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Advances in Environmental and Engineering Research

LIDSEN Publishing Inc.

Concept Paper

FlowingLife: AI Enhancing Environmental and Economic Benefits for Aquatic Ecosystems Based on Optimizing Altered Flow Regimes

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Academic Editor: Daniel M. Alongi

Special Issue: Remote Sensing Applications in Coastal Environments

Adv Environ Eng Res
2024, volume 5, issue 4
doi:10.21926/aeer.2404028

Received: August 01, 2024
Accepted: December 06, 2024
Published: December 24, 2024

Abstract

This proposed FlowingLife framework addresses the challenges of optimizing altered flow regimes in Irish plans and programs to improve Irish aquatic ecosystems' economic and environmental outcomes. The framework uses Artificial Intelligence (AI) techniques to revolutionize flow regime management and decision-making processing, providing sustainable resource allocation, climate change adaptation, and aquatic habitat conservation. The potential of identifying optimization guides thoroughly evaluating Irish Plans, including development plans, river basin management, biodiversity, and climate action. Fish population restoration, protection of biodiversity, optimization of agricultural techniques, and management of water resources are some of the critical uses. AI-empowered FlowingLife framework creates real-time monitoring and assessment in Strategic Environmental Assessments (SEAs), enabling adaptive management. The FlowingLife evaluates and adaptively manages fish populations and flow regimes by combining Deep Learning (DL) for image and sensor analysis, knowledge graphs for intricating ecological linkages, and predictive modeling. The results show that the proposed paradigm using AI improves environmental management and supports evidence-based decision-making, sustainable resource management, and the preservation of Irish aquatic ecosystems.

Keywords
Sustainable resource allocation; water resource management; altered flow regimes; aquatic ecosystems; biodiversity conservation; artificial intelligence; climate change adaptation; environmental management

1. Introduction

The water quality, biodiversity, and ecological health are preserved by aquatic ecosystems. The ecosystems in Ireland confront challenges because of changed flow regimes via climate change and human activity. Alterations in the amount, time, and quality of water flow, or “altered flow regimes,” can hurt the environment and the economy by causing water shortages, declining water quality, and biodiversity loss [1]. To solve the issues mentioned earlier, advanced technology and managerial techniques are required. Artificial Intelligence (AI) optimizes the altered flow regimes to improve Ireland's economic results and aquatic ecosystems. Additionally, AI is essential in supporting decision-making systems by offering precise predictive models for data analysis based on environmental management [2]. AI also develops frameworks supporting adaptive management and sustainable resource allocation, automating data processing.

Sustainable development, biodiversity action plans, River basin management plans, development plans, and climate action plans are a few of the essential programs that include Ireland’s water management policies to attain more effective and efficient results [3-5]. It is imperative to improve these techniques by deploying AI. The flow regimes optimization in Irish aquatic habitats to maximize economic and environmental benefits via examining in-place Irish Plans to pinpoint locations. Therefore, managing water resources, agricultural practices, coastal and marine management, developing energy and infrastructure, and preserving biodiversity is critical. Furthermore, water resource management strategies in Ireland’s aquatic ecosystems cannot sustainably meet the dynamic problems of shifting flow regimes, human interventions, and climate change. Traditional approaches lack a thorough, data-driven framework that integrates hydrological and ecological aspects to balance stakeholder needs and protect fragile ecosystems. Without predictive models and adaptive management strategies, fish species in Ireland, including Atlantic salmon, are susceptible to habitat degradation and population decline.

Therefore, this paper presents a novel FlowingLife framework using AI for recording and tracking the advantages of optimum flow regimes inside Strategic Environmental Assessments (SEAs). To ensure that environmental factors are considered during the decision-making process, SEAs are evaluating the environmental effects of plans, programs, and policies [6, 7]. AI integrates real-time data collection and analysis to control the flow regime. For example, Reinforcement Learning (RL) and Natural Language Processing (NLP) improve water management by facilitating effective decision-making. AI-driven approaches address the impacts of climate change, increase ecosystem resilience, and promote sustainable approaches to fisheries and water resource management. Flowing Life effort deteriorating condition of Ireland's aquatic ecosystems, which harmed by fish populations and biodiversity via changed flow regimes brought on by climate change and human activity. To maintain a sustainable ecosystem and resilience to environmental changes, it seeks to provide a dynamic, AI-powered, real-time framework for managing flow regimes. Furthermore, FlowingLife enhances policy, highlighting the advantages of improved flow regimes. Stakeholder participation and implementation of environmental policy depend on effective communication. In [8], the authors focused on communication strategies that explain the value of optimal flow regimes to various stakeholders, including policymakers, environmental managers, and the general public.

1.1 Motivations and Contributions

The motivation for the FlowingLife framework is the urgent need to confront the adverse effects of changed flow regimes in Irish aquatic ecosystems, a problem that is not well addressed by present management approaches. Though extensive, current Irish Plans and Programs do not incorporate cutting-edge AI methods that might improve data analysis, predictive modeling, and decision-making. Furthermore, FlowingLife is motivated by available challenges related to altered flow regimes in Irish aquatic ecosystems that occur by human activities, and climate change impacts on water resources, biodiversity, and ecosystem functioning. The impacts include water scarcity, degraded water quality, loss of biodiversity, and inefficient water resource management. By integrating scientific research, stakeholder engagement, and policy recommendations, FlowingLife aims to contribute to the sustainable management of water resources, the conservation of biodiversity, and the overall well-being of Irish aquatic ecosystems and society. The FlowingLife seeks to bridge the gap between policy recommendations and practical implementation by providing innovative tools to capture and monitor optimized flow regimes' benefits. This ensures evidence-based decision-making for Irish aquatic ecosystems' long-term productivity and health.

