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Article

Tailored Watershed Assessment and Integrated Management (TWAIM): A Systems Thinking Approach

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Abstract: Control of non-point source (NPS) water pollution remains elusive in the United States (US). Many US water-bodies which have been primarily impacted by NPS pollution have not achieved water quality goals set by Clean Water Act. Technological advances have been made since 1972, yet many water resources fail to meet water quality standards. Common Pool Resources Theory is considered to understand the human dimension of NPS pollution by exploring anthropogenic activities superimposed upon dynamic ecosystems. In the final analysis, priority management zones (PMZs) for best management practice (BMP) implementation must have buy-in from land managers. TWAIM is an iterative systems thinking approach to planning, collecting landscape and land use information and communicating systems understanding to stakeholders. Hydrologic pathways that link the physical, chemical and biological characteristics influence processes occurring in a watershed which drive stream health and ecological function. With better systems understanding and application by technical specialists, there is potential for improved stakeholder interaction and dialogue which could then enable better land use decisions. Issues of pollutant origin, transport, storage and hydraulic residence must be defined and communicated effectively to land managers within a watershed context to observe trends in water quality change. The TWAIM concept provides a logical framework for locally-led assessment and a means to communicate ecohydrologic systems understanding over time to the key land managers such that PMZs can be defined for BMP implementation.

Keywords: non-point source; land-use; watershed management; common pool resources; priority management zones

1. Introduction

The systems thinking approach offers a way for people to appreciate and think more broadly about the watershed system because not everyone sees all aspects of the water within watershed framework. The parable of the blind men and the elephant illustrates how people can perceive and understand things differently yet describe the same animal. Each person remarks that the elephant is like a spear, a wall, a rope, a tree. Responses can be similar as people consider uses of water. For some it is for recreation, for others drinking, appreciation, or minimizing the time water spends on agricultural land. Visualization followed by discussing water within a systems context allows people to understand the views others hold regarding the importance of water resources. Non-point source (NPS) pollution can be described like an elephant; it is big, leaves a large foot print and is difficult to describe from only one vantage point.

Historically, point source pollution could be described as the clear linkage between identifiable sources of pollution and an impaired water resource. Point sources of pollution usually have a fairly straightforward solution that can be implemented by treatment technologies and regulatory authorities. But what is NPS pollution; is it the lack of clearly identifiable linkages or more? Because NPS lacks a strong regulatory tool, in the United States (US), to enforce compliance it is imperative that management agencies invest in ecohydrologic systems understanding and the clear communication of NPS linkages between land use and water resource response. This manuscript highlights some of the difficulties associated with the physical watershed by drawing upon several examples to suggest NPS is more than many mini-point sources of pollution. NPS pollution is watershed system disequilibrium that drives ecological dysfunction and weakens overall stream system health, all with discernable links back to human activity. Given limited funding to solve NPS pollution problems, the concept of "priority management zones" (PMZs) is offered as a means to concentrate resources at a measurable scale. This involves engaging land owners to help them obtain awareness, understanding and "buy-in". These issues will be further discussed in the context of the human dimension considering economic, social and political perspectives.

In an undisturbed watershed, natural processes produce seemingly disruptive activity, *i.e.*, hail damage to vegetation. Nevertheless, natural disruptions are often buffered over time by the remarkable healing characteristics of biological forces working together with physical and chemical processes to restore ecological function. This phenomenon could be considered the watershed's natural dynamic equilibrium. This equilibrium has buffering limits or thresholds which can be exceeded by catastrophic floods, long droughts and human activity. Based on causal observation over varying seasons, humans appear to operate in environmental compatibility. Yet some land use activities occur in small, repetitive, often disassociated quantities, over long periods of time. These nearly imperceptible changes can exceed a watershed's buffering capacity and shift the previous natural dynamic equilibrium in a dysfunctional direction [1]; suggesting that humans do have an incompatible effect.

The water in the watershed, including all forms of subsurface water, is a "common pool resource" (CPR) [2] that typically, is not recognized for what it is by the humans who are impairing the quality of the water. From a watershed perspective, NPS pollution has some identifiable signs (*i.e.*, lost fishery or nitrate contaminated groundwater), yet the apparent sum of pollutant sources does not equal the whole of the problem. There are synergistic processes occurring that are not clearly identified or understood within functional process zones [3] of a riverine system. Balanced synergy between the physical, chemical and biological components of a watershed result in a healthy natural dynamic equilibrium. The challenge of solving NPS pollution is not by just attacking all apparent mini-point sources of pollution, but by better understanding watershed natural dynamic equilibrium [4,5] and the social awareness that water quality affects the CPR. Is the watershed healthy or dysfunctional (dysfunctional meaning the loss of ecosystem services and/or loss of clean water quality for human use)? If ecosystem services appear dysfunctional, are there tell-tale signs? Further, is there evidence that change has occurred from its pre-disturbance condition? Has the collective land use changed or has the climate changed? These questions are difficult to answer, yet to bring about change in rural watersheds, agricultural producers will want data that clearly shows a link between their current land use practice and ecosystem dysfunction [6]. Additionally, before changing practices, they will want to understand the economic value of the water resource and for some, the quality of life associated with a healthy watershed [7]. As such, only collecting data at the mouth of a watershed will not offer a compelling story; much more is not only required but demanded by landowners who may be asked to make an investment in the future.

