SUSTAINABILITY; “LIFE, LIBERTY AND THE PURSUIT OF NEGATIVE ENTROPY”

John Milne, Engineer III, Clark County Public Works

Abstract

This paper introduces how an “entropy-based resource management” organizing principle can be used to develop holistic, cost-effective strategies for rehabilitating disturbed watersheds, so helping communities move towards achieving a more sustainable environment and economy.

Entropy-based resource management is founded on the recognition that natural systems always act to minimize energy loss and so leave each resource in its highest, most ordered thermodynamic state, that is in a state of minimum entropy, after each process has been completed. At heart, an entropy-based strategy is an attempt to create and maintain order in all aspects of resource management, taking aim at the second law of thermodynamics as the fundamental theorem describing how natural resources are utilized and impacted and so the key to developing effective sustainability strategies.

The paper introduces the concept and describes some of the work products developed using this principle including sub-basin retrofit plans, hydrologic accounting procedures and a sustainable roadway grid. The paper concludes by suggesting how team members from several disciplines might collaborate to develop a land use plan that would minimize the entropy of an entire urban area as an integrated system, in so doing creating a truly holistic and sustainable land use plan.

Key Words: Holistic, entropy-based resource management, sustainable land use plan.

Introduction

This paper introduces how an “entropy-based resource management” organizing principle can be used to develop holistic, cost-effective strategies for rehabilitating disturbed watersheds, so helping move communities towards a more sustainable environment and economy.

At heart, an entropy-based strategy is an attempt to create and maintain order, to *create negative entropy*, at all times and in all places. It treats sustainability as an applied physics problem requiring a holistic management approach, by focusing on the second law of thermodynamics as the fundamental theorem describing how natural resources are utilized and impacted and so the key to developing effective sustainability strategies.

The paper introduces some examples of work products developed using this principle including sub-basin retrofit plans, hydrologic and hydraulic accounting procedures and a sustainable roadway grid.

The paper concludes by suggesting how team members from several disciplines might collaborate to develop a land use plan that would minimize the entropy of an entire urban area as an integrated system, in so doing creating a truly holistic and sustainable land use plan.

Entropy-based watershed management

“Instead of engineered stormwater facilities, why don’t you use holistic, watershed-based methods that mimic natural processes?” This criticism was levelled at Clark County during the development of their mid-90s watershed plans. “Mimicking” something might initially seem to be taking a backward step from developing sophisticated computer models. However, when trying to achieve basic engineering objectives, attempting to mimic natural processes does appear to make sense:

- Natural processes are highly efficient; mimicking them could be very cost-effective;
- Natural processes seamlessly interact and work across physical, chemical and biological boundaries; they are truly holistic; and,
- All natural processes are very efficient, not just the one your program is focused on at the moment but all “downsystem” processes that follow.

So a strategy that mimics natural processes shows promise as effective resource management. But what does “mimicking a natural process” mean, in physical terms? The premise behind this strategy is that natural systems always act to minimize energy loss and so leave each resource in its highest, most ordered thermodynamic state, i.e. in a state of minimum entropy, after each process has been completed.

Continuing with that hypothesis, an entropy-based management system for any particular resource would attempt, after every internal process has taken place, to leave that resource:

- In its highest state of matter i.e. solid phase;
- In the highest energy state, i.e. potential energy; and,
- At the highest level of potential energy possible.

In so doing, an entropy-based management strategy is able to emulate how natural systems operate across physical boundaries for the efficient creation and storage and the frugal use of energy and natural resources. It is considered to be applicable from the molecular level up to and including large-scale ecosystems.

Natural Examples

As noted earlier, any system that manages a resource efficiently would favour conserving that resource in its most ordered state, that is in solid phase with high potential energy. That system and similar systems would also be expected to be ubiquitous in nature. Is there such an example in the natural world?

If we take as our resource the annual rainfall falling on a watershed, then snowpack appears to fit the bill. Snowpack along watershed ridge-lines is water in solid phase with the highest possible potential energy. The "knock-on" benefits of having a good snowpack need no further explanation to watershed managers and biologists.

Although the snowpack example appears to support our hypothesis, that example may be of limited value to a watershed manager. Physically creating snowpack, by cloud seeding or other methods, is beyond the means of most communities. So what might the next best thing be?

