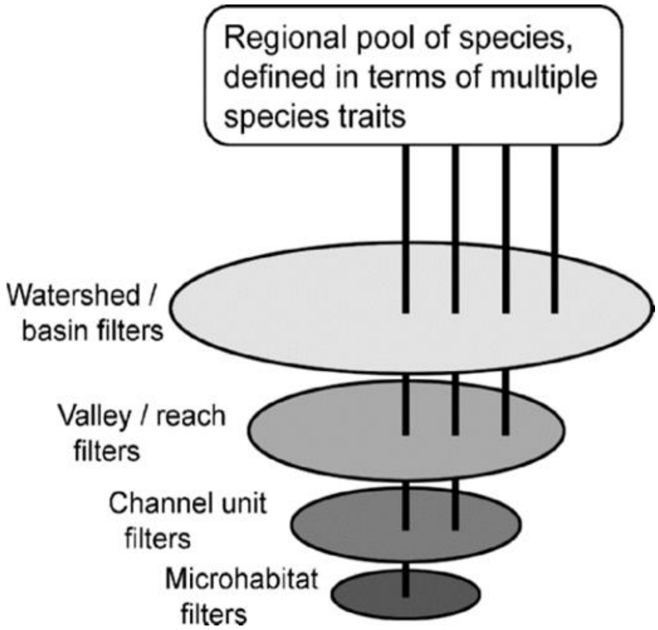

Fig. 1. The number and types of species at a site reflects their possessing traits (trophic, habitat, life history, etc.)

Fluvial geomorphology and flow environment are obviously significant components on fluvial ecosystems. It helps make sense of the enormous variety exhibited among fluvial systems, and thus the habitat and environmental conditions experienced by the biota. The discipline of eco-geomorphology is founded on this habitat-centered view for ecological systems, whereby physical structure is considered to be a dominant driver of ecological patterns. Fluvial geomorphology emphasizes the dynamic interplay between rivers and landscapes. Quantification of the relationships among river features and analysis of the underlying processes contribute to a deeper understanding of how rivers respond to human-induced changes in water and sediment supply that can cause rivers to change their shapes. The larger particles in the armor layer partly shield the finer particles from being dislodged by the flow, but are them-selves more vulnerable to entrainment because they protrude into the high-velocity flow. As a result, large and small particles in the armor layer have nearly equal mobility, and so become entrained at nearly equal discharges (Andrews, 1983) 〔2〕. Stream power, the product of discharge and slope, describes the ability of the stream to mobilize and transport material. Sediment transport is directly related to stream power and inversely related to median grain size, and this is a useful relationship for understanding how a stream might respond to changes in sediment and water supply along its length, or due to human interference (see figure 2).

In fluvial systems the flow of water is a dominant. And characterizing variable that influences diverse aspects of the stream environment. Flow strongly influences the physical structure and hydraulic, such as channel shape, forces operating in the benthic and near-bed microhabitats, substrate composition, occupied by much of the biota, and is important to ecological interactions, rates of energy transfer, and material cycling. Characterizing near-bed flows creates an enormous measurement challenge and has led to a number of imaginative attempts to estimate or directly measure flow micro environments.

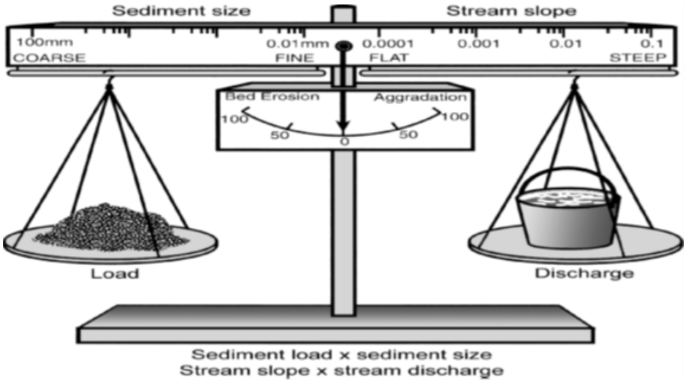

Fig. 2. Lane's Law states that sediment transport is proportional to stream power (streamflow slope) and proportional to sediment size. Thus, stream channels are in equilibrium when: sediment discharge (Qs)* sediment particle size (D50) streamflow (Qw)* stream slope (S). (Reproduced from Brierley and Fryirs, 2005〔5〕)

