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IWRM and the Nexus Approach: Versatile Concepts for Water Resources Education

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Abstract: Integrated Water Resources Management (IWRM) and the nexus approach are tools to identify solutions for water problems across interdependent sectors with interacting social and natural systems. Although both tools aim at solutions for complex water issues using an interdisciplinary approach, IWRM is a management process and the nexus approach is a systems tool to characterize problems. By clarifying their attributes and providing examples, instructors can use them to explain broad social problems and offer practical frameworks for problem-solving. Given their breadth, IWRM and the nexus approach can seem vague and attract criticism, but if they are replaced, the need for them will endure. The concepts are explained, and similarities between them are explored in the paper. Case study sources for them are identified, and the cases are classified by the processes of water resources management as applied across related sectors. How the concepts and their corresponding case studies can be used will vary by context. Suggestions are made for interdisciplinary instruction and discussions in disciplinary settings.

Keywords: *integrated management, case studies, water-energy-food nexus, complex problems*

Water managers and leaders require new tools to identify integrated solutions for problems across many complex and interdependent sectors. Both Integrated Water Resources Management (IWRM) and the nexus approach are tools developed to address issues where water actions interact with social and natural systems (Global Water Partnership (GWP) 2017a; UNECE 2017). Both concepts support problem-solving approaches where diverse groups can cooperate to address shared problems, but how they work can seem vague and abstract.

IWRM and the nexus approach meet recognized needs for tools to address integrative issues. Explaining them for different instructional settings can illuminate solutions in a global, economic, environmental, and societal context, which is a criterion to accredit engineering programs and can apply to other disciplines (ABET 2017). In addition, IWRM and the nexus approach offer practical frameworks for problem-solving. To implement these, a good place to start is in the educational arena, and the Universities Council on Water Resources (UCOWR) is positioned to lead in explaining them through its forums for interdisciplinary cooperation.

While IWRM and the nexus approach are useful concepts, they are difficult to explain and easy to criticize. However, the increasing scopes and scales of global water problems require such complex approaches (World Water Council 2017a). IWRM and the nexus approach will be subject to varying interpretations, and writers have tried to explain how they relate to each other (Rasul and Bikash 2016). Despite this interest in them, IWRM and the nexus approach continue to lack conceptual clarity (Water, Food, Energy Nexus Security Resource Platform 2017a). The fuzziness of these concepts is not unique, however, as the academic field of complex problem-solving is itself in disarray and in need of definitions (Quesada et al. 2005). Therefore, water resources educators should not hesitate to tread areas where solutions are not always clear-cut.

In IWRM, the lack of clarity causes controversy and some thought leaders have even recommended discarding the concept (Tortajada and Biswas

2017). Others suggest replacing it with names such as "Problem-driven iterative adaptation," while retaining IWRM principles (Butterworth 2014). Examples of the nexus approach also show a wide divergence in understanding about its purpose and usefulness. A popular version of it is the water-energy-food nexus (WEFN), which can be used, for example, to quantify virtual water in international trade (Hanlon et al. 2013).

IWRM is usually defined broadly as a "process to promote the coordinated development and management of water, land and related resources to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems and the environment" (GWP 2017a). While it may be a "guiding water management paradigm" (Borchardt et al. 2016), it is not really a definite process because it lacks a systematic series of actions taking place in a definite manner. Rather, it is more of an instrument of change, promoting the use of management principles in problem-solving. The nexus approach lacks a formal definition and is explained in different ways (U.S. Department of Energy 2014; Benson et al. 2015). It generally means that when actions are taken in one sector, it is necessary to consider how they will affect other sectors (UNU-Flores 2017).

Though defining the two concepts precisely is difficult, the need for IWRM and the nexus approach to provide orderly solutions to messy water-related problems will endure. Rather than a problem, this can be an opportunity if effective instructional approaches for them are developed. This paper explores the similarities between IWRM and the nexus approach and offers a framework to explain them in instructional settings. In the paper, both concepts are reviewed, case studies are assessed and placed into categories, and suggestions are made for their use in instructional settings.