High groundwater is water in liquid phase with high potential energy. From our knowledge of how watersheds, wetlands and streams work, we know that maintaining high groundwater elevations can be expected to conserve water effectively as well as generate multiple downstream environmental benefits.

We now have something that a watershed manager can use. A simple entropy-based strategy for effective watershed management might be to promote the establishment and maintenance of high groundwater elevations in all the regulatory, planning and capital construction activities that the watershed manager can influence.

Use as an "Organizing Principle"

We noted earlier that natural systems will always act to minimize energy loss. Recall also that an entropy-based resource management strategy mimics natural systems to create and maintain order in all our natural resources.

Proceeding from these two observations, it seems logical for us to also attempt to mimic natural systems to try to reduce *organizational* energy losses, by creating order in all our management systems. We can achieve this by moving as quickly as we can, expending the least effort possible, from a well-considered watershed improvement concept into on-the-ground construction of a needed project.

To be able to achieve this, our analysis and decision-making methods should be:

- *As simple as possible* (i.e. achieved with the least effort)
- *… but no simpler* (i.e. our thought processes, analysis and decision-making must be holistic and address all natural resources).

To best meet those needs the entropy-based resource management strategy is used here in the form of a simple "organizing principle" for developing sustainability strategies.

The overall strategy can be thought of as a "back-to-basics" approach to sustainability, favoring good judgment and holistic, well-reasoned decision-making over the use of complex methods based on elaborate research and the collection of large amounts of data.

Application of the entropy based resource management organizing principle

The first, most basic application of entropy-based resource management is the "do-nothing alternative", that is to allow natural processes to continue doing as they have always done. To simply trust that natural systems will perform better and more sustainably than a system that you as an engineer could devise, even with all the planning, data-collection, analyses and computer modeling that you might be able to muster.

This initial step not only covers preservation activities but also requires you to first *use* natural processes as much as possible, then to always work in a "top-down" sequence when developing sustainability initiatives. Mimicking natural processes with your own engineering designs would also be a sound choice from that point forward.

In following these steps, we are acknowledging that the fundamental physics of how natural systems operate is efficient and will always produce beneficial outcomes. This acknowledgment frees us to be able to make simple, well-informed judgments on whatever issue is in front of us at the time. We can then move forward expeditiously on sustainability initiatives, having used only limited quantification but still being confident that we will achieve good outcomes.

Because we have that confidence in good outcomes, the detail and accuracy in our quantification needs only be sufficient for us to be able to make reasonable policy decisions. For example, in many situations we need use only "apples to apples" comparisons rather than highly detailed computer modeling.

These simple procedures, logical, orderly and achieved with minimal effort, are perfectly adequate to allow us to go quickly to a reasonable solution to a known problem.

Holistic, "top down" watershed management

An entropy-based watershed management strategy requires that you use top-down watershed management i.e. that you take appropriate measures as soon as rainfall hits the ground and do everything possible from that point downstream.

Top-down watershed management requires that you:

- Focus on primary causes rather than effects;
- Consider watershed needs outside your immediate program objective; and, importantly,
- Include improvements that may be difficult to quantify and for which you may not understand fully all the natural processes at play.

It's worth lingering here on the additional benefits that are realized when a top-down management strategy focuses on a fundamental driving process, and fundamental causes of watershed impacts, rather than the many symptoms and effects of watershed degradation that we see in our streams.

For a natural example of holistic, top-down resource management dear to (some) engineers' hearts, consider the case of single-malt scotch whisky. Most scotch aficionados will tell you that it is the water used in the distilling process that gives each whisky its individual flavour, far more than any transcendent skill on the part of the distiller. Take a trip to the Glenmorangie distillery in Tain, Scotland. The water in the burn looks like Coca Cola as it tumbles over the rocks and black as treacle in the pond at the distillery. Glenmorangie has a very peaty smell and flavour, which many people enjoy. Would they like it as much if we engineers had captured and piped all that "pure highland rainwater" all the way to the distillery?

No, they would not. Apparently the glens know better than we do how to make good whisky, by using holistic, top-down watershed management. And maybe they know what's best for that river's salmon run also.

