THE ECOHYDRAULIC TRINITY CONCEPT - INTEGRATING ECOHYDRAULIC ASPECTS ACROSS RIVER RESTORATION, ECOLOGICAL FLOWS AND PASSAGE OF AQUATIC ORGANISMS

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At the heart of the inter- and trans-disciplinary science of Ecohydraulics is the study trilogy of habitat and ecosystem restoration (including dam removal and wetland rehabilitation), e-flows (ecological, environmental or instream flow regimes), and passage systems for migrations of fish and other aquatic organisms. These ecohydraulic science themes were developed to a large degree independently, yet they form a holistic trilogy compatible with principles aiming to realize and maintain healthy and sustainable aquatic ecosystems in fresh, brackish and saline waters. These three study areas rely on classical aspects of traditional ecological and physical disciplines (e.g. ecology, biology, hydrology, hydraulics, geomorphology), but synthesize such aspects in new ways. Ecohydraulics is considered the culmination of all these study areas into a coherent science, which centers on eco-physical syntheses and transdisciplinarity. Ecohydraulic science and engineering has enabled, and continues to promote, inter- and trans-disciplinary advances as the best way to develop ecologically compatible solutions. Such advances have reached a level where integration of the ecohydraulic trilogy themes may enable efficiencies, synergies and more sound ecologically-based designs.

1 INTRODUCTION

The integration of ecological and physical processes form the foundation for ecohydraulic scientific advances and engineering applications. Aspects of more classical disciplines in science and engineering, such as ecology, biology, physiology, habitat quality, population dynamics, fisheries and aquatic science, geoscience, hydrology, hydraulics, fluid mechanics, water quality, hydrodynamics, ice dynamics, thermal regimes, morphodynamics, water resource management, as well as aspects of newer study areas such as environmental science, ecological engineering, ecohydrology, ecomorphology, biomechanics, bioenergetics have contributed to Ecohydraulics. Just like in other sciences, developments in Ecohydraulic science and engineering occurred gradually. Advances started with multidisciplinary team investigations, where co-ordination of the work conducted by traditional disciplines was the primary objective in bringing them together. This initial phase is often characterized by asymmetry in available information and knowledge between disciplines (e.g. good data and knowledge on hydraulics, lack of data on biology) and usually necessitates considerable professional judgement. The multidisciplinary phase has led to interdisciplinary research and development in ecohydraulics, where more intensive collaboration of those in traditional disciplines and more meaningful integration of their work, are central objectives. In this phase there is good information and knowledge for relevant disciplines, yet the balance in data or knowledge usually favours physical processes over ecological or biological ones, and sound professional judgement is needed to overcome such asymmetries [1, 2, 3, 4, 5, 6, 7]. Although, interdisciplinarity presently dominates most ecohydraulic research and development, recent progress, which reflects the state-of-the evolving science, is characterized by the more advanced transdisciplinary phase. Transdisciplinarity involves more holistic and symmetric science treatment, as well as in-depth knowledge and more thorough integration of all relevant disciplines, marking a more mature state in the evolution of Ecohydraulic science and engineering.

The main ecohydraulic topics form a trilogy which centers on: a) passage for fish and other aquatic organisms; this is the oldest area of study, and includes mitigation measures, such as biota passageways, fishways, fish screens, as well as biota movements in aquatic environments, ranging from freshwater lotic to brackish estuarine, or from oceanic to lentic ecosystems; b) e-flows (ecological, environmental or instream flow regimes); e-flows incorporate species-habitat relationships, ice and thermal regimes, interactions with groundwater, water quality, and floodplain or channel ecology; and c) habitat and ecosystem improvement or replacement, river basin, estuarine, delta, and wetland restoration, as well as dam removal. This ecohydraulic trilogy utilizes a range of tools and approaches - from physical and numerical modelling to empirical laboratory experimentation and field studies – aimed to address fundamental and applied science and engineering questions while generating innovative and feasible solutions for water infrastructure.

