A Multiple Index Environmental Quality Evaluation and Management System

A method that can be applied to a golf course.

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The construction of Colbert Hills Golf Course near Manhattan, Kansas, provided the opportunity for what is perhaps the most extensive environmental research evaluation ever conducted on a golf course.

A METHOD for evaluating environmental quality of large-scale landscapes that bridges scientific research and public use is in great demand. Resource managers, industry and community planners, government policy makers, and scientists all support an improved environment, but connections between processes, remediation, and management aren't always readily available or understandable to such a diverse community. This article describes a versatile, simplified, science-based system for making environmental quality assessments and linking outcomes to remedial management. This complex goal becomes attainable by: establishment and use of appropriate scientific databanks, determination of targets for acceptable and unacceptable impact on critical ecosystem functions, simplified visual integration of many indicators, and linkage to management databases. The process is being developed by a multidisciplinary study of a grassland ecosystem converted for use as a golf course. The system can be easily customized to local conditions and has wide-range application to many types of natural and managed ecosystems.

Ecosystems and a New Golf Course Every Day!

Golf is one of the fastest-growing industries in the United States, yet its environmental impact is largely unknown. Somewhere in the United States, on average, more than one new golf course opens every day (509 new courses opened in 1999).[1] The 26.4 million U.S. golfers[1] play at more than 16,743[1] courses that occupy well over 3 million acres. The annual impact of the golf industry on the U.S. economy was estimated at $30 billion in 1998 and is growing.[1] With the international golfing scene adding significantly to these numbers, both the golf industry and the public are interested in the impact of golf on the environment.

Golf courses provide unique settings for environmental studies. They typically contain segments progressing from high input zones to relatively undisturbed natural settings. Also, management inputs are commonly well documented. Researchers studying golf-related environmental issues find a receptive audience of superintendents through avenues like the United States Golf Association (USGA) *Green Section Record*[2] and the publications and educational programs of the Golf Course Superintendents Association of America (GCSAA).[3] Contrary to popular belief, evidence from these sources, and others, is building that golf courses, with their combination of plant communities, open expanses and natural areas, can be an accommodating habitat for birds, animals, pollinators, fish, amphibians, and other fauna and flora.[4,5,6] There remains, though, a great need to translate research into working management tools for the betterment of golf course ecosystems. Golf courses present perhaps one of the best living laboratories for the systematic study and monitoring of environmental quality from which the improvement of other natural, large-scale ecosystems can be modeled.

In Quest of Quality

Both the scientific community and the public support practices that improve the environment. Given the world's collective knowledge, abilities, interests, and support, one could reasonably expect our modern society to have developed a more sustainable and less destructive interaction with its environment. The fact that we haven't is troubling; however, there is the opportunity for channeling these mutual interests into a process and resulting solution.

Gifford Pinchot[7] and Frederick Law Olmstead[8], at the end of the 19th century, championed the systematic and scientific management of large-scale landscapes. They coupled emerging ecological sciences, like botany and silviculture, to traditional biological sciences. By today's standards, their tools were primitive, yet they may have taught us the value of "looking at the whole forest and not just single trees."

In the modern era of powerful molecular-level technology, a case could be made that the scientific community can describe to the public more than it wants to know about a particular tree or molecule of the tree's genome. However, the description often stops short of any effort to describe the forest. Large databases exist that describe scientific aspects of our environment, but most await translation into workable management tools. At the beginning of the 21st century, a holistic, science-based, public-friendly method for evaluating and managing the relative health of large-scale landscapes seems like the missing link in environmental improvement.

Government, industry, university, and public entities have a continuing interest in a variety of ecosystems. Frequently, their interest is in an appropriate management regime to establish or maintain a quality environment. The phrase "quality environment" is vague and susceptible to conflicting interpretations. Too often, environmental quality is touted as a goal, but one typically lacking an itinerary, roadmap, or destination and, therefore, of little practical use.

Although scientists lean toward characterizing the environment through quantifying and interpreting large numbers of indicators, the resulting set of isolated indices falls short of describing the forest (or the "big picture"), particularly for the non-scientist. Alternatively, condensing many indices into a single index introduces significant theoretical and practical shortcomings. This article describes a utilitarian connection between the evaluative and management segments of environmental quality. The article suggests how, by appropriately combining management strategies with environmental databases, environmental quality can be changed from an empty idea into a workable tool, leading to sustained environmental improvement. This approach might best be viewed as "looking at single trees to see the whole forest." We'll demonstrate this concept using a golf course as our living laboratory, but the system's versatility allows its use on practically any ecosystem.