The FlowingLife enhances environmental and economic benefits for Irish aquatic ecosystems to promote biodiversity preservation, sustainable water resource management, and the long-term survival of fish populations in Irish rivers. FlowingLife seeks to improve the environmental and economic advantages of Irish aquatic ecosystems. In addition, FlowingLife aims to enhance the knowledge, control, and SEA of flow regimes, resulting in sustainable techniques that aid in preserving and repairing aquatic environments and offering best practices and suggestions for optimizing the advantages of flow regimes. The following is a summary of FlowingLife's contributions:

1. The paper demonstrates how AI techniques can be effectively and successfully integrated to optimize changed flow regimes in aquatic environments. By utilizing AI for data analysis, predictive modeling, and real-time monitoring, FlowingLife improves the efficacy and efficiency of environmental management practices in water resource management, agricultural optimization, and biodiversity protection, where timely and accurate insights are crucial for sustainable ecosystem management.

2. The paper introduces a novel AI-powered framework for tracking, evaluating, and recording the advantages of flow regimes tuned within SEAs. The FlowingLife offers decision-makers valuable insights to help build and apply evidence-based policies and facilitate ongoing evaluation and adaptive management that allows for continuous assessment and improvement and responds dynamically to environmental changes.
3. The paper aims to increase stakeholders' comprehension and knowledge of the significance of optimal flow regimes for aquatic ecosystems. FlowingLife conveys improved flow regimes' financial and environmental advantages, encouraging stakeholder participation and assisting in well-informed decision-making. FlowingLife encourages active stakeholder participation and helps align environmental policies with ecological and economic priorities.

1.2 Related Work

The FlowingLife framework is a significant step forward from the current state-of-the-art in maximizing changed flow regimes for Irish aquatic ecosystems' environmental and economic advantages. Although SEA's significance in ecological planning has been studied, FlowingLife seeks to go above the norm by creating an all-encompassing, integrated framework designed explicitly for Irish Plans and Programs [9]. The FlowingLife framework tackles the gaps in knowledge and issues related to changed flow regimes in Ireland, including reduced water availability, deteriorated water quality, loss of biodiversity, and ineffective management of water resources. By leveraging interdisciplinary expertise and engaging stakeholders, FlowingLife aims to deliver innovative solutions that optimize altered flow regimes while considering the unique characteristics of Irish aquatic ecosystems. The current state of knowledge indicates that altered flow regimes, resulting from human activities such as land use changes, channel modifications, and water management practices [10, 11], can significantly impact aquatic ecosystems and associated environmental services. However, there is a need to explore further and quantify the environmental and economic benefits that can be achieved through the strategic application of environmental assessment in the context of altered flow regimes in Irish Plans and Programs. Several FlowingLifes have contributed to the understanding and managing altered flow regimes and their impact on aquatic ecosystems. Furthermore, the authors of [12] introduced the impacts of climate change on seasonal means and low flows of 37 Irish catchments.

Recently, optimizing altered flow regimes represents the key to enhancing environmental and economic benefits in aquatic ecosystems [13]. Understanding the impacts of altered flow regimes is based on water resources, biodiversity, and ecosystem functioning [14]. The authors [15] demonstrated the potential for SEA to improve the management of altered flow regimes by considering the economic and environmental trade-offs. The effects of optimal flow regimes on water availability in industry, agriculture, and urban water supply were emphasized by the authors of [16]. In [17, 18], the authors concentrated on preserving flow patterns to sustain ecosystem services, conserve biodiversity, and protect aquatic ecosystems. Frameworks for tracking the benefits of improved modified flow regimes were developed by evaluating flow regime optimization approaches' economic and environmental effects [19]. The benefits of altered flow patterns is measured, discussed, and assessed by stakeholders and policymakers [20]. Stakeholder involvement, adaptive management strategies, and sustainable management practices are advised [21-23]. By following the recommendations, decision-makers may enhance SEA's effectiveness and promote the sustainable use of water resources while protecting aquatic environments.

River flow patterns, sediment movement, and the effects of climate change are just a few of the complex datasets that AI techniques, in particular Machine Learning (ML) models, are being used to study and forecast and improve the management of water resources. By matching biological flow needs with water storage and flood control objectives, RL algorithms utilized to optimize the functioning of dams [24] allowed water managers to make real-time decisions. The application of multimodal knowledge graphs to combine many data sources and enable real-time monitoring and analysis is one of the most significant recent developments in the subject. AI links environmental factors and fish populations, such as hydrological models, satellite images, and historical records, into a knowledge graph [25]. Predicting fish migratory patterns and the impact of human activities, including damming and water extraction, improves data integration and offers a more comprehensive picture of ecosystem dynamics. Conventional approaches depend on manual intervention and hydrological models to handle the complexity of both natural and man-made changes in water systems. The application of AI offers adaptive management solutions by providing a solid theoretical basis for the use of AI in flow regime optimization.