2 SYNERGIES AND THE ECOHYDRAULIC TRILOGY

The trilogy of ecohydraulic themes were developed to a large degree independently, yet there are often synergistic opportunities by considering all three together. For example, below a dam, river flows may be needed 1) to attract and pass fish, 2) to provide appropriate e-flows, and 3) to ensure the effectiveness of habitat restoration measures. Since this trilogy of themes assess parallel ecohydraulic characteristics and serve congruent purposes, it may be more ecologically sound, and at the same time more efficient, to analyse the three together and investigate optimum flow release regimes to meet the needs of all three. This approach integrates the ecohydraulic trilogy flow needs, and maximizes synergistic opportunities for more holistic, effective and balanced mitigation measures and projects. A more integrated study of fish attraction (5-10% of river flows; [8]), e-flows (80-95% exceedance flows; [9]), and flows near bankfull discharge, which are key to river restoration and habitat modifications, may benefit both ecological and project needs.

The following two case studies illustrate to some degree the advantages of integrating more than a single ecohydraulic trilogy theme, when developing new or modifying existing hydroelectric projects. Even though these are best case examples and one of the trilogy themes was more dominant, flow requirements for all three themes were met or exceeded.

2.1 Dunvegan Hydroelectric Project

The Dunvegan Hydroelectric Project, was proposed by Canadian Hydro Inc. on the Peace River in northern Alberta, Canada. This low-head (7.6 m), approximately 400 m wide project, involved the development of upstream and downstream fishways, and included habitat improvements to compensate for habitat loss. An appropriate e-flow regime was ensured by the proposed run-of-river operation of the project. Initially, a traditional dam, fishway and navigation lock were proposed with an estimated electricity production of 80 MW. Reconceptualization and ecohydraulic studies followed, which integrated biological and hydraulic variables through physical and numerical modeling. These investigations paved the way for a completely revamped project which met ecohydraulic criteria and was expected to allow upstream and downstream passage for multiple fish species, as well as increase its generating capacity to 100 MW. The dam, powerhouse, spillway, turbines and bar racks were all conceptualized and investigated with a primary objective to maximize opportunities for upstream and downstream movements of the many potamodromous species in the Peace River. Innovative upstream and downstream fishways were developed, starting with nature-like concepts and ending with high constructability, cost-effective structures [8]. A paradigm shift was realized with this project in terms of design process, operational flexibility, and adaptability to alterations based on monitoring, new information or knowledge. Designing through challenging each project component with the objective to maximize benefits to fish, fish habitat, and other environmental issues, viewing project operations from a similar lens, as well as providing for adaptive management, is germane to innovation. A follow-up comprehensive monitoring program was also developed to guide flow management and project operation, to assess passage effectiveness and habitat improvements, and to ensure the feasibility of the adaptive management strategy. The innovative solutions rendered Dunvegan Hydro a green project, although construction has been postponed since Canadian Hydro Inc. was taken over by TransAlta.

Attraction and guidance flows for multiple freshwater species and sizes to assist them in locating upstream and downstream fish paths were used as strategic assets in developing design and operational aspects of the project. The two upstream fishways, one on each bank, incorporated auxiliary water supply systems, each consisting of a sluice and diffuser panels, to provide velocity and flow control, for each fishway entrance over a range of tailwater conditions. Attraction flow capacity exceeded recommended values [8]. Furthermore, a guide wall with submerged conduits to further guide fish to upstream fishways was tested in the laboratory with a hydraulic model and optimized. The guide wall re-directs turbine flows which have already generated power. Flow patterns were optimized to lead fish, which move upstream near the river banks, toward the fishway entrances. Fish protection included turbine intakes with tightly spaced inclined racks to exclude larger fish, as well as high survival turbines for smaller fish. Ten full depth bypasses were incorporated across the powerhouse, providing flexibility over a wide hydraulic operational range for optimizing downstream passage paths for fish [8]. Flow releases through these fish bypasses ranged from 5-60 m^3/s, although a discharge of 10

m^3/s per bypass is anticipated as the normal operating condition. The 100 m^3/s normal condition flow releases through the bypasses, represent 13.3% of the estimated river flow at 95% exceedance (753 m^3/s), 6.5% of the 50% exceedance flow (1540 m^3/s), and 3.9% of the 5% exceedance flow (2549 m^3/s). Although the emphasis for the Dunvegan Hydroelectric Project was on fish passage, synergistically habitat improvements and e-flows were also assured by the flows provided to attract fish upstream and guide them downstream.