Co-evolution of IWRM and the Nexus Approach

Both IWRM and the nexus approach emerged in response to the needs for interdisciplinary tools to address complex issues. These same needs led to integrative paradigms in other sectors, such as the currently-popular "One Health Initiative" (2017). In fact, many new concepts have been developed to explain complex and interacting sectors involved in water issues. Most seek to displace what are perceived as linear and technocratic approaches to problem-solving.

To understand the IWRM concept, it is useful to explore its origins. It emerged from international dialogue dating from the 1977 United Nations Mar del Plata Water Conference (Biswas 2011). The concept has been developed and promoted by the World Water Council (2017b) and the Global Water Partnership (GWP 2017b), whose Technical Committee has responsibility to shepherd it. The origins of the nexus concept also date back several decades. As used in environmental management, it dates to the 1980s, but it has gained prominence recently. Its broad vision, as explained at the Bonn 2011 conference on the WEFN, is to improve water, energy, and food security by integrating management and governance, building synergies, promoting sustainability, and transitioning to a green economy (Hoff 2011; Martin-Nagle et al. 2011; UNU-Flores 2017).

The underlying concept of IWRM is water management itself, which is used in different contexts, such as environmental water, water in pipes, wastewater, stormwater, and floodwater. These contexts have led to a related integrative paradigm named "Total Water Solutions," that signals how water managers are "interested in water no matter where it is found" (LaFrance 2013). While this may sound simplistic, it is actually a powerful idea about transforming how water utilities approach management in an integrated fashion. Another currently-popular slogan is "One Water," which advocates viewing drinking water, wastewater, and stormwater as connected.

Defining IWRM is complicated by the fact that no consensus has been reached on precisely defining the related concept of water management itself. An example of its definition is "the control and movement of water resources to minimize damage to life and property and to maximize efficient beneficial use" (United Nations Secretary-Generals' Advisory Board on Water & Sanitation 2017). However, once the word "resources" is added to "water management," the definition can become more complex. Savenije and Hoekstra (2017) explained that "People from different backgrounds seldom have the same idea about

what water resources management implies." They concluded that water resources management is a diffuse field that includes "the whole set of scientific, technical, institutional, managerial, legal, and operational activities required to plan, develop, operate, and manage water resources."

Although the concept of water management has expansive explanations, it is still narrower than IWRM, whose most-quoted definition is the one by the GWP (2017a) that was given earlier. The use of language to explain the concepts is important, and IWRM may simply be the same as water resources management, but with more emphasis on its integrative attributes.

Writers have criticized IWRM as too visionary and vague, oriented too much toward engineering or planning, and indifferent to societal needs (Ioris 2008; Moss 2010; Campana 2011). In the extreme, it is criticized as being an instrument of establishment institutions to promote a water crisis and impose elitist solutions (Trottier 2008). In their criticism of IWRM, Tortajada and Biswas (2017) wrote, "these non-performing concepts will become even more irrelevant in a future world which will be more complex, uncertain and unpredictable. Future water problems cannot be solved by using past paradigms and experiences that have not proven to be effective."

In response to such criticisms, IWRM could be viewed as not a process at all, but a vision of what water management should be (Moss 2010), or it could be viewed as simply good water resources management (Braga 2017). Addressing the criticisms, the Stockholm Water Institute (2019) explained that despite the criticism, it is an instrument of change to deal with the fragmented approach to water resource management. In that sense, it is like a bandage applied to the poorly-defined concept of water resources management.

No single definition is dominant for the nexus approach and, because it lacks the extensive analysis that IWRM has attracted, no systematic criticisms have emerged. A nexus is a connection between things, but this simple concept becomes more complex by explaining which attributes of connected sectors are included. Explanations of the nexus approach, as applied to different *environmentally-related sectors, sound like the familiar "systems approach" (*Vijay et al. 2014; UNU-Flores 2017) or simply as an approach that considers issues jointly, which is a goal of comprehensive planning itself (Rasul and Sharma 2016).