Surface roughness can be measured directly from particle dimensions, or by using a bed profiler such as a level plate. Mean velocity, depth, and surface roughness are simple hydraulic variables that provide useful information about the flow environment (see figure 3). Re quantifies the ratio of inertial forces of the moving fluid to the viscous properties of a fluid that resist mixing. It is a dimensionless number that can be used to distinguish types of flow and the forces experienced by an organism while Fr is a dimensionless velocity to depth ratio, and differentiates tranquil flow from broken and turbulent flow. Low values of Fr are characteristic of pool habitats and higher values of riffle habitats. Using open-channel measurements and certain constants one can estimate hydraulic variables including channel Reynolds number (Re) and Froude's number (Fr). With an estimate of shear velocity (u*), which can be derived from the velocity profile near the streambed, and substituting the height of roughness elements for water depth, one can estimate roughness (boundary) Reynolds number (Re*). This variable and the dimensionless shear stress, which is related to the square of shear velocity and inversely related to particle size, describe the conditions under which particle movement is likely. Both near-bed velocity and bed shear stress increase with increasing relative roughness and mean velocity. Abiotic factors include all physical and chemical variables that influence the distribution and abundance of organisms.

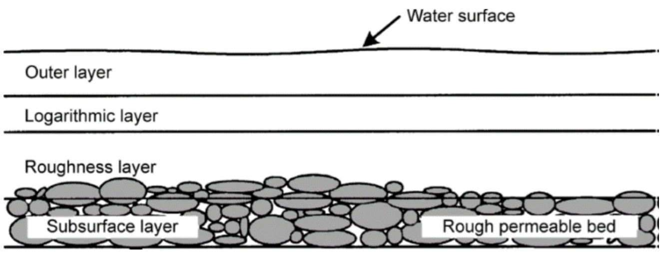

Fig. 3. Subdivision of hydraulically rough open-channel flow into horizontal layers. Flow velocities within the"roughness layer'' are unpredictable based solely on knowledge of flow in the logarithmic layer. This figure is not drawn to scale.

Current, substrate, and temperature often are the most important variables in fluvial environments, and all organisms show adaptations that limit them to a subset of conditions.

We argue that the inclusion of higher order (turbulent) properties of the flow constitutes a more complete and ecologically relevant characterization of the hydraulic environment that biota is exposed to than standard eco-hydraulic variables alone. The use of turbulent flow properties in eco-hydraulics, therefore, has the potential to contribute towards achieving river research and management goals (river habitat assessment, modelling, rehabilitation) but more information on the mechanisms by which turbulence affects biota is required before this potential can be realized. From the simple formula, such as Manning's formula, for setting the suitability, we may have the two values, minimum and max-mum, each for velocity, water depth, bed slope, and channel width, and totally we have 16 situations of combination for calculating the corresponding suitable discharges. After we look back to the long-term mean data records of discharge, QF the optimum discharge chosen for design will be defined with the corresponding velocity, water depth, channel width and bed slop, to form the necessary flow environment for the given, or said chosen, habitat life need (see figure 4).

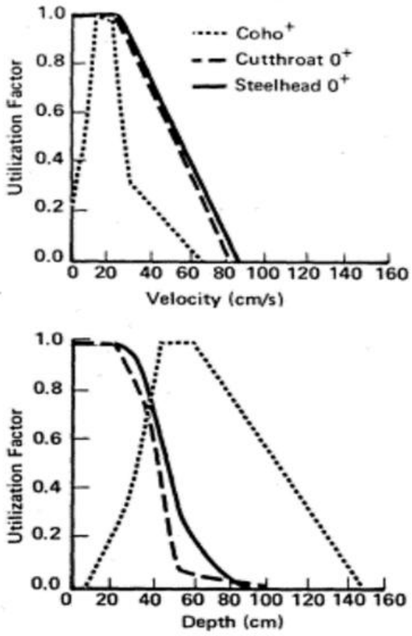

Fig. 4. Utilization factor, an index of preference, of salmonid populations in relation to velocity and depth. The data shown were collected for several species of salmonid fry in streams in Washington by the Washington State Department of Game, Olympia, for use in the Instream Flow Incremental Method model developed by the U.S. Fish and Wild-life Service. (Bovee and Cochnauer 1977〔6〕, Bovee 1982〔7〕, Postel S, Richter B. 2003 〔28〕, and Tharme RE, King JM. 1998 〔31〕 for a description of the IFIM methodology and the utilization factor.)