2.2 E.B. Campbell Hydroelectric Project

The hydropeaking E.B. Campbell Hydroelectric Station on the Saskatchewan River, in the Canadian Province of Saskatchewan, operated with no e-flow releases between 1964 and 2003. Hydrological data and exceedance values for pre and post operation of the station showed considerable alterations to the natural hydrograph. Flow management was changed to address concerns primarily with fish and fish habitat below the station. As an interim measure, a minimum daily flow release of 75 m^3/s started in 2004 and an instream flow needs (e-flow) study followed. The e-flow study provided estimates of weighted usable areas (WUA) and quantified instream flow needs for key fish species at three study sites within approximately 40 km of river downstream of the station [10]. The recommended flow release regime is outlined in Table 1, which provides a minimum flow release value for different periods of a year. These Biologically Significant Periods (BSP), as defined in Table 1, represent important time periods for the different fish species in the Saskatchewan River. Spawning is the most sensitive to flow changes as available habitat can be limiting and eggs of most species are not mobile. It is important that sufficient spawning habitat is available. If higher flows are available during spawning it is important that flow does not decrease to a level that causes spawning areas to go dry during the period between spawning and larval emergence and drift. It was concluded that establishing a varied e-flow regime is the best option to mitigate the effects of and restore basic ecological integrity and productive capacity on the Saskatchewan River downstream of the E.B. Campbell Hydroelectric Station. The percent exceedance values for flow releases (Table 1) are within the 80-95% range recommended from other studies [9].

It is worth noting that in this hydropeaking case study, the estimation of WUA includes a restoration measure to ensure viable habitat and avoid fish stranding at low flows. It was assumed that adult fish can only occupy habitat that is at least 20 cm in depth, regardless of the regulation of the system. This assumption was built-in in the calculation of the WUA and corresponding e-flows for each BSP. Therefore, two aspects of the ecohydraulic trilogy, i.e. e-flows and habitat restoration, were integrated to arrive at the recommended flow release values in Table 1. Furthermore, if fish attraction flows of 5-10% of river flows [8] were hypothetically considered in this case, they would be well within the recommended flow releases for each BSP. Attraction flows could simply be part of flow releases, although they would be directed to appropriate areas near fishways to be effective. The recommended flow releases actually provide the flexibility to provide attraction flows which would exceed the vast majority of cases where fish passage is the only consideration.

Table 1. Recommended minimum flow releases by BSP and corresponding flow % exceedances (based on mean weekly natural river flows and modified WUA for minimum depth of 20 cm) for the E.B. Campbell Hydroelectric Station on the Saskatchewan River, Canada.

	BSP (Biologically Significant Period)			
	Fall & winter spawning	Early spring spawning	Spring spawning	Growing season
	1 (15 Oct-29 Apr)	2 (30 Apr-27 May)	3 (28 May-24 Jun)	4 (25 Jun-14 Oct)
Flow (m^3/s)	75	300	450	250
Exceedance for BSP mean weekly flow	91.5%	89%	95%	95%

3 CONCLUSIONS AND RECOMMENDATIONS

It is important to investigate the ecohydraulic trilogy themes together, rather than in isolation. This will allow consideration of impacts and mitigation measures for projects to be more holistic and integrated, taking advantage of synergistic effects between the trilogy themes. The case studies outlined above, demonstrate that in some cases providing flows for one or two dominant trilogy themes, may ensure adequate flows for all three. In other cases though, particularly for projects in which all three themes are as important, a more thorough trilogy integration may offer the best synergistic potential. Further work is needed to demonstrate the importance of considering synergistic effects of all three trilogy themes. This is particularly important for many projects which are not best case examples like the above, and probably barely meet the flow requirements for even one theme. Considering the entire trilogy, may enable efficiencies, synergies and re-inforce the need for better solutions by placing more emphasis on how important effectiveness is for mitigation measures and their cost-benefit balance.

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