1.1. Watershed "CSI" Approach

In the US, there is a popular television program referred to as "CSI" which stands for Crime Scene Investigation. In the program, scientists are shown using the latest technological tools to understand and solve a crime; all within the hour-long airing of the show. The idea behind "Watershed CSI" is similar to the show with the exception of the subject matter and duration of time spent investigating. This manuscript is about water not criminal activity and years of study over wet and dry, cold and warm seasons are needed to gain hydrologic pathway and process understanding. Further, those doing Watershed "CSI" work must also build relationships with landowners to collect clues (data) to create historic and a possible current pollutant impact scenario similar to a crime scene hypothesis. This work is about cause and effect. In "CSI", the effect is death and the investigative job is to determine the cause and convict a murderer. In watershed work, cause and effect may be more elusive due to scale and lag time; nevertheless, a systematic methodology is still required for gathering data to tell a story.

Simply, monitoring loads and concentrations of pollutants in a stream is not adequate to build understanding to restore or protect the environmental quality of a stream. The application of a runoff model is useful in predicting what changes can occur with the implementation of best management practices (BMPs), if the model represents reality based on ground-truth validation. McDonnell and others [5] have argued that watershed heterogeneity and process complexity present such an overwhelming obstacle that no computer simulation model will adequately capture the hydrologic pathways and processes of a given watershed. Geographic information systems (GIS) can aid decision-makers by providing a visual means of organizing geographic data, e.g., soils, terrain,

land-use. However, the layers are often produced at a scale that does not capture the dynamic hydrologic pathways of pollutant transport and assimilation. Nevertheless, a tool such as LiDAR (Light Detection And Ranging) has the potential to provide detailed observation at the meter scale [8]. Procedures like Watershed Assessment of River Stability and Sediment Supply (WARSSS) [9] offer a systematic method for asking and documenting important hydrologic pathways and processes at varying landscape positions, yet some metrics may not be relevant to specific study watersheds because WARSSS is focused primarily on sediment issues. Paola and others [10] have called for a new unifying science that integrates the disciplines of hydrology, geomorphology and ecology because we continue to struggle with our collective understanding of how both physical and biological phenomena occur across scale.

What is lacking in the above watershed assessment and management techniques is the tailored and iterative integration of disciplines that leads to better systems understanding. Tailored meaning personal attention provided to specific land parcels in order to account for the unique features of a given landscape and land use manager. Iterative implies observation of processes and behavior over seasons. Integration refers to combining the physical, chemical, biological sciences and the socio-political tools needed to engage stakeholders. TWAIM is not about advocating a particular new runoff model, GIS tool, biogeochemical analysis, way of monitoring or fluvial assessment technique, but rather, a way of thinking about "specific" watershed management issues so local soil and water specialists and land use managers gain more understanding of their land and their neighbors' land. This is a "systems-thinking" approach that calls for interdisciplinary dialogue and big picture "visioning".

The popular television show CSI offers a protocol format of how TWAIM could work. In the CSI program, detectives collect evidence and then analyze the clues (data). They then continually adjust their hypothesis until the perpetrator is identified and enough evidence is developed to make a convincing argument before a judge/jury. With TWAIM, the assessment team must also collect evidence, analyze data, and often adjust their systems understanding based on new data. The assessment team, similar to the CSI detectives, must build a case for water quality impairment and create a convincing argument to the land manager and/or the rural community. Further, this process must occur long enough to observe and document ecological and water quality trends apart from natural cycles. An infrequent storm event (100-year) can produce large amounts of erosion damage and land managers can argue the sediment in the stream was due to a natural disaster and not poor land use management. For impaired water-bodies across the US, total maximum daily loads (TMDLs) demand an action plan that will restore water quality to some definable reference quality. Before the plan is implemented, the decision makers must understand the study watershed system variables—the ones that can and the ones that cannot be managed. Short of this up-front investment of time and energy, implementation efforts can and will fall short.