Low Impact Development

Perhaps the best-known modern example of top-down watershed management, although it has not been termed as such, is the use of Low Impact Development (LID) techniques for stormwater management.

Infiltrating stormwater runoff into the ground surface as early as possible supports plants, recharges groundwater and maximizes groundwater elevations (i.e. minimizes the entropy of the resource). This leads to a cascade of environmental effects, all beneficial.

It is not necessary to know exactly how each downstream process plays out to know that encouraging LID is basically a good watershed management call that can be made without the need for extensive data collection, study and analysis. Using LID is simple, but not simplistic, constitutes effective top-down watershed management, and is a sound entropy-based resource management strategy.

Hydrologic and Hydraulic Accounting

Although the simple strategy of encouraging Low Impact Development is sound and can safely be implemented, use of any single management method cannot meet every need of a watershed manager. There clearly is a need for additional, similarly effective watershed management measures.

It's also clear that there will be instances in which we must move from a purely qualitative assessment to the next level of completing a simple, limited quantitative analysis.

Hydrologic and hydraulic accounting are two simple techniques that have proven to be very useful and compatible with an entropy-based watershed management strategy. Both methods use powerful and sophisticated hydrologic and hydraulic software in very simple ways to identify needed and cost-effective projects. Those same techniques are then used later to complete alternative analyses and preliminary designs for the selected engineering projects.

Hydrologic accounting uses a continuous simulation hydrology model (WWHM) to compare two or more stormwater mitigation project alternatives based on the computed size of the hypothetical upstream watershed that they "can provide full mitigation for". The stormwater mitigation can be in terms of flow control and/or water quality treatment.

While hydrologic accounting can provide most of the analysis needed to identify cost effective stormwater mitigation projects, evaluating a system of linked projects, such as may be included in a master plan for a severely disturbed basin, is more complex. Here, hydraulic accounting can help.

Hydraulic accounting uses a sediment transport module within hydraulic river analysis software (HECRAS) to compare the annual sediment load generated by two alternative stormwater mitigation plans, both acting upon a single, idealized stream reach. The mitigation plan with the least annual export of sediment from the basin is selected.

Clark County Examples

Having explained how this organizing principle can be used to develop effective watershed management strategies, this section describes some Clark County examples.

2008-2011 Stormwater Capital Improvement Program

The 2008-2011 Stormwater Capital improvement Program (SCIP) made extensive use of a top-down watershed management strategy and the county's hydrologic and hydraulic accounting procedures to identify, compare and prioritize stormwater mitigation and watershed improvement projects.

Those simple analyses were completed without extensive study, data collection and analysis, so that the county was able to move projects forward quickly into construction.

The 2008-2011 SCIP was by far Clark County's most successful watershed rehabilitation effort. A big reason for that was that policy-makers were highly motivated to get on-the-ground results quickly, and so were willing to expend funds based on reasonable representations of the cost-effectiveness of competing projects.

Clark County Amphitheatre Sub-basin Retrofit Plan

Here the organizing principle was expressed as a simple game plan to "pump up the groundwater as high as possible then plant everything". In other words, conserve as much as possible of the annual precipitation and maximize the photosynthesis throughout the watershed.

The Amphitheatre plan accomplished this in a series of simple steps:

Step 1: Develop Infiltration Zone Mapping and Matrix

Infiltration Zone maps and an associated Infiltration BMP Matrix were developed to identify the most cost effective infiltration BMP that could be used under any of the soil and groundwater combinations found in county watersheds.

The Infiltration Zone maps overlaid soil types with groundwater depths to provide a map showing the most effective areas for infiltration of stormwater runoff. Hydrologic accounting calculations (see earlier) were then used to list each BMP's cost-effectiveness, in terms of their "Cost per Fully-Mitigated Impervious Acre", in the Infiltration Zone matrix.

Step 2: Site the most cost-effective infiltration BMP at every feasible retrofit location in the sub-basin

Starting at the top of the sub-basin and working downstream, the Infiltration Zone maps and matrix were used to site the most cost-effective infiltration/retention BMP at every feasible retrofit location. The aggregated BMPs make up Sub-basin Plan Alternative 1, the "Maximum Improvement" alternative.