As the ecological habitat of fish is a very important element of ecological restoration, we chose fish flow as an ecological flow. Therefore, the instream flow was determined as the maximum value between drought flow and fish flow de-pending on seasonal variation at a particular reach of stream. The evaluation of instream flow is given in Equation (1):

QIN = max (QF, QD) (1)

where QIN is the instream flow, QF is the habitat (fish) flow, and QD is the drought flow.

III. TURBULENCE

Turbulent flow exhibits seemingly random behavior, has three-dimensionality and rotationality and is intermittent in time and space over a range of scales (Nikora, 2010〔25〕. Turbulent fluctuations in flow velocities have been implicated in suspended sediment transport (Bagnold, 1966) 〔4〕, bedload transport and the development of bed morphology, mixing of dissolved and particulate substances (Zhen-Gang, 2008) 〔34〕, primary productivity and the growth and destruction of algae (Stoecker et al., 2006〔30〕; Labiod et al., 2007 〔20〕), biomechanics and bioenergetics (Enders et al., 2003; 〔12〕 Liao et al., 2003a〔22〕 and the distribution of aquatic organisms (Cotel et al., 2006; 〔9〕 Smith et al., 2006〔29〕. Water behaves as an uncompressible, homogeneous, Newtonian fluid in rivers and its flow is governed by equations describing the conservation of mass, momentum and energy. These mass–momentum (Navier–Stokes) and energy equations are set out by Tonina and Jorde. The basic principles underlying fluid mechanics are described in any introductory-level text on hydraulics (Kay, 2008) 〔18〕. The full set of equations describing turbulent flow is provided by Nezu and Nakagawa (1993) 〔24〕 and several other re-search-level texts. The turbulence intensity is a vector quantity. RMS values reflect the normal Reynolds stresses including in the final term, whilst the diagonal Reynolds shear stresses in τij. A summary of overall turbulence is given by Turbulent Kinetic Energy (TKE) as a scalar quantity, is a useful descriptor of turbulence in complex three-dimensional flows. An essential feature of turbulent flows is that they are rotational or, in other words, they are characterized by non-zero vorticity. Vorticity (ω) describes the curl (curve) of the velocity vector and is equal to twice the angular velocity (rate of rotation of the fluid at a point). An eddy can be defined as a region of flow with finite vorticity (Webb and Cotel, 2010). 〔33〕 The fundamental concept underpinning the statistical description of turbulence is the eddy or energy cascade (EC). (seeFigure 5)

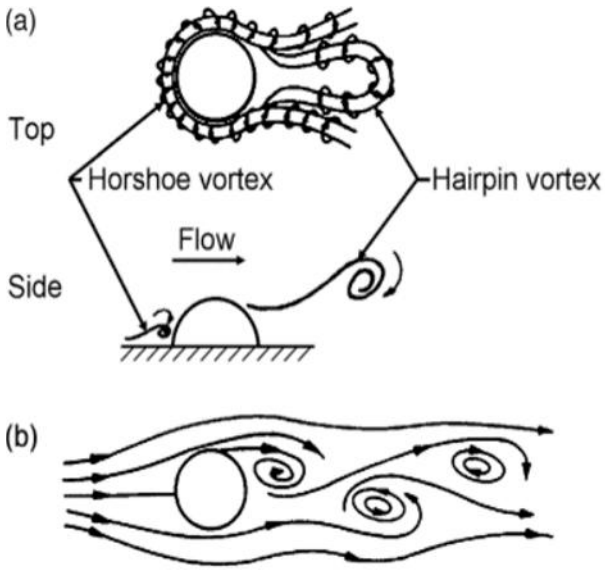

Fig. 5. (a) Illustration of horseshoe and hairpin vortices over a hemispherical body.(b) Top view of streamlines associated with the K´arm´an vortex street.