1.2. Functional Process Zones and Priority Management Zones

Watershed NPS pollution requires tailored iterative integration because unlike point sources of pollution, NPS has nearly unlimited variables (*i.e.*, climate, landscape, soils, geology, hydrology, biology, land use management and associated pollutant generation) that converge differently in most every watershed. Professionals working in ecology have been aware of these issues for decades and

have proposed various models to explain some unifying principles [1,3,11,12]. Thorp and others [3] have argued the stream channel/valley type must be viewed as more than a conveyance system; it should be viewed as ecologically linked within the watershed via functional process zones. Schultz and others [13], following a similar line of reasoning, have suggested watershed functional traits. This idea of looking at functional traits implies that we cannot necessarily understand the genesis of all the input variables that created the watershed, but we can describe traits that integrate all of its relevant history [13]. The functional process zones require some degree of definition so we can determine if important functions are present or lacking in a particular study watershed. Our assessment of watershed conditions should include a picture of desirable functions, traits and features. This could be termed the "reference condition" for the unique set of characteristics associated with the study watershed. We then need to understand what change in processes moved the study watershed away from its natural dynamic equilibrium into dysfunction. The physical, chemical and biological conditions of the stream corridor and in-stream water often provide evidence of the degree of dynamic equilibrium or dysfunction in the watershed. These ideas offer a foundation for the concept of PMZ; the PMZ should mimic health functional process zones that illustrate natural attenuation of pollutants such as excessive sediment or nutrients. A fundamental constraint with applying these concepts to improve water quality is selecting the scale at which to focus.

1.3. Scale of Process Recognition

Watershed scale is a critically important factor in understanding processes, functions and system dynamic equilibrium. Dooge [14] defined scale as the quintessential hydrologic issue that needed better understanding to advance our understanding of watershed management. Often "watershed scale" is derived by some economic or political efficiency for legal purposes. But the watershed district (large enough tax base to support an office and staff) scale is not necessarily the best scale for BMP implementation. There is no simple answer to the "right" size because heterogeneity and intrinsic complexity often vary by scale. If the scale becomes too large the evaluation of BMP effectiveness becomes vague because of excessively long lag-time [15]. If the scale is too small, a riparian corridor may not exist, thus limiting the ability to observe linkage to perennial flow zones. Heterogeneity and complexities between the upland, transitional zone and riparian corridor may limit the ability to create "landscape-linked" BMPs. Landscape-linked refers to cumulative down-gradient ecohydrologic effect or treatment train of BMPs. If we apply the concept of functional process zone to the creation of landscape-linked BMPs, then the landscape drives the individual management activities. For example, a hilly landscape that allows overland flow to occur will need conservation tillage to limit sediment movement at the source and perennial vegetation on the hillslope to intercept detached sediment. In a flat terrain, where water tends to pond and infiltrate down to a subsurface drain which then flows laterally to a ditch, will require different BMPs. The treatment train in this example requires a vegetative buffer around any surface open-intake to minimize sediment movement from the site and treatment at the subsurface drain outlet. Treatment at the outlet must also consider nutrient attenuation; in particular, denitrification via wetland with organic rich microorganisms. Prioritization of landscape-linked BMPs within small watersheds is necessary for targeting limited BMP

implementation funds; hence the need for a method that can piece together scenarios that can link more than one BMP on a given landscape. These strategically located landscapes become the PMZs.

Effective implementation of BMPs occurs with those who manage the land (*i.e.*, agricultural producer or government agency). Realistically, there is a limit to the number of land managers (public or private) who identify themselves as neighbors and are willing to work together for a common ecological or water quality goal or CPR objective. Furthermore, these managers must be convinced of their common ecohydrologic linkage and that their private water and land management decisions have impacts in the public watershed management domain. Integrative management effort requires grass-roots initiative and cooperation and not necessarily a top-down government mandate. Government plays a role in providing grant dollars and technical assistance. Who gets the help and how are those decisions made? Are they being applied like a laser guided missile? Perhaps more importantly, why do some land managers refuse help? Generally, a few landowners need regulatory enforcement to stop gross negligence [16]. A tailored, integrated data driven iterative approach can and should aid local units of government in making more cost-effective decisions about PMZs. The existing approach of first-come first-serve (*i.e.*, who walks through the conservation office door first) has placed conservation practices on the landscape, but has not always resulted in measurable water quality improvement in the US.