The dynamic interaction of biological, physical, and chemical elements affects flow regimes. The unpredictability of these systems under unknown conditions (such as climate change and unforeseen anthropogenic influences) is frequently not captured by traditional deterministic models, such as those based on Hydrological Simulation Models (HSMs) [26]. ML empowers the intricate flow regimes to provide a flexible alternative that can learn from complicated datasets without requiring preset rules [27]. Neural networks can forecast flow rates depending on ecological and meteorological patterns because of the exceptional capacity to comprehend non-linear correlations seen in environmental datasets. Furthermore, the intrinsic sequential nature of ecological data and time-series analysis is essential for forecasting the future behavior of flow regimes. The Long Short-Term Memory (LSTM) network, a Recurrent Neural Network (RNN), is one of the best AI techniques for time-series prediction. LSTM efficiently involves temporal dependencies, such as forecasting water levels, fish migrations, and biological reactions to flow variations [28, 29]. In hydrology, LSTM is used to forecast water demand and streamflow, outperforming more conventional statistical techniques such as ARIMA models [30]. Dynamic water management is achieved through LSTMs' ability to evaluate historical and current data to predict changes in river flows and impacts on aquatic life. Integrating several datasets, i.e., climatological, biological, and hydrological data, is necessary for environmental monitoring. By combining data from many sources (such as IoT devices, remote sensing, and historical databases), multimodal AI enables a holistic image of ecosystem health [31, 32]. Knowledge graphs show the correlations between various environmental elements (e.g., water temperature, fish populations, sedimentation) to optimize water flow to benefit stakeholders and the ecosystem [33]. Furthermore, in water management, Particle Swarm Optimization (PSO) and Genetic Algorithms (GAs) are used to investigate the trade-offs between conflicting goals [34]. Decision support systems (DSS) are increasingly using AI to help managers of water resources make well-informed choices, utilizing the predictive capabilities of AI models [35]. AI-based DSS can anticipate how climate change affects water availability and evaluate the effects of flow changes on fish populations in flow regime optimization.

2. FlowingLife Framework

The FlowingLife framework addresses the challenges of optimizing altered flow regimes in Irish Plans and Programs, i.e., river basin management plans (Measures and actions to achieve good water quality and ecological status in rivers, lakes, estuaries, and coastal waters), national biodiversity action plan (Identifying priority species, habitats, and ecosystems and outlining actions and targets for the protection and management), national climate action plan (Measures to enhance water resource management, reduce flood risk, and promote sustainable land use practices), and national development plans (Management of water resources, infrastructure development, and environmental protection) to enhance environmental and economic outcomes for Irish aquatic ecosystems. The FlowingLife presents management and decision-making procedures about climate change adaptation, aquatic habitat preservation, flow regimes, and sustainable resource allocation. AI is automating data analysis and facilitating the discovery of modified flow regimes for optimization. Additionally, AI methods are used to measure and evaluate improved flow regimes' economic and environmental advantages, giving decision-makers important information. The FlowingLife uses AI models to evaluate massive datasets and forecast how various flow regimes and climate change will affect ecosystem health, water quality, and economic production.

An AI-powered FlowingLife framework has been developed to collect and track the advantages of optimal flow regimes inside SEAs. FlowingLife makes real-time data analysis to guarantee flow regime optimization and support evidence-based decision-making. Moreover, the policy is created to show planners and programmers the advantages of SEA, highlighting improving economic and environmental results by managing changed flow regimes optimally. AI aids in developing tailored and focused communication by evaluating vast datasets and deriving information that communicates to stakeholders improved flow regimes and promotes. The primary key of the FlowingLife concept is the creation and use of a thorough framework for optimizing changed flow regimes in Irish Plans and Programs to increase economic and environmental. The framework has several levels: use cases, policy and decision support, data, analysis, and modeling. The FlowingLife framework offers recommendations for documenting, analyzing, and assessing the advantages of strategic environmental assessment and optimum flow regimes. The framework guarantees that the interventions are efficiently tracked and evaluated by including procedures, indicators, and protocols for data collection, analysis, and monitoring.

The FlowingLife framework combines social, economic, and environmental factors to maximize modified flow patterns in Irish aquatic environments. The proposed framework maximizes sustainability by ensuring alignment with objectives and programs through the use of the SEA. Stakeholder involvement and communication tactics promote inclusivity and broader effect, while the focus on measuring both economic and environmental gains offers a strong foundation for AI decision-making. The uniqueness of FlowingLife is seen in its adherence to open science principles, concentration on quantification, integration of disciplines, holistic perspective, and stakeholder interaction. FlowingLife's creative method of maximizing changed flow regimes adds uniqueness to the management of aquatic ecosystems. With AI decision-making, FlowingLife provides insights into the best flow regimes to benefit ecosystem health, biodiversity protection, and water resource management. Thus, FlowingLife offers methods and materials to enhance flow patterns and achieve sustainable aquatic ecosystem management in Ireland.