Two essential features of an eddy are its orientation and intensity. The resumption of steady swimming after disturbance from horizontal eddies required additional rolling movements in comparison to recovery from vertical eddies. It has been suggested that susceptibility to destabilization from eddies of different orientation, as the maximum angular momentum of eddies, is related to body morphology, with laterally and dorsoventrally compressed fish more susceptible to horizontal and vertical eddies respectively. Very few studies have examined fish habitat selection with respect to turbulence. These have most often been undertaken in artificial settings in the laboratory. Field studies of fish habitat se-lection with respect to turbulence are limited to two examples focusing on salmonids. Eco-hydraulics has suffered from an overreliance on correlative approaches based on relatively simple, mean characteristics of the flow, yet turbulence is a ubiquitous phenomenon in rivers. The inclusion of turbulent flow properties, especially for the 1D, 2D, or 3D models, in eco-hydraulic research, therefore, should enhance our mechanistic knowledge of physical–ecological interactions. Evidence on the effects of turbulence on the microhabitat selection of non-salmonid species is lacking and no attention has been paid to fish-turbulence links at the mesoscale (0.1m−10m), where the results of eco-hydraulic research are often applied. Even for salmonid species the accumulated knowledge is sparse. What knowledge we do have from the field is limited to summer low flow periods, yet the feeding behavior of juvenile salmonids is known to vary seasonally and critical population bottlenecks may occur at other times of the year.

3D modelling is considered the approach with the most predictive capability, because it explicitly accounts for most of the flow processes, without turbulence, which may be parameterized. However, applications have shown that uncertainty due to the turbulence closure may have fewer effects on model results than those of stream topography, boundary condition information and mesh quality (USACE, 1996〔32〕; Lane et al., 2004〔21〕; Pasternack and Senter, 2011〔26〕). Their use is still limited to some special cases because little ecological and aquatic habitat knowledge is available to take advantage of the full dimensionality and the long computational time.

On the other hand, 2D models provide flow properties which better match the present available ecological and biological knowledge. Consequently, they are becoming to the mainstream tools for eco-hydraulic applications both at the reach (10–50 channel width) and segment (50– 1000 channel width) scales. They use simplified turbulence closures based on isotropic turbulence, which may be adequate for most applications. 1D modelling uses rather crude engineering techniques to calculate water surface elevations and then calculate individual cell velocities as described for the 1.5 or pseudo-2D approaches. They are cross-sectional based and thus selection of cross-section locations is very important (Pasternack and Senter, 2011)〔26〕. They require calibration because the roughness term lumps together several energy losses from the grain to the reach scales. Therefore, predictions outside the range of observed discharges are questionable.

Differences of aquatic habitat suitability index results predicted with 1D and 2D hydraulic models may be smaller than the actual flow difference because flow velocities are only one among several attributes (depth, substrate and distance from cover). Therefore, careful selection of the model by evaluating the stream characteristics, questions and data available is recommended.

IV. THE UNCERTAINTIES ALWAYS EXIST

A holistic, such as the ecosystem approach is now at the forefront of environmental flow methodologies, drawing upon hydrological, hydraulic, and habitat analyses, and expert judgment to construct a suitable flow regime for a managed system. These are increasingly complex and interdisciplinary undertakings, allowing the evaluation of alternative scenarios, and designed with the intent to protect the river ecosystem while meeting human needs as shown in figure 6. These are increasingly complex and interdisciplinary undertakings, allowing the evaluation of alternative scenarios, and designed with the intent to protect the river ecosystem while meeting human needs.

Now we see increasingly that the ecological engineering approach is perturbed by the uncertainties introduced by social and cultural concerns. In other words, the current phenomenon of restoration professionals experiencing uncertainties on all fronts may be simply an indicator of a rapidly broadening viewpoint and recognition of problems without com-mensurate solutions.

To be successful on a sustainable basis, stream restorations must be both technically sound and enjoy strong public support. Although decisions in stream restoration are essentially value driven, sound science is fundamental to con-strain the range of possible solutions and evaluate possible alternatives.

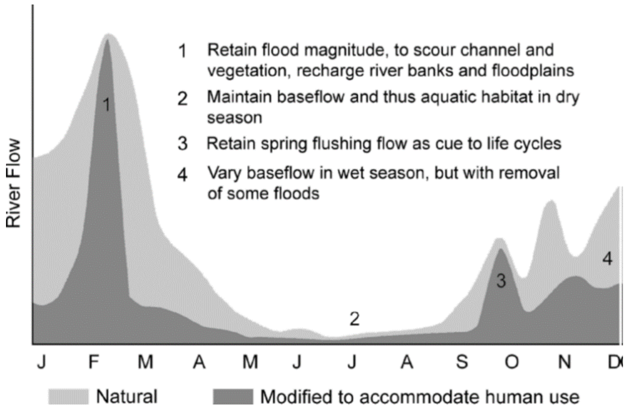

Fig. 6. Natural (light shading) and modified (dark shading) hydrographs for selected rivers in South Africa, illustrating a flow scenario that provides only half as much water as the natural hydrograph and is intended to accommodate human uses while keeping the river as healthy as possible. This scenario illustrates some key principles identified by a panel of scientists.