Therefore, I suggest the need to move away from random acts of conservation and provide solid convincing evidence to land managers of the hydrologic pathways and processes that are driving poor water quality [6]. Recent analysis of land retirement programs in Minnesota suggests that better water quality and ecological function occurred where buffers were targeted and established along stream corridors in central Minnesota [17]. Analysis of riparian cattle grazing in southeastern Minnesota showed that cattle could graze next to the stream with limited ecological damage but only for specified times and seasons [18]. In south-central Minnesota, Lenhart and others [19] showed the value of strategic restored wetland placement in transitional zones (below row-crops, yet above a stream channel). Each study was designed to consider specific details at an appropriate scale. Restoring degraded water quality requires attention to detail at scales that limit ambiguity. A clear water quality story is what land use mangers want to hear. If they understand specific links between their current land use actions and water quality, they are more apt to consider alternative land use options [6]. Yet, understanding alone is not enough to bring about change, land use managers must weigh new options based on their study of markets and associated incentives. Nevertheless, getting to this stage is more than half the battle because most land use managers believe they are currently doing "the right thing". They are typically motivated by the entrepreneurial free-enterprise system; a system where economic return trumps other concerns such as ecosystem services.

2. Onerous Frontier: Scaling the Socio-Economic-Political Mountain

2.1. Common Pool Resources (CPR)

The work of Ostrom [20] provides a socio-economic-political framework for exploring the big water quality picture. So-called "common pool resources" (CPR) story (theory) has been used to engage critical thinking about onerous issues that have defied simple management solutions. CPRs can

be defined as natural or human derived resources that have beneficial use to the public, (*i.e.*, water quality) above and beyond private use; and whose size or characteristics makes it costly, but not impossible, to exclude potential beneficiaries from obtaining benefits from its use. CPRs face problems of pollution or overuse, because they are finite. NPS pollution is largely a problem of ignorance or denial of this phenomenon called CPR. Ostrom [20] recognized that such resources tend to be overused since each individual with access to CPRs will seek to maximize their private benefit with little concern for the public costs generated. Costanza and others [21] began a campaign to assign economic value to ecosystem services calling it "natural capital", for nature is not free—there is a cost associated with clean water. Since costs associated with things like NPS pollution do not accrue to the individual, but to the collective society, the unregulated free-enterprise structure promotes use beyond the economically optimal; where the optimal includes recognition of natural capital [22]. More specifically, any available CPR not producing an economic return is often viewed as a loss of profit because as a society we have not typically placed an economic value on nature. Overuse or misuse is likely to occur even when the existence of the resource system is threatened; which is a failure to acknowledge the need for a sustainable future. In other words, the aggregated actions of rational individuals are not, in the end, rational, but lead to negative cumulative impacts in both space and time [23].

A classic example of not accounting for the CPR is the demise of the Aral Sea in west Asia, where water was diverted from the Aral Sea to grow cotton under the Soviet regime. The people who lived around the sea depended on the quantity and quality of the water to survive. When water was diverted from the Syr Darya and the Amu Darya Rivers, the Aral Sea became smaller and more saline. Cotton producers started drawing from the CPR, originating as snow-melt runoff in the mountains, without regard to the off-setting loss of CPR to the fisherman who earned their livelihood from a fully replenished Aral Sea [24].

When the Soviet regime decided that cotton production was more important than sustaining local fishing economies of the region, they changed the rules of the game by setting a higher priority on cotton than fish; the Soviet regime did not consider all the ramifications of this decision on dependant ecosystems. This limited viewpoint contributed to unintended consequences. In the US, the rules of the game for agriculture are set by the Farm Bill, federal legislation that determines subsidies for farmers. The Farm Bill, negotiated every 6 years by the US Congress, is primary about food security; environmental considerations are secondary. A portion of the Farm Bill provides incentives to reduce NPS pollution via programs like EQIP (Environmental Quality Incentive Program) administered by the Natural Resources Conservation Service (NRCS) of the US Dept of Agriculture. Other federal dollars are offered via the Environmental Protection Agency through a program called Section 319 (in reference to the section of the Clean Water Act). These programs have spent billions of dollars over years, yet they show very little return on investment based on measured water quality improvement [15]. The most classic example of program failure, as defined by minimal return on investment and distortion of data, is the Chesapeake Bay [25]. This East Coast estuary near Washington D.C. has received polluted runoff for decades, primarily from the rural watershed that extends across several states. Because the bay is large and the watershed is even larger, the complexity of managing just the physical BMP implementation is overwhelming, regardless of the socio-political factors. The US Congress has asked "what went wrong"? But more accurately, the persistent pollution

problem is likely a lag-time issue [15]. Or is this a story of limited recovery potential [26]? Slow recovery or no recovery is very frustrating to those who pay for a product, but see little return on investment. Would things be any different if all land use was forced to comply via regulation?