It is evident that IWRM and the nexus approach have similar goals, take a multi-sector approach, and focus on overlaps across sectors with the goal of making better plans by understanding interactions (Stockholm Water Institute 2019; Water, Energy & Food Security Resource Platform 2017a). These similarities lead educators to attempt to explain them, but without much distinction. For example, the University of Geneva (2017) offers a course module entitled "From Integrated Water Resource Management to the Water-Food-Energy and Ecosystem Nexus." It uses IWRM to focus on the coordinated management of water and associated resources and the nexus approach to show how water users interact with other sectors. It is not clear why the nexus approach is needed to supplement IWRM, since it already includes interaction among sectors. Perhaps an explanation is that IWRM starts with a water management perspective while the nexus approach is a way to view elements of a system (United Nations General Secretary's Advisory Board on Water and Sanitation 2017). However, the nuances between them are difficult to discern because both are multi-sector tools.

One nuance is that the leadership role may be different between IWRM and the nexus approach. In IWRM, one set of leaders comprises those who manage water itself. Another set comprises officials who make decisions about water, but who may be involved with issues of other sectors. Examples include local planners and officials, including regulators. With the nexus approach, assignment of the leadership role is not fixed because it is about a cooperative approach to identifying win-win strategies among diverse players and is not a process itself.

IWRM and the Nexus Approach as Paradigms for Complex Problems

While IWRM and the nexus approach are both attempts to characterize and resolve complex issues related to water, the question remains of how they can be used. Their application to social issues is especially challenging, where problems seem nuanced, difficult to define, and needing

more careful approaches than technical solutions would indicate. An example is the shift toward non-structural solutions to flood problems, where typical engineering solutions had favored dams and channel works, but Gilbert White changed the conversation to emphasize human adjustment to floods (American Association of Geographers 2017).

IWRM can be sensitive to social issues as shown by the fact that it has a management instrument for "promoting social change" (GWP 2017c). It is related to other approaches proposed for complex social problems, which advocate incremental solutions rather than single projects. This approach to messy problems is explained by Hassan (2014), who proposed a "social lab" process to involve stakeholders struggling to seek a consensus. In reviewing his book, Bernholz (2014) wrote that such approaches are needed because standard planning processes of government and civil society are out of step with current knowledge of complexity, systems, networks, and how change happens.

In a similar vein, Mirumachi (2015) wrote pessimistically that managing water is a "wicked problem" and straightforward solutions will not work. She also thought that water managers might claim a spirit of cooperation, but it is not real because national interests and power asymmetries will drive the outcomes. Elinor Ostrom (1990) formulated an "Institutional Analysis and Development Framework" to relate concepts of collective action problems to social structures, positions, and rules, addressing complex problems by connecting policy analysis to analytical approaches used in the physical and social sciences.

The general concept of institutional analysis is used in different ways to explain social processes, which are inherent in IWRM. Ziegler (1994) offered a method that used key questions to define a situation by learning what goes on, what processes need adjustment, what know-how is available, what should happen, and what the impacts of change are. By adding details about authority and participation, laws and controls, incentives, roles, and management culture, a conceptual model of how the management and control systems work can be created. It will include identification of the key issues in each set processes and institutional changes required to lead to improvement.

These methods align with the discipline of systems thinking, which is a popular method of looking at the big picture. As explained by Senge (1990), systems thinking is one of the five disciplines of creating the learning organization. The others are personal mastery, mental models, shared vision, and team learning. The tools of systems thinking coordinate well with IWRM, and the nexus approach could also be viewed as a systems tool to create a valid mental model.