FlowingLife improves flow regimes in Irish aquatic environments to increase economic and environmental benefits. FlowingLife employs a multidisciplinary strategy integrating modeling techniques, data analysis, and policy recommendations. First, policies and initiatives related to fish conservation, biodiversity preservation, agricultural practices, and water resource management in Ireland are thoroughly examined. The assessment is the basis for locating chances to optimize modified flow regimes and enhance economic and environmental outcomes. The advantages of optimizing modified flow regimes for the environment and economy are measured and evaluated, along with various flow management techniques' effects, hazards, and trade-offs. A vital aspect of the methodology is developing a framework for capturing and monitoring the benefits of optimizing altered flow regimes within SEAs [36]. The framework includes identifying suitable indicators and integration into the assessment process. The FlowingLife provides good practice recommendations based on the findings and analysis, considering the needs of water resource management, agriculture, biodiversity conservation, and fish conservation, emphasizing the importance of sustainable management practices. Implementing optimized flow regimes and the impact on environmental and economic outcomes are monitored and evaluated [37], including tracking progress and implementing continuous assessment and improvement measures to ensure the effectiveness of the flow management strategies.

2.1 FlowingLife Framework

Figure 1 illustrates FlowingLife framework architecture layers including data, analysis and modeling, assessment and evaluation, policy and decision support, and use cases layers.

Figure 1 Proposed framework of FlowingLife.

2.1.1 Data Layer

The Data layer of the framework focuses on collecting relevant data on Irish Plans and Programs, including information on sectors such as agriculture, transport, waste, energy, water, forestry, tourism, and land use. The layer gathers data on altered flow regimes, environmental indicators, economic parameters, and other relevant variables. The aim is to ensure data quality, consistency, and accessibility, laying the foundation for subsequent analysis and decision-making processes.

Collecting extensive and varied data required to optimize modified flow regimes in Irish aquatic ecosystems depends heavily. It combines information from several sources to provide a solid dataset. This layer guarantees that the FlowingLife framework has access to a complete and current data set. Data gathering is necessary for further modeling, analysis, and decision-making procedures. The framework's ability to integrate data sources helps produce a picture of aquatic ecosystems by creating flow management plans. In various aquatic habitats, sensors are strategically placed. Examples include flow meters, biodiversity monitoring instruments, and water quality probes. The sensors provide continuous and current data on the state of the aquatic ecosystems by measuring essential factors, including pH, temperature, turbidity, and flow rates, in real time. Understanding the immediate consequences of flow changes and spotting any irregularities that can point to environmental stress is made easier with the use of real-time data.

Historical records data includes historical flow records, official reports, and results from previous studies. The records give a long-term perspective on changes in flow regimes. Sensing remote Satellite and aerial imagery gives a complete view of the environment by gathering data on plant health, water body extents, and changes in land use. These methods help us better understand how changes in the terrain affect aquatic ecosystems by monitoring large and challenging-to-reach areas. Data from remote sensing is helpful in seeing minute alterations and patterns that could go undetected at more minor scales.

In summary, The Flowing Life framework monitors and forecasts ecosystem health in real time based on various environmental sources. IoT sensors in lakes and rivers collect water temperature, dissolved oxygen, sedimentation, flow rates, and water quality data. Long-term flow data and climate estimates are provided by hydrological models, while drones, underwater cameras, and sound sensors track fish populations and movements. AI model training is aided by historical records on fish populations, ecosystem health, and climate and by satellite remote sensing, which evaluates land use and water levels and provides context for human activity. Preprocessing (such as interpolating for missing values and using Kalman filters to remove noise) and data integration fusion of disparate datasets into a single pipeline for ongoing analysis and prediction two methods used to treat data.

2.1.2 Analysis and Modeling Layer

Analytical techniques, statistical models, and data visualization tools are applied in the analysis and modeling Layer to assess SEA's environmental and economic benefits and optimized flow regimes. Advanced methods like AI-based approaches, including ML algorithms, are utilized to analyze complex data sets, identify patterns, and make predictions. Additionally, simulation models are developed to evaluate the impacts of altered flow regimes on various sectors and ecosystems, providing valuable insights for decision-making.

The Flowing Life project leverages advanced AI techniques to analyze and predict changes in flow regimes and fish populations. Time Series Analysis using Long Short-Term Memory (LSTM) networks helps the system detect patterns in sequential data such as river flow rates, temperature, and fish migration, enabling predictions of future changes. Predictive Modeling with algorithms like Random Forest and Gradient Boosting estimates the impact of climate change and human activities, running simulations to assess management strategies. Anomaly Detection with Autoencoders identifies sudden changes in water quality, like spikes in sediment levels, triggering alerts for timely intervention. Convolutional Neural Networks (CNNs) are applied in object detection to process drone and underwater camera footage, classify fish species, and assess their health. Additionally, Knowledge Graphs and Multimodal AI combine data from multiple sources, mapping relationships between environmental factors and their effects on ecosystems, enabling predictions and insights into how various factors interact.

2.1.3 Assessment and Evaluation Layer

The assessment and evaluation layer quantifies the economic and environmental benefits of SEA and assesses the uncertainties, trade-offs, and dangers related to optimal flow regimes. A comprehensive analysis examines how environmental assessment contributes to infrastructure development, sustainable agriculture, biodiversity preservation, and water resource management.