2.2. Balancing Regulation and Incentive

The emphasis on government intervention relies upon the establishment of a regulatory party to govern public resource use and thus, "assure" collective cooperation. However, in the US, regulatory agencies at the federal and state level, lack a full set of regulatory tools to ensure compliance that poor land use management will be corrected by BMPs. Assuming that collective action problems are in fact, irresolvable. A coercive mechanism would appear to be the only viable alternative from this perspective [23,27]. The other proposed solution to CPR problems is the elimination of common property altogether by privatizing property or water resource rights. Western US water law, in effect, is a privatization of CPR based on a first-come first-serve principle. By granting each individual or corporation ownership of the resource (or a part thereof), it is assumed that (1) they ensure their piece of the pie, (2) because the water resource is part of their capital, they would manage it sustainably [2]. However, each of these approaches is problematic. Full government regulation, for example, will not necessarily be able to perform key functions: determining efficient resource use, monitoring implementation or punishing transgressors [23]. Each of these relies upon accurate information and knowledgeable field staff, neither of which can be assured by a centralized authority.

Privatization, on the other hand, may work in some instances, but cannot work in others [20], for example: Grazing rights on US federal lands is a form of appropriation externality [27] CPRs that could be privatized effectively by spatial management. However, the idea is less applicable to NPS pollution of the Chesapeake Bay. There are external costs associated with the private use of such resources or more specifically the lack of proper land use management that an individual imposes on the community through the use of their private property management decisions (*i.e.*, allowing sediment and attached nutrients to enter into a stream) [2,26]. Specifically, this could be referred to as a technological externality; land use managers who have taken land out of row-crop production to build a treatment wetland have made a technological and financial investment to limit sediment and nutrient damage to down gradient water resources [6]. Examples exist where individuals have developed "self-governed common-property arrangements in which the rules have been devised and modified by the participants themselves and also are monitored and enforced by themselves" [20]. The assumption here is that the group must be small enough to be "self-governed" or convinced of their collective need to "buy-in"; the example of the Aral Sea or even the Chesapeake Bay do not lend themselves to a small elastic self-governing group because the physical scale involves too many people with too many vested interests.

In contrast to the examples of the Aral Sea and the Chesapeake Bay, the example of watershed drainage management illustrates landowner cooperation. In the central portion of the US, drainage law, different from western US water law illustrates this arrangement. The need for drainage among a collective group of landowners drove the creation of watershed districts. Thus, while CPR problems are both common and difficult, they can be resolved in a way that avoids both the extremes of government regulation on the one hand, and privatization on the other. It takes the assumption that

individuals, though largely self-interested, can transcend the limits assumed by the rational choice paradigm [23], and be guided by a longer term vision, and a more enlightened view of collective self-interest.

From this discussion, it should become clear that TWAIM involves more than physical or chemical data collection from the landscape; it also involves getting people to think differently about the water resources they collectively manage and need to survive. TWAIM should not be viewed as a civic engagement tool, but more of the "gap-filling" between civic engagement tools, landscape assessment, implementation and post-implementation monitoring. The creation of small watershed groups or districts, where everyone in the group is recognized as a "neighbor" such that sufficient peer pressure could be applied to a potential "bad actor" [16] could hold some promise for solving NPS pollution at varying scales. The key is keeping the group small so that self-governance can tailor specific solutions to specific management issues. Unfortunately, this makes large scale NPS pollution difficult to gather all the needed information to manage for change across the typical career (30–40 years) of one individual water resource manager. This work is onerous in many respects because it requires a multidisciplinary effort. Is it possible within a typical 2–4 year study to collect watershed ecological features, economic and social data in a way that can be effectively communicated to stakeholders? Perhaps, but it depends on collecting data at the appropriate scale and building word pictures about the data story that communicate technical information in non-technical terms to the people who manage the land [7,28]. This is what TWAIM aims to accomplish—big picture watershed systems thinking and communicating.

3. TWAIM Objectives

3.1. Developing Systems Understanding

The TWAIM process first considers the end users and if they are environmentally educated about watershed systems; effective civic engagement will work better if the overall bar of system understanding can be raised. Some stakeholders want to know the current condition of their water resources and what can be done to improve the stream corridor. Other stakeholders only want to know how to resist any potential for change. Lack of cooperation is a clear limitation. Characterizing the willingness of watershed participants (land managers and others who have a vested interest) requires socio-political assessment tools [7,28]. Nevertheless, whichever socio-political tools are used in civic engagement, they need to be tailored to the people who live in the watershed. Rural farmers will likely view the world differently then suburban dwellers. Therefore, the proverbial watershed CSI team must also consider how they will approach and work with watershed stakeholders. As part of the up-front system design, the CSI team needs to develop specific profiles of each landowner in the study watershed following the example of successfully used social assessment tools [7,28]. This implies that a local conservation specialist should not wait for landowners to walk into the local field office and ask for assistance. The conservation specialist should become a student of each landowner's behavior, temperament and pursue them in a relationship to win their confidence and trust. Lastly, TWAIM does not end with an implementation plan, but continues to monitor and assess in an iterative manor the effectiveness of applied BMPs and stakeholder perceptions of water quality change. Good customer