Golf on the Grasslands and Environmental Research

During 1999-2000, Colbert Hills Golf Course was constructed on a 312-acre native grassland site near Manhattan, Kansas. Soils, water resources, flora and fauna on this site represent a natural Kansas tallgrass prairie ecosystem. Environmental researchers at nearby Kansas State University were presented an excellent opportunity to study the impact a golf course has on the environment. Prior to construction on the site, researchers collected baseline data on environmental indicators selected to describe original conditions of the native grassland ecosystem. As architectural plans were being finalized, the course superintendent assisted in the selection of research sites and indicators. Water quality, soil quality, turf management, grassland ecosystems, avian ecosystems, aquatic ecosystems, and insect ecosystems were studied. Subsequent measurement of the same indicators has progressed through construction and, now, operation and use of the course. This project represents perhaps the most extensive environmental research evaluation ever conducted on a golf course.

Coupling with the research team, the course superintendent, an agronomist from the PGA Tour golf course properties, and a scientist from the United States Department of the Interior have used the Colbert Hills project to develop a multiple indexing system to gauge the environmental quality of the golf course. Named the Colbert-Thien (pronounced "teen") Environmental and Evaluation Management system, CTEEM is a versatile, informative, simplified, science-based method for identifying environmental processes in need of remediation and a source of management strategies to apply toward improving those conditions.

With this research, we're attempting to determine the ecological impact of converting a native grassland site to a golf course. We also aim to develop guidelines useful to the golfing industry for minimizing and remediating any negative environmental impacts of golf course construction, operation, and use.

Methodology

As described earlier, characterizing ecosystems requires both data and interpretation. Using today's technology, scientists can measure a large number of indices – so many, however, that they can often be confusing to the non-scientist. Alternatively, reducing many indices to a single index has theoretical shortcomings and practical limits associated with oversimplification of interpretations.

The CTEEM system overcomes both of these limitations by coupling multiple indices from a large-scale landscape into an easily understood visual gauge of environmental quality. By linking the identification of degraded processes and remediation guidelines, the CTEEM system comprises a complete environmental assessment and management package.

A soon-to-be-developed urban area adjacent to the golf course will add a new dimension to our monitoring activities. The flexibility of the environmental evaluation model described here lends promise to its use as a prototype for application to practically any size or type of ecosystem.

For continued comparison of change from original grassland conditions, the researchers have available some undisturbed sites on the Colbert Hills property and databanks from the Konza Prairie, a National Science Foundation designated Long-Term Ecological Research (NSF-LTER) site.[9] Both the Konza Prairie and Colbert Hills sites are representative of the native tallgrass prairie in the Flint Hills of eastern Kansas and physically exist within a few miles of each other.

Environmental quality, in its simplest form, is an assessment of essential ecosystem functions. The CTEEM system blends existing technologies to identify, monitor, assess, illustrate, and offer management strategies for any number of environmental quality indicators in an easy-to-understand format. First, essential functions and their measurable indicators are identified and monitored. Data from individual indicators are then graphed on control charts where sustainable ranges have been identified. Next, control chart indices are logically grouped and illustrated in a "spider radar" graph where environmental indicators outside of sustainable limits are easily detected. Finally, managers can access options for remediating degraded indicators.

Steps necessary for implementing the CTEEM system are:

• Identify critical functions of an ecosystem. Each ecosystem can be subdivided into natural functions (reactions, processes, and/or cycles) critical to sustaining that ecosystem. Ecological sciences can provide valuable guidance in selecting the functions most reflective of the ecosystem under study. Primary functions in an ecosystem can be further broken into subsystems. For example, in the grassland/golf turf ecosystem currently under study, soils are assigned critical functions in plant growth, soil tilth, environmental buffering, soil life, and natural cycling functions.[10] Within the natural cycling category, carbon sequestration in soil might be one critical function selected for evaluation because of its impact on so many soil properties.

• Select appropriate indicators to evaluate these functions. Several indicators may be necessary to adequately assess each function. Then again, one indicator may be useful in evaluating several functions. The scientific literature provides a wealthy repository of potential indicators. The great diversity in golf courses and scope of the evaluation can both be accommodated in this step by customizing the indicator selection to local conditions. Care should be taken to identify a list that is informative, measurable, and economically feasible. In keeping with the previous example, one indicator of carbon sequestration might be soil organic matter (SOM) content.

• Measure indicator status. Technology has provided access to rapid and comprehensive analyses for most needs. In some cases, modern or historic databases can provide essential information. Measurement frequency will be indicator dependent. With some, annual or seasonal testing will be sufficient, while others may be automated to sample on shorter intervals. Some measurements may be linked to monitor specific episodes (rainfall events, chemical applications, management changes, etc.). For this example, commercial testing laboratories routinely provide analysis of soil samples for organic matter content.