The hydraulic characteristics of flow through channels are important component of fish habitat evolving in stream systems in which water velocity and flow depth vary spatially within the watershed and temporally on a daily, seasonal, and annual basis. Water is a valuable resource for humans (direct consumption, power, irrigation, and industry) and provides

essential habitat for many organisms, including highly valued fish species such as salmonids. Clean water is essential for ecosystems and society worldwide. Aquatic habitat is influenced by processes active not only in the near-stream(riparian) zone (e.g., provision of shade) but also over the entire watershed (e.g., hillslope hydrologic processes that control the supply of water or the generation of slides). The tolerance of species to a range of flow conditions has been evaluated by measuring the hydraulic characteristics observed at feeding stations: fish are observed in natural streams, their feeding stations marked, and velocity, depth, and substrate are measured at each station. and that these ranges are defined by frequency distributions for each selection variable. The utilization factor (an index of preference) for velocity and depth varies with species (figure 4). Despite the differences in distributions that are evident in figure 3, there is also considerable overlap in the tolerance of species and age groups to the same hydraulic conditions. Project design may include a variety of channel dimensions and characteristics, for example, and avoid relying on a single rigidly defined morphology, so that if original understandings of the system are not exactly correct the final project will have some flexibility. In other cases, it may be wise to simply allot more space for channel changes in the designed project to accommodate unforeseen adjustments. By dealing directly with uncertainty, re-searcher and decision maker increase the probability in successfully restoring a river with enhanced environmental and social benefits.

Uncertainty in river restoration and environmental management has been pointed out. The arguments and evidence presented challenge the view of scientific deterministic certainty and societal beliefs that certainty is necessary in restoration. A typology for discriminating uncertainty was reviewed that can be used to separate uncertainties that can lead to unforeseen and undesirable consequences from uncertainties that lead to potentially welcome surprises. Where there are significant uncertainties on social and cultural aspects, these should probably be settled before proceeding to settle technical uncertainties. There may be little point in quantifying its catchment production and morphological qualities.

Cultural preferences (commonly unacknowledged) largely shape restoration goals. Building a culturally preferred form (such as a stable, meandering channel) is perfectly reasonable as a restoration goal, but we suspect that the field would benefit from an explicit recognition of this as motivation, rather than cloaking such projects in seemingly scientific de-tails of channel morphology and (commonly vague) references to improved fish habitat. To the degree that cultural preferences remain unacknowledged, they introduce greater uncertainty in the trajectory of restoration projects. Cultural preference for tidy landscapes over messy landscapes should be acknowledged, so that 'overgrown' riparian zones can either be 'framed' or simply avoided in urban areas. For ecological design to be truly successful and widely accepted, designers will need to find ways to make stream restoration compelling as designs Concept of 'eco-revelatory design' suggests that by accepting humans into the restored ecosystem and designing the project to reveal ecological processes, we may achieve ecosystem restoration (to the extent possible in urban areas) while still gaining public acceptance.

V. APPLICATION OF HYDRODYNAMICS ON FLUVIAL- ECOSYSTEM

Spatial environmental heterogeneity is a primary factor that may influence reproductive success and growth of plants and animals. Decreased habitat complexity may negatively impact the growth and survival of freshwater organisms. Therefore, selective differences and asymmetric competition for habitat may provide a mechanism that allows the co-existence of size classes and species. Conversely, disturbance of the spatial environment by human intervention, may also disrupt fish communities. The term habitat is often subdivided into macrohabitat, mesohabitat and microhabitat. Macrohabitat may describe the general type of space in which an animal lives, and applies to a scale larger than the animal's normal daily range (Kramer et al., 1997),〔19〕typically spatial scales of 10 meters (Frissell et al., 1986〔13〕; Allan, 1995〔1〕) or often more. Data on geomorphology, hydrology and climate on a scale of stream reaches or sub catchments, combined with fish habitat observations, may be referred to as macrohabitat studies (Cunjak and Therrien, 1998) 〔10〕. Mesohabitat studies typically quantify eco-hydraulic characteristics of stream reaches (habitat types) within the normal daily range used by fish. Habitat includes both abiotic and biotic factors, in complex interaction. On the individual level, choice of holding station (microhabitat) is often thought to be best described by optimal foraging theory, the fish at-tempts to maximize net energy intake (Bachman, 1984〔3〕; Hughes, 1998; 〔16〕; Hayes et al., 2007〔15〕), modified, however, by (pre-dation) risk and competition. Of course, choices of key hydraulic factors mostly depend on habitat selection, especially the suitability and frequent discharge on the function of hydraulic factors, such as water depth, flow velocity, bed slope, bed roughness (Luo, 2020).〔23〕In an eco-hydraulic context, habitat suitability has often been quantified as univariate habitat suitability curves (HSCs), constructed by measuring these key physical characteristics of patches occupied by fish. To establish habitat selection criteria, however, it is also necessary to measure habitat availability, i.e. to include patch-es not occupied by fish.