assistance acknowledges the need for follow-up and on occasion, the need to make adaptive changes to meet both landowner and water quality objectives.

3.2. Creating a Vision

An essential ingredient of TWAIM is hypothesis development based on the most complete physical, chemical, biological, economic and socio-political understanding of the watershed information. Visioning and targeting PMZs must be iterative because with each new piece of information, system understanding can change. For example, a land manager over the course of a watershed study learns that more economic gain could be achieved by rotational grazing *vs* conventional grazing in a marginal landscape. The new information could be the tipping point to motivate the land manager to invest resources into cool and warm season grasses that will also provide wildlife and water quality ecosystem services [29].

The assessment tools should combine varying degrees of existing, estimated and observed data for the purposes of developing landscape-linked BMPs for relatively small (12 to 14-digit hydrologic unit code) watersheds. Landscape-linked BMPs are BMPs that first define pollutant origin and then address a pollutant's potential to move, from the upland or other source (point source), into and through a transitional or hillslope zone into the riparian corridor and water-body [9]. By linking BMPs there is the potential for an environmental value added affect, *i.e.*, water quality improvement, restored habitat, enhanced aesthetics and infrastructure protection [26]. These would generally be considered desirable enhancements of the CPR.

3.3 Building Partnership

After gaining an understanding of stakeholders within a defined small watershed along with adequate information about how the watershed system works, the team or specialist can systematically work with each landowner or manager gaining buy-in with the perceived leaders of the group [7,28]. At this point, the conservation specialist may only have a few landowners or managers who are willing to pilot some BMPs in selected locations. This may appear to be less than ideal; however, there are typically early adopters and surrounding neighbors who are watching. Neighbors will be scrutinizing the pilot activity and asking questions about their concerns to the watershed leaders. In time, the knowledgeable conservation specialist will gain the trust of landowners or managers and some will want to try more BMPs provided their key objectives are met; this gets back to "tailored or flexible management. In the past, rigid program rules have led to an all or nothing mentality by some government agencies; this approach is not tailored, nor does it integrate in a manner that seeks win-win scenarios. The NRCS, local governmental entities along with non-government organizations (NGOs) should aim to "partner" with the landowner or manager, not just for the short term until they comply with the rules, but over the long-term so that both government or NGO and the land manager are convinced the PMZ is correct and the BMPs are providing desirable outcomes. For example, getting buy-in, in a small watershed in central Minnesota required drainage corrections of a select group of landowners whose drainage need overshadowed water quality management considerations like grassed buffers. However, once their collective drainage need was addressed they agreed to pilot innovative denitrification treatment practices. Over time, developing a story that lends a convincing argument for

why a PMZ(s) (*i.e.*, multispecies buffer in a floodprone area) are good for water quality and beneficial for the landowner or manager and neighbors, builds institutional confidence. At this point, if your organization has been diligent in gaining the trust of the watershed leaders, they can now serve as the point of contact with other neighbors to gently persuade and help build a watershed coalition [7,28]. Some landowners or managers may still be skeptical, however all throughout the process, pertinent data has been strategically collected by the monitoring team—not just water quality data, but data important to the skeptical land manager, *i.e.*, forage quality and quantity and associated animal response to a different forage management regime [29].