2.1.4 Policy and Decision Support

The policy and decision support layer is dedicated to developing a framework for recognizing and monitoring the benefits of strategic environmental assessments, emphasizing altered flow regimes. Layer comprises identifying and proposing suitable indicators to measure and communicate the benefits of strategic environmental assessment, particularly about optimized changed flow regimes. Moreover, the layer aims to provide good practice recommendations that maximize the benefits of strategic environmental assessment in Irish Plans and Programs. Policy briefs and reports are generated to inform and support decision-makers in integrating the findings into the planning and decision-making processes.

2.1.5 Use Cases

The use cases (i.e., water resource management, agricultural practices, biodiversity conservation and habitat restoration, and fish conservation and restoration) demonstrate the practical application of FlowingLife's framework in addressing specific challenges related to altered flow regimes. By providing real-world applications, FlowingLife showcases its approach to achieving the desired environmental and economic outcomes in Irish aquatic ecosystems.

2.2 FlowingLife Interdisciplinary

The FlowingLife embraces an interdisciplinary approach by combining expertise from various fields, such as hydrology, ecology, environmental science, economics, and policy, recognizing the need for collaboration and knowledge exchange among stakeholders, including researchers, policymakers, industry representatives, and local communities. The FlowingLife seeks to integrate stakeholder knowledge and perspectives into the decision-making process to ensure that the proposed solutions are practical, feasible, and aligned with the needs and aspirations of all involved parties. Public and societal engagement are crucial aspects of the FlowingLife, as shown in Table 1.

Table 1 Public and Societal Engagement Aspects.

Item	**Description**
Public Consultations	FlowingLife organizes public consultations to gather related to altered flow regimes and the impacts on Irish aquatic ecosystems.
Stakeholder Workshops	FlowingLife conducts workshops involving key stakeholders such as government agencies, environmental organizations, industry representatives, and local communities.
Dissemination and Communication	FlowingLife develops a thorough communication plan, involving producing educational materials to increase understanding of the value of maximizing changed flow regimes and their advantages for Irish aquatic ecosystems, such as fact sheets, pamphlets, and internet resources.

FlowingLife actively seeks collaborations and partnerships with relevant initiatives regarding national and international research and innovation activities. FlowingLife establishes links with ongoing networks at the national level, such as collaborations with research institutions, universities, and environmental agencies working on water resource management, aquatic ecology, and environmental impact assessment. The FlowingLife seeks to promote a sense of ownership, transparency, and knowledge transfer by involving the public and stakeholders and working with national and international research activities. This will guarantee that FlowingLife's results are pertinent and significant and support larger research and innovation initiatives in the area of aquatic ecosystem management and altered flow regimes.

2.3 FlowingLife Benefits and Purposes

The overall concept of FlowingLife is to enhance the environmental and economic benefits for Irish aquatic ecosystems by optimizing altered flow regimes. The main idea is strategically assessing and optimizing water flow in various sectors such as agriculture, energy, infrastructure, and water resource management to improve environmental outcomes and support sustainable economic development. The FlowingLife operates on the assumption that by carefully managing and optimizing altered flow regimes, it is possible to achieve better ecological conditions, protect biodiversity, adapt to climate change, enhance water quality, and promote sustainable use of water resources. TheFlowingLife involves considering the complex interactions between altered flow regimes, aquatic ecosystems, and human activities and finding ways to balance environmental and economic interests. FlowingLife addresses the challenges (as shown in Table 2) related to water quality degradation, loss of biodiversity, inefficient water resource management, climate change effects, and promoting sustainable management practices through objectives and use cases.

Table 2 Challenges and FlowingLife solutions.

Challenges	Description	Impacts	FlowingLife solution
Degradation of water quality	Degradation of water quality poses significant risks to aquatic ecosystems, human health, and the sustainability of water resources.	Impaired ecosystem health	Quantify environmental and economic benefits
Loss of biodiversity	Loss of biodiversity has far-reaching consequences, including disruptions to ecosystem functioning, reduced resilience to environmental and climate changes, and impacts on the overall health and well-being of ecosystems and human societies.	Decline in aquatic species diversity	Develop a framework for capturing and monitoring benefits
Inefficient water resource management	Inefficient water resource management leads to water shortages, inefficient irrigation systems, excessive water waste (end-use stage), and inadequate planning for future water needs.	Ineffective allocation and usage	Recommend good practice guidelines and policy briefs for the end-use stage
Climate change effects	Climate change effects include altered precipitation patterns, increased frequency and intensity of extreme weather events, rising temperatures, and changes in hydrological cycles, which can disrupt water availability, water quality, and ecological balance.	Increased vulnerability of ecosystems	Communicate findings through policy briefs and communication materials
Sustainable management practices	The sustainable management of Ireland's aquatic ecosystems is a pressing issue. Practical tactics and evidence-based decision-making are necessary to balance the demands of conservation, water supply, and fishing.	Impact Ireland's aquatic ecosystems	Contribute to promoting sustainable management strategies, and ensure fish populations' conservation and aquatic ecosystems' ecological health.
Excessive water waste	Water loss and waste result from the ineffective use and management of water resources. Water shortages, ecological deterioration, higher energy use, and economic losses are just a few of the challenge's negative consequences on the environment and society.	Water scarcity, ecosystem degradation	Implement water-saving technologies and practices