The physical environment in natural rivers can be highly variable, with regard to hydraulic conditions, temperature, visibility, cover, substrate alteration and erosion. However, anthropogenic flow alteration downstream of hydroelectric plants may lead to a harsh environment of frequent and unpredictable disturbances for freshwater organisms, in an evolutionary sense, with no natural analogue. The consideration of changing morphological characteristics is a key aspect when evaluating the impact of hydropeaking on fish habitats (Clarke et al., 2008).〔8〕. In particular, operation over decades shifts the balance of sediment transport processes. Rapid flow fluctuations can be categorized by changes in magnitude (flow ratio), the rate of change, frequency, duration and timing (Junk et al., 1989).〔17〕Artificial flow fluctuations should be defined as flow fluctuations induced by hydro operations, and they can simply be identified as situations where one or several of these factors exceeds natural limits. However, it is often the combination of these parameters that creates the most harmful effects. The flow ratio is the highest flow divided by the base flow. In natural systems, the ratio may also be very high when comparing floods to low-base-flow situations, but these very seldom happen shortly after each other. The rate of change in water level and flow in natural systems may be large when flow is increasing due to heavy rainfall events, but is very seldom so pronounced during retention of flow. Under natural conditions, a rapidly changing water level normally follows changes in weather conditions. The duration of peaking events is often defined as the time for one 'cycle', the duration of the high-flow event until base flow is re-established. This compares to the time during which full power production or high-flow hydro operations are going on. However, for most studies of impacts, the duration between two peaks in flow or the duration of the recession in flow and the dewatering period is the most important to focus on. We recommend using the time between two peaks to describe the duration of a low-flow event rather than the duration of a high-flow event. The frequency of peaking describes how often peaking operations are carried out. A typical frequency of peaking produces power during the daytime, when the demand is high, and stops operations during the night.

VI. MANAGEMENTS OF UNCERTAINTIES ON

Fluvial networks are both heterogeneous and hierarchical has been freshly infused by collaborations between ecologists and geomorphologists. Ecologists engaged in the study of running waters have developed a number of conceptual models whose purpose is to synthesize empirical information that describes structure, function, and processes of lotic eco-systems over their enormous range of natural variations. Such models are of great value in organizing what might otherwise be a collection of seemingly unique case studies

into a broader understanding based on unifying principles and predict outcomes in new settings and explain differences observed among differing discharge or occurring in different landscape and climatic settings. The view that the biological assemblages of streams are made up simply of those species able to reach a particular location and survive in the habitats that it affords while in other way, the view that bio-logical communities have repeatable structure that results not only from environmental factors, but also from the inter-actions among species, including certain key species. The stream environment is heterogeneous across all spatial and temporal scales. Individual habitat patches typically are distinctive in their environmental conditions including current, substrate, temperature, organic matter accumulations, biofilms, and so forth. Many species will differ in how well they are suited to particular conditions along an environmental gradient, and because multiple environmental gradients exist, species sorting along environmental gradients is likely to play a significant role in determining local abundances. Rivers are shaped by environmental factors that control essentially all aspects of the river's physical appearance, vary from place to place, and can be organized. Climate, topography, geology, and vegetation cover are fixed environmental variables that the river cannot influence, and because climate tends to be expressed at a larger spatial scale than topography, their influence is approximately hierarchical.