There are many tools for systems thinking, ranging from mind maps to complex simulation algorithms. One tool, the DPSIR framework (for drivers, pressures, states, impacts, responses), can be used to create a conceptual systems model of a nexus that includes the control points available to water managers. It can also show cause-effect relationships in social-ecological systems and has been used to describe many types of systems (Gari et al. 2015). The effects on water systems from basic drivers such as population growth and climate change can be shown, along with derived drivers such as changes in land use, species transitions, technology, external inputs such as irrigation, resource consumption, and other natural physical and biological drivers. (Bradley and Yee 2015).

The existence of competing paradigms leads to the conclusion that the science of complex systems is not settled. To illustrate, the nexus concept is a special case of "coupled natural and human systems," which is the name of a 16-year program of the U.S. National Science Foundation (2017). In this program, investigators have studied many nexus situations involving overlapping systems that link water to other human and natural systems. Many of the NSF studies can be used as examples of the systems approach.

IWRM and Nexus Case Studies

Despite extensive discussion of IWRM and the nexus approach, both still lack conceptual clarity. Studying how groups perceive them may help more than to focus on abstract definitions. To study this, cases of IWRM and the nexus approach are reviewed in this section. The examples of IWRM cases are from a previous study (Grigg 2015, 2016). They included those published by the GWP, mission-specific organizations, research institutes, individual researchers, and private companies. These were

classified into archetypes by management situations, which will be listed later.

Eleven case IWRM categories were identified (Grigg 2016): institutional development; policy planning; river basin coordination planning; program planning; infrastructure planning; operations planning and assessment; regulation; financing; conflict management; analysis and assessment; and knowledge and information support. All of these categories include multi-sector cases, and it is evident that the nexus approach could be used within them to identify opportunities for resource savings and optimization.

Like the IWRM cases, the nexus cases address diverse situations with the central theme of connection of water and energy to some aspect of food systems. The examples are from a workshop on the WEFN that was co-organized by the writer and from the Water, Energy & Food Security Resource Platform (2017b). While the nexus cases are mainly about the WEFN, other combinations are also possible, such as water-climate and water-health.

The WEFN cases can seem like a laundry list, but they are really examples of systems methods used in inter-sectoral resource management problems. Examples from agriculture include energy from biomass, changes in grass cover in forest regions, and interventions to improve water quality, among others. Examples for village development in developing countries include a household biogas digester, improved cook stoves, and a biomass gas-based mini grid. Other examples include a national-level natural resources policy study, a book on the WEFN and the green economy, and the nexus applied to river basin management. Nexus cases are offered by a more diverse set of sources than IWRM cases. For example, two major professional associations included examples from agriculture, energy and environmental management (IUCN and IWA, 2017), and references to WEFN cases by other groups (German Association for International Cooperation and Local Governments for Sustainability (GIZ and ICLEI) 2014; Colorado State University 2017; GRACE Communications Foundation 2017; LIPHE 2017; World Business Council for Sustainable Development 2017).

WEFN projects organized by the U.S. National Science Foundation (2017) also illustrate the nexus approach and are a good source of instructional resources. Workshops organized in the projects were place-based, issue-based, and technology-based, and they showed the WEFN as applied in urban and rural contexts.

The selection of cases as outlined above shows similarities and differences between IWRM and the WEFN. IWRM is a management concept, and the nexus approach is a systems tool to identify inter-relationships to exploit when taking actions to improve resource sustainability. Stated another way, IWRM begins with something to be managed and the nexus approach begins by looking for something to manage. After interrelationships among resources are identified, projects or other actions may be formulated, whether they are water-centric or not. The nexus is not a process; however, if it is used as the basis for an action approach, then it is an integral part of a process.

Both concepts can be used in problem-solving situations, but the nexus concept applies more to the problem formulation phase, and additional actions must be planned to create an action process. IWRM as a management process extends across all steps, including project delivery and regulatory actions.

As an example where the two constructs seem similar, if IWRM is applied to a situation involving coordinated management of water, food, and energy in a watershed the two approaches seem almost identical. As an example where they are different, if a WEFN case is about recycling food waste to generate biogas energy for a community, it will not involve IWRM. Both constructs can involve multiple sectors, but with IWRM the situations are water-centric and leadership is presumed to be with the water sector. In the nexus approach, leadership choices are not specified and might fall outside of the water sector. IWRM can be applied at different levels and might focus only on the water sector, as in the integration of multiple water services.