• Establish control chart indices (Figure 1). Control charts offer an informative method of comparing indicator measurements to ranges that delimit sustainable and degrading conditions.[11] The key to using control charts lies in setting appropriate and acceptable target boundaries that delineate sustainability and degradation. In some cases only minimum or maximum boundaries may be appropriate. Control limits can be established with the assistance of state extension services, literature surveys, management experience, model predictions, consultants, regulations, or other sources. For this example, a minimum SOM content of 1% might be selected as a lower control limit for some soils based on diminished soil tilth or water-holding capacity at lower levels. While high SOM is edaphologically desirable, maintaining organic matter content above 3% may prove economically unfeasible on many soils and so could establish an upper control limit.

• Transform multiple indices into environmental quality evaluation graphs (Figure 2). In this step, indices from any number of quality control charts are normalized onto a "spider radar" graph. This format produces an easy-to-understand visual presentation of environmental quality. A high quality ecosystem exhibits a nearly circular "radar" image with all indicators falling in the sustainable range. When some indicators fall outside the sustainable range, the circular "radar" image becomes skewed. The cause of degradation (i.e., which indicator) and its severity (i.e., amount of skewing) are readily apparent based on irregularity in the diagram's form. Alternatively, a circular form could denote a severely degraded environment if all indicators lie outside the sustainable limits.

Appropriate computerization can render either an episodic event or be animated for a systematic view of environmental quality changes over time. The compliance of an individual index to boundary conditions over time can also be viewed. This flexibility allows users to track the status of either an individual indicator or an array of indicators in response to natural cycles, catastrophic events, or normal managed inputs.

• Select appropriate remedial management for degraded indicators. In the CTEEM system, evaluation graphs summarize which indicators (and hence, which ecosystem functions) lie outside their assigned sustainable limits and are contributing towards the degradation of the ecosystem. The obvious next step is to computerize links from these indicators to a remediation databank or website where appropriate management steps for improving the environment can be suggested. That step is currently in development.

• Monitor indicators over time. Long-term monitoring of essential indicators will illustrate how environmental quality responds to natural disruptive events or management programs.

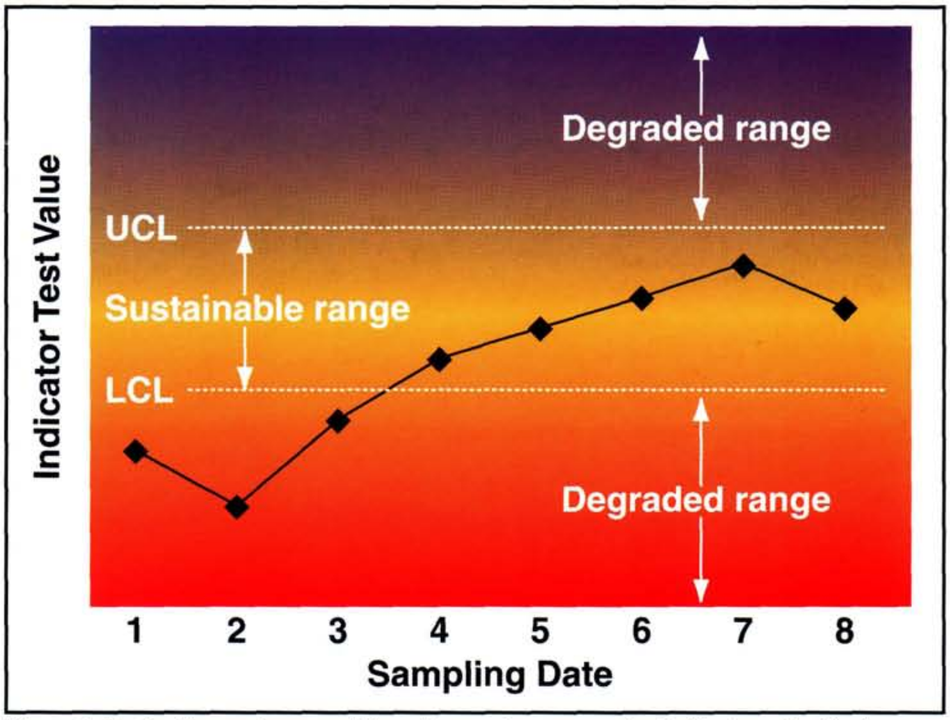

Figure 1. Evaluating environmental quality requires measuring indicators of critical ecological functions over time. These values are modeled onto control charts where test values are plotted on a time line. Superimposed on the control chart are upper (UCL) and lower (LCL) control limits based on known or desired tolerances of degradation. Values between the UCL and LCL would then represent a sustainable condition. Indicators that fall outside the sustainable range would signal a need for targeted remediation. Each indicator used for assessing an ecosystem would be modeled onto a control chart.