The Maximum Improvement plan alternative included several common LID BMPs such as rain gardens, eco-roofs and retention ponds. Adjusted flow controls on the existing detention ponds acted as the furthest downstream "BMP of last resort".

Step 3: Alternative Analysis; Phase 1

In Step 3, additional plan alternatives were developed simply by reviewing the hydrologic accounting summations and deleting the least cost-effective individual BMPs. This quickly identifies two or three more affordable plan alternatives for more detailed analysis.

Step 4: Alternative Analysis; Phase 2

In this final step, hydraulic accounting computations were used to model the remaining plan alternatives in more detail, and as systems rather than as a collection of individual BMPs.

As indicated earlier, the selected Sub-basin Retrofit Plan was the one that resulted in the least export of sediment from the sub-basin that could be achieved within the available budget.

Sustainable Land Use Plan (water resources)

Recognizing that watershed plans have been only partially successful in preventing watershed degradation, this graduate school term paper proposed using the land use planning process as a potentially more effective management intervention point.

The Cougar Creek basin, an urbanizing basin tributary to Salmon Creek, was used as an example to try to develop a sustainable land use plan. The annual rainfall supply was selected as the resource of concern.

The plan was developed in a four-step procedure that used available GIS information to develop a series of maps:

Step 1. Current Comprehensive Plan

The first map used was the current adopted land use plan, mostly econometric and transportation-based.

The goal was to develop a new plan with the same mix of land uses but distributed throughout the watershed in a way that would produce less impacts, cost less and be more sustainable.

Step 2: Use a groundwater flow model to determine the best arrangement of land uses

The assumption here was that the most sustainable land use arrangement would be the one that produced the highest groundwater elevations throughout the watershed.

The method used was to:

- Assign groundwater recharge and discharge values to Industrial/ Commercial, Residential and Parks/Open Space land uses;
- Place each of those three generalized land uses in the upper, middle or lower portions of the watershed;
- Analyze alternative land use placements using a groundwater flow model (Modflow) to compute the resulting groundwater elevations; and,
- Determine the optimal arrangement of land uses i.e. the one that produced the highest groundwater elevations.

Step 3: "Envirometric Overlay"

The Envirometric Overlay map was developed based on the outcomes from the groundwater model, and sited land uses where they would maintain the highest groundwater elevations throughout the watershed.

The solution worked out to be Residential at the highest elevations, Parks/Open Space in the headwaters and valleys, and Industrial/ Commercial in the lower watershed. Basically, place the land uses with the most *net recharge* in the highest locations in the watershed and avoid adding new groundwater drains.

Step 4. Sustainable Land Use Plan

The last map was a simple compromise between the original Comprehensive Plan and the Envirometric Overlay. It showed the final revised zoning plus some associated new infrastructure.

For the Cougar Creek basin there was not much change. Because I-5 is a critical north-south transportation corridor, that crucial transportation need dictated, to a large extent which land use type was used where.

However, some industrial development was moved to the lower basin, serviced by a new roadway arterial. And several small parks were combined into one large regional park, sited to protect the headwaters area.

Other Clark County examples
Other county work products developed using this strategy include:

- A watershed water balance approach was used to re-establish the natural drainage patterns, recharge functions and groundwater elevations in a degraded headwater wetland;
- An increased county focus on Protecting and restoring headwater wetlands;
- Increased use of trench dams in drainage and utility pipe trenches; and,
- The successful defense of a county road-widening project against a legal challenge that the increase in impervious area would reduce groundwater recharge and so impact adjacent wetlands.

Entropy-based resource management

Entropy-based management of resources other than the annual rainfall supply, and the coordinated management of multiple resources are explored in this section.

Energy and transportation
Consider the difference in traffic flow patterns between a roundabout and a signalized intersection. At a roundabout, a car moves through the intersection without stopping. At a traffic intersection stop light, the car engine is running and using fuel but the car is not going anywhere. This is an unnecessary and unproductive increase in entropy; an entropy change from a liquid with high potential energy to a gas with high kinetic energy.

If we next note that energy use is more related to *corridor travel time* (i.e. the time the car engine is running) than *maximum design speed*, we can see that we may be able to develop a lower entropy, more energy-efficient roadway grid by changing the design focus to minimizing the average corridor travel time. This can potentially be achieved by replacing a series of traffic signals with a roundabout corridor that allows continuous traffic flow without forced stoppages; i.e. by creating more orderly traffic flow.