Use in Instructional Settings

If IWRM and the nexus approach are used in instruction, benefits can accrue at two levels: explanations of broad approaches to solving societal problems can be useful in courses such as environmental science and policy where water is not the only topic, and explanations of specific tools can be useful in focused water management courses.

Instruction about broad approaches to societal problems aligns with the vision of Boyer (1996) to couple university scholarship with engagement in society. These should be pointed toward public leadership, which is a main subject of interdisciplinary schools of public administration and government. Some instruction about public leadership is needed in any field concerned with water management, even if it is not the main topic.

Explanations of broad approaches can begin with general discussions of societal problems and include water issues such as scarcity, pollution, flood damages, and lack of safe drinking water, among other problems. Once these broad problems are noted, case studies in the frameworks of IWRM and the nexus approach can demonstrate how knowledge and engagement apply to complex problems involving different sectors. The instructor can select cases that illustrate knowledge and tools specific to the relevant discipline. For example, the GWP (2017d) IWRM Toolbox includes cases to illustrate how discipline-oriented management instruments can be applied.

Many other cases are available. To illustrate a powerful lesson with both IWRM and nexus attributes, the Cochabamba (Bolivia) Water War case draws in several significant global issues (GWP 2017e). The central issue is management of an urban water supply system to improve performance and access. A government-sponsored attempt to privatize the system failed after large-scale social unrest, and the water system was turned over to a citizen cooperative to manage. The unrest led to a change in government and the presidency of Evo Morales. The case received wide attention through a book (Olivera 2004) and a movie entitled "Even the Rain." The nexus issue is in the systems combination of technical, economic, and social issues in the city. Instructors can use this case for different learning objectives relating to poverty, urban economics, health, and water management.

Specific tools for water management courses will have immediate impact at a practical level for students who will work in the water sector. Examples of these tools from the GWP (2017d) Toolbox can be derived from the management instruments, which range broadly across disciplines. A case that features a technical tool such as a decision support system might be chosen. The GWP (2017f) offers a case about planning in the Nile River Basin, with many lessons about shared governance, transboundary water management, hydrologic change, and various uses of water in a large and complex international basin. Given their popularity, many other cases about decision support systems can be located easily in research journals of the water sector.

As another example of IWRM instruction, the writer's course in Water Resources Planning and Management explains the concept in a general way. The lesson plan focuses on sectors such as water supply and hydroelectricity, and explains tools such as hydrologic simulation models that are used in safe yield analysis. This work is used in cooperation with an instructor in Pakistan, who is implementing a course with the title Integrated Water Resources Management (U.S.-Pakistan Centers for Advanced Studies in Water 2017). The course has some broad content, while the remainder focuses on concepts and tools for water resources management itself. Another cooperative effort was an IWRM training course in Peru for managers in the national water agency. It also included broad concepts but emphasized specific tools of management needed in Peru.

Instructors in many types of courses can consider inclusion of instruction about IWRM or the nexus approach. As explained by Savenije and Hoekstra (2017), water resources management should include diverse points of view, so no single course or program will have a monopoly on it. Only a few courses will use IWRM as a title, and most of those will probably be short courses for specialized training (United Nations Department of Economic and Social Affairs 2017). It would be surprising to find a full course with nexus in the title, although a course on socio-environmental modeling might include much of the same content. A discussion of the nexus concept can be embedded in an explanation of IWRM and used as a conceptual framework to explain intersections of problems and the special interests of sectors.

Considering the disciplines represented in UCOWR, it is evident that interest in IWRM should be significant to the interdisciplinary community of scholars participating in its annual conferences. Examples of possibilities for IWRM instruction include water engineering and science courses

such as hydrology, modeling, systems analysis, and river mechanics; geography courses such as water resources planning; political science and sociology courses about water law and social aspects of water; economics courses such as water resources economics; and applied courses such as irrigation management. Additional topics such as climate change, ecology, coastal water, and environmental health also relate strongly to water management.