3.4. Adaptive Management

Lastly, governmental conservation organizations or NGOs involved with water quality must assess their actions and share ideas about what they learned during the watershed systems study and implementation process in order to gain perspective. Time spent in the watershed observing the hydrology, vegetation and associated potential for pollutant generation will likely develop experiential learning as some pathways and processes become less mysterious. Although potential pollution sources (point or nonpoint) are of concern to watershed management, the hydrologic pathways and processes (*i.e.*, assimilation) of transport that link them to water resources are of equal or greater importance. Office data from LiDAR may point the way to pollutant origin, but field observation must validate the pathway and process. The environmental CSI monitoring specialist may define the strength of connection between pollutant(s) and water resource(s); however, that information must be effectively communicated to the conservation specialist to design the necessary attenuation measure. Accepted NRCS BMP practices, such as a grassed waterway, will deliver erosion and phosphorus attenuation. However, nitrate pollution will likely elude this BMP and move into the water resource via subsurface routes. Therefore it is helpful for team members to think in terms of "buffer capacity" between the terrestrial and the aquatic regimes. Buffer capacity is central to the BMP designer mind-set when selecting PMZs. All team members (CSI assessors and conservation specialists) must consider and ask: "could the environmental health of this water resource be significantly improved by preventing or buffering the transport of potential pollutants at this location? Or could in-stream biological response improve if the bedload sediment transport regime [9] were restored providing the necessary aquatic habitat? After applying technical assessment tools, does the hydraulic residence allow for adequate recovery? If recovery is only marginal, will it be difficult to obtain buy-in from landowners or managers? Typically, BMPs move the water resource restoration in the right direction; nevertheless, the water restoration goal may be woefully under met. Though the allotted project time frame may be expired, an extended management effort is often needed; one that requires iteration and adaptive management. Adaptive management is a key element of watershed systems thinking. In summary, the entire team must consider issues of lag-time, the feasibility of recovery potential, and a hypothesized BMP treatment train that will protect or add buffering capacity in a cost-effective manner.

4. Conclusions

Developing systems understanding allows the entire watershed team (CSI assessors and the conservation specialists) the ability to create a restoration vision; vision is critical for successful

implementation. Restoration is about more than chemistry—it is about a healthy stream ecosystem and stream ecosystems are common pool resources that can be challenging to manage. Integration requires a certain amount of deconstruction to understand the principle components such as the functional process zones of the watershed and the people managing the landscape; however in the end, solving NPS pollution must consider win-win sustainable solutions. One size does not fit all, watershed teams must specifically tailor; each team must tailor data collection and solution efforts, such as defined PMZs, for the specific study watershed and the communication techniques that capture the attention of watershed leaders.

The above examples illustrate how layers of analysis and field observation can add new information to an initial set of assumptions. It should be clear that follow-up investigation is needed to clarify more precise understanding of pathways or factors influencing the processes for different geographic locations. This is why the assessment must be iterative! Interpretation of data occurs at least seven times: (1) in the office with existing data, (2) in the field during data collection, (3) after analysis or when test results come back, (4) after a re-visit following a storm event, (5) during a different season, (6) during BMP implementation, (7) after BMP implementation and (8) systematically with stakeholders throughout the assessment and implementation phases. Keep in mind that the CSI work can appear to be "research" to some policy oriented groups, yet the watershed team must distill data into information to tell a convincing story and influence land use managers to adjust their practices. The story should be kept simple so all stakeholders can follow along, yet at times, team members may need to drill down into technical detail for those stakeholders who want greater understanding and BMP guidance and assurance. The payoff, however will pave the way for partnership in solving NPS pollution.

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References and Notes

1. *Thermodynamics and Ecological Modelling*; Jorgensen, S.E., Ed.; CRC Press: Danvers, MA, USA, 2001; pp. 1-3.
2. Hardin, G. The tragedy of the commons: The population problem has no technical solution; It requires a fundamental extension in morality. *Science* **1968**, *162*, 1243-1248.
3. Thorp, J.H.; Thoms M.C.; Delong M.D. The river ecosystem synthesis: Biocomplexity in river networks across space and time. *River Res. Appl.* **2006**, *22*, 123-147.
4. Magner, J.A.; Brooks, K.N. Integrating sentinel watershed-systems into the monitoring and assessment of Minnesota's (USA) waters quality. *Environ. Monit. Assess.* **2008**, *138*, 149-158.
5. McDonnell, J.J.; Sivapalan, M.; Vache, K.; Dunn, S.; Grant, G.; Haggerty, R.; Hinz, C.; Hooper, R.; Kirchner, J.; Roderick, M.L.; *et al.* Moving beyond heterogeneity and process complexity: A new vision for watershed hydrology. *Water Resour. Res.* **2007**, *43*, W07301.
6. Tomer, M.D. How do we identify opportunities to apply new knowledge and improve conservation effectiveness? *J. Soil Water Conserv.* **2010**, *65*, 261-265.