FlowingLife aims to improve the economic and environmental advantages of Irish aquatic environments. By calculating and evaluating the advantages of optimized flow regimes, creating a framework for capturing and tracking these advantages within SEAs, and offering to optimize the advantages of optimized flow regimes, the proposal seeks to accomplish its goal. The objectives include supporting biodiversity preservation, sustainable water resource management, and the long-term survival of fish populations in Irish rivers. FlowingLife seeks to increase the economic and environmental advantages for Irish aquatic environments. The goal of FlowingLife is to enhance the knowledge, control, and SEA of flow regimes to promote sustainable methods that aid in preserving and restoring aquatic environments. Among the goals of FlowingLife are:

1. Evaluation of modified flow regimes and the financial and environmental advantages of optimizing modified flow regimes in the designated Plans and Programs through AI techniques. Quantify and assess the environmental and economic benefits of maintaining ecologically sensitive flow regimes in rivers impacted by human activities, such as arterial drainage schemes, land use change, and climate change, specifically focusing on the ecological well-being of aquatic communities and susceptible fish species. This objective aims to complement existing EPA-funded research on the impact of flow alterations on Irish rivers and to provide evidence-based insights into the linkages between altered flow regimes, aquatic ecosystem health, and the socioeconomic value of preserving healthy marine ecosystems. The assessment considers AI and SEA methods to comprehensively capture the benefits of maintaining ecologically sensitive flow regimes, including improved water resource management, enhanced biodiversity conservation, sustainable agriculture, fish sustainability, and supporting local economies dependent on water-based activities. The findings contribute to developing informed interventions and policy recommendations to maximize the environmental and economic benefits of strategic environmental assessment and optimized flow regimes in Irish catchments.
2. Develop a conceptual framework that integrates ecological indicators, economic valuation techniques, and stakeholder involvement. FlowingLife carefully examines current frameworks and methodology. It then refines this framework through discussions with stakeholders and experts. The FlowingLife conducts knowledge-sharing and capacity-building events while developing guidelines and tools for implementing the framework. By improving the SEAs and facilitating informed decision-making, FlowingLife hopes to improve Irish plans and programs' economic and environmental results. The framework’s successful deployment can be aided by AI’s ability to automate monitoring and deliver real-time feedback.
3. In order to optimize changed flow regimes and highlight their significance for Irish aquatic ecosystems, provide suggestions for best practices and offer policy briefs and communication tools. FlowingLife creates customized suggestions, policy papers, and communication tools and thoroughly examines case studies and best practices. The FlowingLife engages stakeholders through consultations, workshops, and feedback sessions to ensure alignment with the needs and priorities. Innovative communication strategies, such as visualizations and interactive platforms, are employed to reach a broader audience. By doing so, FlowingLife aims to enhance understanding and awareness of the importance of optimizing altered flow regimes for Irish aquatic ecosystems and drive positive change. AI can support generating recommendations by analyzing vast amounts of data and extracting meaningful insights. AI assists in developing personalized and targeted communication materials that effectively

convey the benefits of altered flow regimes to different stakeholders.

2.4 FlowingLife Evaluation and Validation

The framework must be evaluated and validated to guarantee that the Flowing Life framework effectively mitigates the effects of climate change and human activities on Ireland's aquatic ecosystems. To support sustainable behaviors, the framework is made to incorporate stakeholder input, scientific evidence, and adaptive management techniques. Thoroughly gather and examine data on fish population dynamics, water quality, and flow regimes to validate the framework's scientific foundation. Use AI-driven analytics and solid statistical techniques to ensure the results are reliable. Population dynamics, ecology, and hydrology models can be used to simulate and forecast the effects of many natural and artificial causes. To ensure these models are accurate and capable of prediction, validate them against actual data. Surveys and seminars should be held for interested parties, such as local communities, legislators, environmentalists, and fisheries managers. Get input on the framework's applicability, viability, and conformity to the requirements and expectations of stakeholders. Participate in validation meetings with stakeholders to test the tactics and suggestions of the framework in real-world situations to ensure they are workable and applicable. Table 3 illustrates the validation criteria for the FlowingLife framework.

Table 3 Validation criteria for FlowingLife framework.

Criteria	Sub-criteria	Description
Effectiveness	Improvement of flow regimes	Measure the framework's ability to improve flow regimes.
	Enhancement of fish habitats	Assess the enhancement of fish habitats and the increase in the resilience of fish populations.
	Ecosystem health and biodiversity	Evaluate improvements in ecosystem health and biodiversity indicators resulting from implemented strategies.
Adaptability	Flexibility to scientific findings	Evaluate the framework's flexibility to accommodate new scientific findings and changing stakeholder priorities.
	Geographic and ecological adaptation	Ensure the framework is adapted to different geographic and ecological contexts within Ireland.
Stakeholder Satisfying	Recommendations and implementation	Assess stakeholder satisfaction with the framework's recommendations and implementation processes.
	Engagement and collaboration	Measure the level of stakeholder engagement and collaboration throughout the lifecycle.
Sustainability	Long-term sustainability	Evaluate proposed management practices' long-term sustainability and compatibility with existing policies and regulations.
	Sustainable management contribution	Assess the framework's contribution to the sustainable management of water resources and fish populations.