Geology determines the availability of ions and the supply of sediments, topography determines slope and degree of containment, climate and soils determine vegetation and hence the availability of organic matter and extent of shade, and so on. Landscape ecology studies the interactions between spatial pattern and ecological processes in heterogeneous systems across a range of scales, emphasizing the importance of discrete patches, ecotones (the boundaries between patches), and the connectivity among patches. In general, ecological processes are scale dependent so that factors operating at larger scales influence smaller scale systems but not the converse, in accord with the hierarchical directionality of influence.

There is an increasing recognition in environmental management that ethical and social dimensions are the primary drivers, with scientific and technical dimensions playing a secondary role. Thus, an emerging challenge which the restoration community is faced with is combining these dimensions to 'do the right thing right.' Out of the decision- making arena has emerged the pragmatic view of coping with uncertainty. Restoration can be a very expensive exercise but there is often little basis for managers to assess how much confidence they should have in conceptual models that are presented to them. Methods have been proposed that can be used to test the validity of conceptual models.

In some case, the most effective way to reduce uncertainties is to run trial programs in the actual systems being restored. Even in these cases, the model and uncertainty analysis can provide the basis for designing the trial to ensure that it tackles the key sources of uncertainty in model predictions. It is possible to design monitoring activities without regard to uncertainties during the planning phase of a restoration project. However, it is proposed that stronger integration of monitoring and modelling activities will lead to greater improvements in the knowledge underpinning river restoration. It would be wiser to decide what is ecologically relevant first and then use hypothesis testing to detect ecologically relevant effects; the use of other statistical tools such as power analysis and decision theory also is recommended. We state that restoration ecology in general 'is a bridge between the social and natural sciences.' It is impossible to separate scientific and policy questions in restoration ecology and this, in and of itself, introduces uncertainty into what other-wise might be viewed as value–neutral or 'objective' scientific conclusions. It is important to clearly distinguish be-tween the use of methods and tools of science to understand the phenomena of nature and the acquisition of scientific information about a restoration issue and the setting of policy; but in practice, there is not always an unambiguous demarcation.

Policy makers set agendas that determine the questions that are asked of scientists; scientists formulate hypotheses in ways limited by their tools and their imaginations and disciplinary conventions. Consequently, the information they provide to the policy makers is limited and socially determined to a degree and therefore there is a complicated feed-back relation between the discoveries of science and the setting of policy. While attempting to be objective and focus on understanding river restoration phenomena, scientists and other researchers should be aware of the policy uses of their work and of their social responsibility to carryout science that protects the environment and human health. In trying to fulfill this responsibility, scientific and other uncertainty needs to be taken into greater account.

VII. CONCLUSIONS

Eco-hydraulic studies don't frequently consider multiple spatial and temporal scales, although results are often used to highlight relationships or impacts at other sites over time. It remains a major challenge to collect sufficient data over relevant spatial (site, reach or catchment) and temporal scales that are of direct interest to researchers and managers. Improvements in data collection methods to address larger spatial scales through the use of manned and unmanned air-craft and drones with remote sensing techniques equipped with optical instruments, LiDAR or video cameras have al-ready been applied in eco-hydraulics. It is also challenging to apply detailed numerical modelling tools with a fine spatial resolution to large sections of rivers. Even with modern computational techniques, this requires a lot of resources and remains a future challenge. The use of different types of numerical models interlinked to cover varying spatial scales is a useful way to overcome this challenge. Data collection, modelling and analysis strategies must not only cover different spatial scales, but also different temporal scales. Many physical processes vary with season and between years, but also at smaller time scales such as day–night variations, hourly or even minutes and seconds for example when considering the influence of turbulent eddies. For instance, flow may vary from day to day and water temperature may vary from early morning to midday in most natural rivers. From the initiation of research that has subsequently been recognized as laying the foundations of eco-hydraulics, it has

always been an applied science with re-al-world management applications and implications. However, the balance between fundamental understanding and the advances in science and technology enabling us to undertake our research is not always easily or readily transferable to the management arena. it is important that the results of eco-hydraulic models and laboratory investigations are vali-dated in the field wherever possible to demonstrate their applicability and ability to characterize the complexity of the real world. Understanding the fundamental associations and relationships between hydraulic forces and floral and faunal communities, species and their habitats, modelling them and using this information to provide management recommendations continue to be important and challenging goals for river scientists, managers and other end users. If those engaged with eco-hydraulics research are to make a significant contribution to the sustainable development of riverine ecosystems, then focusing of efforts towards reaching these goals is paramount. Only then can the results of this re-search be translated into meaningful management recommendations.

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