7. Davenport, M.A.; Leahy, J.E.; Anderson, D.H.; Jakes, P.J. Building trust in natural resource management within local communities: A case study of the Midewin National Tallgrass Prairie. *Environ*. *Manage*. **2007**, *39*, 353-368.
8. Reutebuch, S.E.; Andersen, H-E.; McGaughey, R.J. Light Detection And Ranging (LIDAR): An emerging tool for multiple resource inventory. *J*. *For*. **2005**, *103*, 286-292.
9. Rosgen, D.L. *Watershed Assessment of River Stability and Sediment Supply (WARSSS)*; Frantila, D, Ed.; Wildland Hydrology Books: Fort Collins, CO, USA; 2006.
10. Paola, C.; Foufoula-Georgiou, E.; Dietrich, W.E.; Hondzo, M.; Mohrig, D.; Parker, G.; Power, M.E.; Rodriguez-Iturbe, I.; Voller, V.; Wilcock, P. Toward a unified science of the Earth's surface: Opportunities for synthesis among hydrology, geomorphology, geochemistry and ecology. *Water Resour*. *Res*. **2006**, *42*, W03S10.
11. Turner, M.G. Landscape ecology: The effect of pattern on process. *Annu*. *Rev*. *Ecol*. *Syst*. **1989**, *20*, 171-197.
12. Vannote, R.L.; Minshall, G.W.; Cummins, K.W.; Sedell, J.R.; Cushing, C.E. The river continuum concept. *Can*. *J*. *Fisheries Aquat*. *Sci*. **1980**, *37*, 130-137.
13. Schultz, K.R.; Seppelt, E.; Zehe, H.J.; Attinger, S. Importance of spatial structures in advancing hydrological sciences. *Water Resour*. *Res*. **2006**, *42*, W03S03.
14. Dooge, J.C.I. Looking for hydrologic laws. *Water Resour*. *Res*. **1986**, *22*, 46-58.
15. Meals, D.W.; Dressing, S.A.; Davenport, T.E. Lag time in water quality response to best management practices; A review. *J*. *Environ*. *Qual*. **2010**, *39*, 85-96.
16. Nowak, P.J.; Cabot, P.E. The human dimension of resource management programs. *J*. *Soil Water Conserv*. **2004**, *59*, 128A-135A.
17. Christensen, V.G.; Lee, K.E. In *Effects of Agricultural Land Retirement of the Minnesota River Basin*, Proceedings of Riparian Ecosystems & Buffers, American Water Resources Association summer specialty conference, Virginia Beach, VA, USA, 30 June–2 July, 2008.
18. Magner, J.A.; Vondracek, B.; Brooks, K.N. Channel stability, habitat and water quality in south-eastern Minnesota (USA) streams: Assessing managed grazing practices. *Environ*. *Manage*. **2008**, *42*, 377-390.
19. Lenhart, C.F.; Brooks, K.N.; Henely, D.; Magner, J.A. Contributions of organic matter and suspended sediment to turbidity: Muddying TMDLs in the Blue Earth River Basin. *Hydrol*. *Sci*. *Technol*. **2007**, *23*, 127-135.
20. Ostrom, E. *Governing the Commons: The Evolution of Institutions of Collective Action*; Cambridge University Press: New York, NY, USA, 1990.
21. Costanza, R.; d'Arge, R.; de Groot, R.; Farber, S.; Grasso, M.; Hannon, B.; Limburg, K.; Naeem, S.; O'Neill, R.; Paruelo, J.; *et al*. The value of the world's ecosystem services and natural capital. *Nature* **1997**, *387*, 253-260.
22. Woolcock, M.; Narayan, D. Social capital: Implications for development, theory, research and policy. *World Bank Res*. *Observer*, **2000**, *15*, 225-249.
23. Hibbard, S. DePaul University, Chicago, IL, USA. Personal notes, 2010.
24. Micklin, P.P. Desiccation of the Aral Sea: A water management disaster in the Soviet Union. *Science* **1988**, *241*, 1170-1176.

25. Blankenship, K. GAO report faults the way Bay Program presents its data. *Chesapeake Bay J*. December **2005**.
26. Norton, D.J.; Wickham, J.D.; Wade, T.G.; Kunert, K.; Thomas, J.V.; Zeph, P. A method for comparative analysis of recovery potential in impaired waters restoration planning. *Environ*. *Manage*. **2009**, *44*, 356-368.
27. Econport (http://www.econport.org/econport/request?page=man_cpr_issues) provides a clear example of appropriation externality, from which the author was able to contrast Water Quality for the purpose communicating CPR differences.
28. *Swimming Upstream: Collaborative Approaches to Watershed Management (American and Comparative Environmental Policy)*; Sabatier, P.A., Focht, W., Lubbell, M., Trachtenberg, Z., Vedlitz, A., Matlock, M., Eds; The MIT Press: Cambridge, MA, USA, 2005.
29. White, T.A.; Barker, D.J.; Moore, K.J. Vegetation diversity, growth, quality and decomposition in managed grasslands. *Agric*. *Ecosyst*. *Environ*. **2004**, *101*, 73-84.