Both IWRM and the nexus approach can focus on public leadership to foster cooperative solutions, and instruction can show how win-win strategies for water management can be identified to increase total social returns and opportunities to correct inefficiencies and injustices.

Presentations about IWRM and the nexus approach should present material with academic as well as practical content, or in a "pracademic" way (Stockholm Water Institute 2019; Posner 2009). This could begin with the definitions presented earlier in the paper to clarify that water is managed in different contexts and must respond to many diverse sector needs. Then, the explanation can be about how an integrated approach will be better than a single-purpose approach.

Although the courses might not share the IWRM brand, many of them will be closely related to it. A reference to show the diversity and richness of programs and courses will be the UNESCO Chairs related to water resources (International Center for Integrated Water Resources Management (ICIWaRM) 2017). The list of UNESCO (2017) Chairs shows some 40 topics distributed around the world, and many of them involve IWRM topics that could be used in instruction. These include integrated river management; conflict resolution and transboundary water governance; hydropolitics; hydroinformatics; ecohydrology; sustainable water services and cities; water, culture, and indigenous peoples; and gender in water management, among others.

Conclusions

The concepts of IWRM and the nexus approach were developed because management tools were needed to address the complex issues inherent in the connections of water decisions to other sectors. Based on its levels of acceptance, IWRM became popular among international water leaders to provide a framework to address complex water-related issues with accepted principles and management instruments. The nexus concept has also become popular for use in framework and policy studies, as well as in planning for co-management of water, energy, and food resources. It can help stakeholders identify win-win projects, programs, and partnerships at different levels.

How IWRM and the nexus approach can be applied will vary between governance levels and across different types of countries. Given their many possibilities, how IWRM and the nexus approach can be used are best illustrated by cases. Many sources of cases are available, such as those in the GWP's IWRM Toolbox. The nexus cases exhibit attributes of a system-based approach to a range of resource management issues. Like the IWRM cases, they address highly-diverse situations with a central theme of connection of water to other sectors, such as energy, food systems, health, climate, and others and, like IWRM, many sources of cases are available.

The cases show similarities and differences. IWRM is, according to its definition, a management process, while the nexus approach is a systems tool to identify inter-relationships between resource categories. Given this aspect of the nexus approach, it will apply to many instances where IWRM is applied. In that sense, the nexus approach is like a special case of IWRM in situations where a given set of resource sectors is involved.

Whether it involves IWRM or the nexus approach, water will be a core element in the management situation or interaction among resource sectors. How to allocate the leadership role is a subtle nuance between the two paradigms. IWRM will be water-centric and leadership will normally come from the water sector. With IWRM, one set of leaders manages water itself, and another set comprises officials who make decisions about water, but who may be mainly involved with other sectors. Examples include local planners and officials, including regulators. In the nexus approach, the allocation of leadership roles is not evident because it is a shared and cooperative approach to identifying win-win strategies among diverse players. In either paradigm, the core leadership issue is the need to foster cooperation.

In instruction about IWRM and the nexus

approach, no discipline program area will have a monopoly, and many courses can include explanations of how the concepts work in a general way. Disciplinary presentations can be followed by examples and cases from diverse perspectives. Benefits can accrue from imparting broad knowledge about societal problems as well as from building water management capacity with specific tools.

While there has been a great deal of discussion about the shortcomings of IWRM, it is time to move on. Taking the criticism to heart can create an opportunity to explain it as an instrument of change and to utilize knowledge from the nexus approach to clarify it. The underlying concepts will remain complex and difficult to explain, but the need for concepts such as IWRM and the nexus approach will increase with the scale and severity of water issues.

Ultimately, the payoff from application of the concepts will be to improve the total returns to society from management of water and related resources. UCOWR members can take a leading role in explaining them in a range of disciplines.

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