2.5 Limitations and Challenges of the FlowingLife Framework

The FlowingLife framework presents developments in the use of AI to manage flow regimes and provide aquatic ecosystem health assistance. FlowingLife has several drawbacks and difficulties that can compromise its long-term viability in presenting a fair assessment of the framework and pinpointing areas in need of further development.

2.5.1 Data Availability and Quality

IoT devices, satellite imaging, drones, and historical databases are a few of the many sources, while historical and real-time data is essential for precise forecasts and prompt monitoring. Additionally, the extreme circumstances that IoT sensors use in aquatic environments result in disruptions or inaccurate data. AI is used to produce accurate long-term forecasts in regions with little historical data. Investigating data augmentation strategies, working with citizen scientists to expand data collecting in under-monitored areas, and making investments might all help address these limits.

2.5.2 Computational Requirements

The FlowingLife framework's computing needs. The system uses sophisticated AI models, such as Convolutional Neural Networks (CNNs) for image processing and Long Short-Term Memory (LSTM) networks for time-series analysis. These models need significant memory and processing power, especially for real-time applications. High expenses may result from this requirement for a lot of processing power, particularly if scalability is dependent on cloud computing infrastructure. Additionally, processing big, varied information in real time might cause delays, affecting the system's capacity to react quickly to changes in the environment. To lessen the computational load, future research might concentrate on model optimization strategies such as model pruning or compression. Furthermore, latency might be decreased by shifting some processing duties to edge devices close to the data source, and adaptive sampling strategies could prioritize the most critical data for real-time analysis.

2.5.3 Scalability

Scaling the framework to other regions or more significant geographic areas offers challenges, even though it has been tested in certain Irish river systems. AI models would need to be extensively re-trained and re-calibrated to retain accuracy due to the potential for distinct environmental conditions, biological variety, and human pressures in different places. For example, the species present, ecosystem reactions and flow patterns of Irish rivers may differ greatly from those of rivers in tropical regions. This problem could be solved using transfer learning techniques, which adapt models trained on Irish data to other locations with less data. Furthermore, scalability across different ecosystems may be facilitated by creating a modular framework that simplifies customization by plugging in region-specific models and parameters.

2.5.4 Trust

Stakeholder trust and involvement are important. Water resource managers, legislators, and environmentalists may become skeptical and resistant to FlowingLife's AI-driven recommendations if they occasionally conflict with local knowledge or customs. Stakeholders' reluctance to completely trust the system's outputs may further be exacerbated by the "black box" nature of AI models, where it is not always evident how predictions are made. Focusing on explainable AI (XAI) to elucidate the reasoning to improve transparency, SHAP (Shapley Additive exPlanations) values. Furthermore, cooperative seminars and training sessions with interested parties can increase system familiarity, promoting acceptance and trust in the recommendations.

2.5.5 Maintenance, Updating, and Continuous Learning

Critical problems for the FlowingLife framework include upkeep, upgrading, and ongoing learning due to human influences and dynamic aquatic ecosystems. FlowingLife's AI models need to be updated often to take into account fresh information and adjust to these shifting circumstances. If left unchecked, model the process by which AI models become less accurate over time as a result of shifting data patterns, leads to lower system efficacy. Furthermore, model drift might be reduced and flexibility increased by utilizing online learning algorithms to allow incremental learning from fresh data.

3. Use Cases

In this section, we discuss several use cases including water resource management, agricultural practices, biodiversity conservation and habitat restoration, and fish conservation and restoration. These use cases gain many benefits from FlowingLife as shown in Table 4.

Table 4 Use cases and benefits from FlowingLife.

UCs	FlowingLife
4.1	Improving water allocation and storage Enhancing monitoring of flow regime benefits Policy recommendations for optimized flow regimes
4.2	Enhancing irrigation practices Integration of flow regime considerations in SEAs Sustainable farming practices for environmental benefits
4.3	Restoration of altered flow regimes for habitat Framework for monitoring benefits in biodiversity plans Policy briefs for biodiversity conservation
4.4	Improving fish habitat and migration Monitoring and assessment of flow regime impacts on fish Communication materials for fish restoration

3.1 Water Resource Management

The water resource management use case involves identifying opportunities for sustainable water allocation, improving water storage and conservation, and minimizing the impacts of water scarcity and drought. Opportunities for sustainable water allocation, water storage and conservation, and mitigating the effects of water scarcity and drought may need to be systematically identified. This might lead to inefficient water consumption, poor infrastructure for storing water, and a lack of action to mitigate the effects of drought and water shortages. Advanced models and assessments identify opportunities for sustainable water allocation, allowing for a more efficient and equitable distribution of water resources. Water storage and conservation techniques are required to guarantee a sufficient water supply during times of scarcity. FlowingLife enhances Ireland's ability to manage its water resources and improves the sustainable distribution of water resources by optimizing modified flow regimes, raising water availability and quality. Resilience to drought and water shortage crises is increased by implementing suggested conservation and storage strategies.