So, using an entropy-based resource management approach to try to develop a more energy-efficient roadway grid leads us to use roundabouts at every feasible opportunity rather than standard signalized intersections.

Note the simplicity of this proposal from another viewpoint. We've been trying for many years to design cars that use less energy (petrol) per mile; shouldn't we also design our roads to do the same?

Sustainable roadway grid
Here the entropy-based resource management strategy is extended one crucial step further to assess what might be the most sustainable roadway grid system to service (say) a sustainable land use plan.

We know that nature works very efficiently on all systems at the same time. We can also mimic this *holistic* feature of natural systems; we can walk and chew gum at the same time. The last example showed how we could design our roads for more sustainable use of energy; can we also promote sustainable water resource management at the same time? This is easily done; we simply combine a roundabout corridor with a "green street" roadway cross section.

The roadway grid now combines the most sustainable energy use design with the most sustainable water resources design. With its frugal use of both energy and water resources, this now represents a truly holistic and sustainable roadway grid system.

Table 1, below, summarizes some outcomes from a comparison between the two competing roadway grid alternatives for a one-mile roadway corridor:

Table 1;

Roundabouts vs. Signalized Intersections

	% Reduction for Roundabout Alternative
Transportation and Energy Use	
Capital cost	17%
Annual fuel cost	21%
Travel time	21%
Intersection Fatalities	89%
Intersection Injuries	76%
Stormwater and Water Conservation	
Annual runoff volume to streams	100%
Stream erosion	Reduced
Annual groundwater recharge	Improved
STREAM WATER QUALITY	
Total suspended solids	100%
Total zinc	100%
Total copper	100%
Summer stream temperature	Reduced
Air Quality and Environmental	
Project impervious area	9%
Wetland impacts	100%
Total hydrocarbons	26%
Carbon Monoxide	19%
Carbon Dioxide	21%
Methane, Nitrous Oxide, HFC	21%

The results show a reduction in energy use (here represented by annual fuel cost), confirming the roundabout corridor alternative as the more energy-efficient, more sustainable roadway grid.

As in previous examples, use of an entropy-based resource management strategy has led us to intervene early in a fundamental process to achieve our main objective as well as many additional benefits. There is something to please everyone. For capital budget hawks this is the cheapest, most cost-effective roadway infrastructure. For environmental advocates, there is carbon dioxide reduction and presumably some associated slowdown in global warming. Wetlands will benefit from improved groundwater recharge, and fish will benefit from deeper, cooler base flows in streams. And, for our citizens, there is a safe, fast, comfortable and inexpensive commute, surely what we are looking for in a good, sustainable roadway design.

This example perhaps sums up the entropy-based resource management strategy best.

That is, to use this organizing principle to develop simple but nonetheless comprehensive management strategies, covering multiple resources, that will help move us forward quickly to a sustainable future.

Compatible sustainability initiatives

Although they were not developed using an entropy-based resource management approach, following are some recent sustainability initiatives that are consistent with this organizing principle and offer us cause for optimism as the quest for sustainable communities continues into the future:

- Increasing use of Low Impact Development techniques;
- Stormwater Credits and Stormwater Control Transfer Programs;
- Stormwater capture and aquifer replenishment;
- Increasing use of solar energy;
- Wind energy linked to pumped storage or underground injection of compressed air;
- Turbines inside gravity water supply lines; and,
- Artificial photosynthesis for fuel.

A key objective of this paper has been to promote the use of simple, logical assessments over the use of highly elaborate planning efforts that include extensive research, data collection and modeling. However, as simple entropy-based management methods begin to be implemented, it is likely that more detailed quantitative analysis methods will be needed. In this regard, systems analysis procedures such as the "maximum entropy method" may offer promising ways to fine-tune the resource management procedures outlined in this paper.

Development of a Sustainable Land Use Plan

As noted earlier, one key to sustainability is to make the earliest possible effective management intervention in the land use planning process. The sustainable land use plan described earlier optimized the land use pattern for sustainable use of a single resource i.e. the annual rainfall supply on a watershed. Following an entropy-based resource management strategy to its logical conclusion, however, a fully-sustainable land use plan would need to optimize *all* systems and resources necessary for life in the community. It would need to minimize the entropy of the entire urban area as an integrated system, while supplying all the needs for a given population within a given geographic boundary.