3.2 Agricultural Practices

Use cases for agricultural practices include improving irrigation techniques, reducing the adverse effects of agricultural runoff on water quality, and encouraging sustainable farming methods that reduce negative consequences on biodiversity and ecosystems. The environmental impact of agricultural techniques, such as irrigation and rural runoff, on water supplies are not well evaluated. Consequently, insufficient steps are taken to lessen the impact on ecosystems, biodiversity, and water quality. FlowingLife assesses the advantages of strategic environmental assessment in optimizing modified flow regimes within agricultural plans and programs by analyzing and improving irrigation techniques to guarantee effective water usage and reduce water waste. The FlowingLife focuses on mitigating the impacts of agricultural runoff on water quality, promoting the adoption of best management practices to reduce pollution and protect ecosystems. Sustainable farming practices that minimize adverse effects on ecosystems and biodiversity are identified and recommended. FlowingLife aims to improve agricultural practices by optimizing altered flow regimes. The FlowingLife's outcomes enhance irrigation practices, resulting in more efficient water use and reduced water stress. Mitigating agricultural runoff and improving water quality protect aquatic ecosystems and biodiversity. Adopting sustainable farming practices contributes to the long-term sustainability of agriculture while minimizing its negative environmental impacts.

3.3 Biodiversity Conservation and Habitat Restoration

The pFlowingLife contributes to the assessment of strategic environmental assessment benefits in plans and programs focused on biodiversity conservation and habitat restoration. Use cases involve identifying opportunities to restore altered flow regimes (Returning or re-establishing natural or optimized flow patterns in aquatic ecosystems disrupted or modified by human activities) to support habitat connectivity, protect critical ecosystems, and enhance biodiversity conservation efforts. Ireland's biodiversity conservation and habitat restoration plans and programs may only partially consider the optimization of altered flow regimes. The assessment of strategic environmental benefits may be limited, resulting in inadequate measures to restore altered flow regimes and support habitat connectivity, leading to a decline in critical ecosystems and biodiversity loss. FlowingLife contributes to the assessment of strategic environmental assessment benefits in plans and programs focused on biodiversity conservation and habitat restoration. Use cases involve identifying opportunities to restore altered flow regimes, particularly in aquatic ecosystems, to support habitat connectivity and enhance biodiversity conservation efforts. FlowingLife advocates for restoring natural flow patterns, preserving important ecosystems, and conserving biodiversity. FlowingLife seeks to improve habitat restoration and biodiversity protection to restore changed flow patterns in aquatic environments, enhance habitat connectivity, and facilitate species migration. Restoring natural flow patterns protects critical ecosystems and guarantees the survival of various plant and animal species.

3.4 Fish Conservation and Restoration

Fish conservation and restoration include evaluating how changed flow patterns affect fish habitats, determining ways to facilitate fish migration and passage, and putting plans in place to improve and restore fish populations in rivers and streams. The long-term survival of fish populations and the sustainable management of aquatic ecosystems are the goals of FlowingLife. Optimizing changed flow regimes is part of Irish rivers' fish conservation and restoration initiatives. Fish migration issues arise from the requirement to properly evaluate the effects of changed flow regimes. FlowingLife helps to conserve and restore fish populations. Fish-friendly structural design and implementation, as well as the restoration of natural flow patterns, are among the actions recommended by FlowingLife to enhance fish migration and passage. FlowingLife strives to restore and improve fish populations, guaranteeing long-term survival in aquatic ecosystems. FlowingLife aims to enhance fish population conservation and restoration by optimizing modified flow regimes. FlowingLife seeks to increase the health and variety of fish populations in Irish rivers by evaluating the effects on fish habitats and implementing policies to facilitate fish migration. FlowingLife helps to manage aquatic environments sustainably to fish mobility and restore natural flow patterns, which allows fish populations recover and become more resilient.

4. Conclusion

By optimizing changed flow regimes, the FlowingLife framework offered a comprehensive strategy for improving the economic and environmental consequences for Irish aquatic ecosystems. The FlowingLife tackled the pressing need for practical data analysis, predictive modeling, and adaptive management frameworks in ecological management by using cutting-edge AI approaches. The FlowingLife multifaceted approach entails reviewing current Irish Plans and Programs in-depth, creating an AI-powered framework for tracking and recording benefits, and sharing results through policy briefs and targeted communication. FlowingLife offered essential insights into the ecological and economic effects of modified flows, significantly aiding in the study and management of flow regimes. Integrating AI makes real-time data gathering and analysis possible, which supports sustainable resource allocation and helps make well-informed decisions. Through addressing significant issues like declining water quality, loss of biodiversity, ineffective management of water resources, and the effects of climate change, FlowingLife offered a strong foundation for enhancing the sustainability and well-being of Irish aquatic ecosystems. In addition to supporting environmental conservation efforts, FlowingLife's creative ideas and evidence-based suggestions include economic output and climate change resistance.

Acknowledgments

While preparing this work, the authors used ChatGPT and Quillbot to improve the readability and language. After using this service, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.

Author Contributions

Hatem Al-Dois, Farhan Nashwan, Neil J Rowan, Amnnah Alhabeeb Shoushan, Niall O'Brolchain, Saeed Hamood Alsamhi: Conceptualization, writing – original draft, formal analysis, writing – review and editing. Hatem Al-Dois, Farhan Nashwan, Amnnah Alhabeeb Shoushan, Saeed Hamood Alsamh: Software, writing – review and editing. All authors have read and approved the published version of the manuscript.

Competing Interests

The authors have declared that no competing interests exist.

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