Minimizing the entropy of a complex, human-built system is a daunting quantitative exercise. However, as indicated earlier, we can elect to mimic a natural eco-system, say a Pacific Northwest forest, to provide clues as to how team members from several engineering and scientific disciplines might contribute to a solution.

Just as trees grow as high as possible, trapping as much of the sun's energy and creating as much biomass as possible, our buildings might tend to be taller, use solar panels to supply the energy needed for the building and its inhabitants, and use roof cisterns to capture and store much of the annual rainfall. For optimal water conservation, land use types would need to be arranged in a systematic way within the watershed, as discussed earlier. To minimize entropy within the transportation system, residential and work buildings would need to be close together, serviced by mass transit utilizing an orderly, sustainable roadway grid.

Some of these measures are already being implemented, others may be used in the future, and all are consistent with and can be conceived and developed by a multi-discipline team using an entropy-based resource management strategy.

Conclusions

This paper has suggested how an entropy-based resource management organizing principle can be used to develop effective watershed rehabilitation strategies and also contribute to other areas of resource management and sustainability.

Rather than focus on the many symptoms of watershed degradation, this strategy looks for the primary cause, focusing on the second law of thermodynamics as the key to developing effective sustainability measures and programs. The organizing principle seeks to create and maintain order, to “create negative entropy”, in all things, in all places, at all times.

Recognizing the large number and wide array of inter-related resource management problems that could potentially be mitigated using this approach, entropy based resource management has been implemented in the form of a simple organizing principle for developing watershed rehabilitation and sustainability initiatives. As such, it can be thought of as a back-to-basics approach to sustainability, founded on a trust in the value and efficacy of natural processes. The use of logical decision making procedures and simple comparative computations is emphasized over completing ever more elaborate research and modelling.

Use of this organizing principle has prompted a paradigm shift in Clark County’s resource management and infrastructure development operations:

- Maintaining groundwater elevations as high as possible is now viewed as a primary goal of watershed management;
- While we recognize that recharge of groundwater is important, we also emphasize the need to minimize groundwater *discharges;*
- A generalized need to maximize both groundwater and surface water storage is a focus;
- Having recently embraced the use of Low Impact Development techniques, we are also applying that same strategy, as “LID on a watershed scale”, to much larger, regional-scale watershed projects;
- The preservation and rehabilitation of headwater areas is emphasized;
- The use of roundabouts and other methods of reducing corridor travel times play a bigger part in transportation system designs;
- Sub-basin retrofit plans facilitate the speedy rehabilitation of priority watershed areas; and,
- In the future, sustainable land use plans may prove to be more effective in preventing watershed impacts in the first place.

The sustainable roadway grid and sustainable land use plan prototypes described in the paper demonstrate that effective interdisciplinary coordination and collaboration will be needed if we are to replicate the efficiency and holistic operation of natural systems. Order needs to be established not only at the molecular level, but also in all our operations, programs, regulations and governmental structures, for us to move towards a sustainable future.

Create negative entropy. (Sustainability and) happiness will surely follow.

Author Biography

John Milne is a civil engineer with forty years experience in civil and water resources engineering in Great Britain and the United States.

John began his career in Edinburgh, Scotland, working on the design and construction of highways and drainage and wastewater systems, followed by a brief spell in Edinburgh District Council's Architects Department.

On his move to the United States, he worked with a land use developer in Detroit, Michigan before moving to work with a civil/water resources design consultant in Denver, Colorado.

For the last twenty-five years, John has worked as a design engineer with the Clark County Public Works Department in Vancouver, Washington, where he has worked on watershed planning, stormwater regulations, flood plain management and the design and construction of highway, drainage and stormwater mitigation infrastructure.

John's son, Ross, is a molecular biologist and contributed to the development of this resource management strategy.

John Milne, P.E.
Clark County Department of Public Works
1300 Franklin Street, P.O. Box 9810
Vancouver, WA 98666-9810

John.Milne@clark.wa.gov