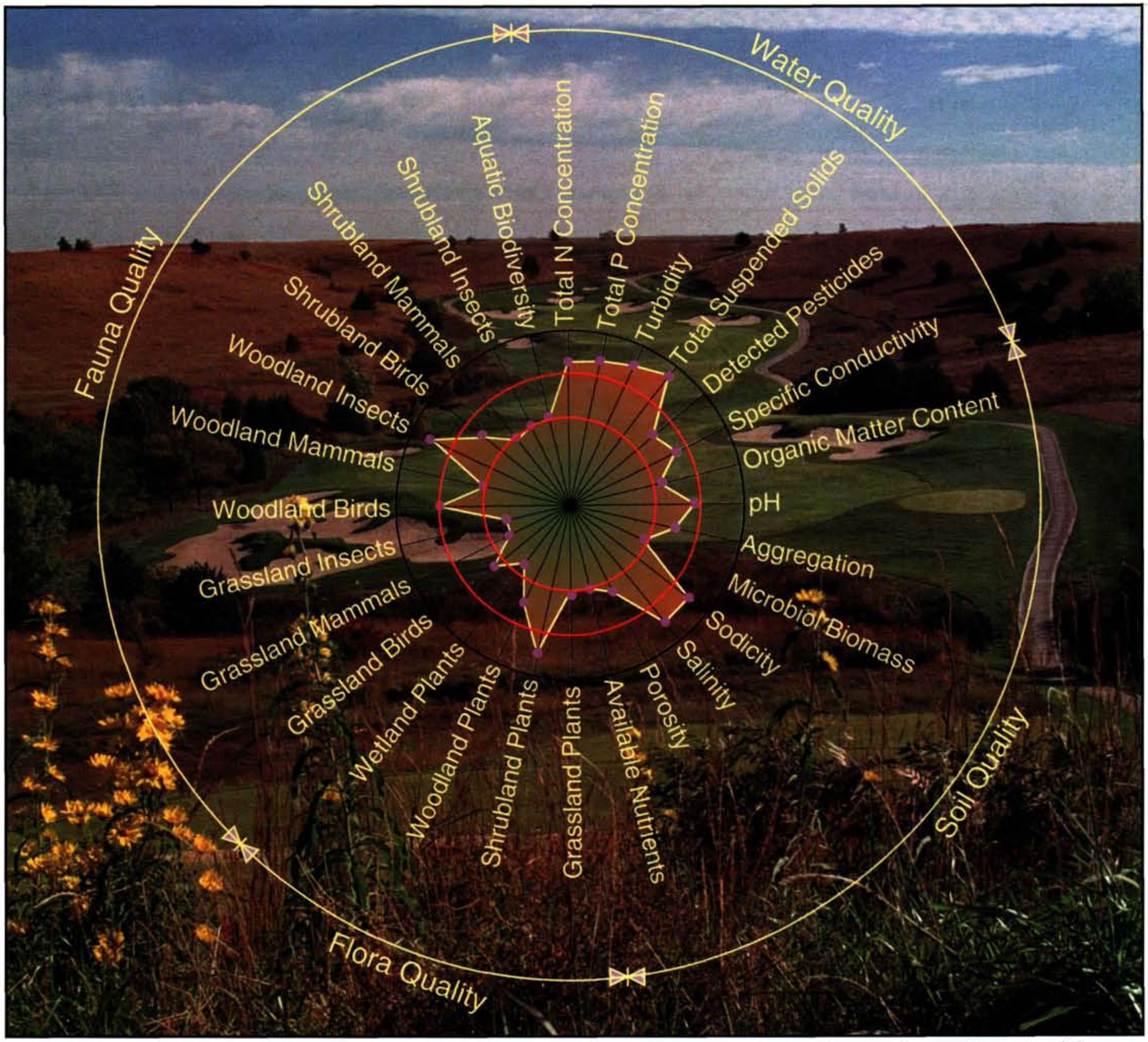

Figure 2. An environmental quality evaluation spider radar graph illustrates how well multiple indices conform to the limits of that indicator's sustainable range (as identified with control charts like those in Figures 2, 3, and 5). Indices (purple dots) that lie within their target range (zone between the red lines) show ecosystem indicators operating in a sustainable mode. Indices lying outside their target range, either too high or too low, represent degradation. Only soil porosity and total nitrogen concentration in water represent actual data from this site; the other indices shown in this example do not represent actual data and are for illustrative purposes only. A high-quality ecosystem would show a nearly perfect radar circle (colored area outlined by purple dots) within the sustainable range. Degraded functions lie outside the sustainable range and skew the radar circle. Outer arcs group indicators into management areas (soil, water, fauna, and flora quality).

These seven steps in the CTEEM system present a conceptual scheme for implementing an environmental quality evaluation and management program. It is currently being applied to a grassland ecosystem where portions have been converted into a golf course, but the principles are applicable to a host of ecosystems on practically any scale. Any phase that harbors some shortages of information, procedures, and/or recommendations exposes future research needs. Currently, all techologies necessary for implementing this program are available from a variety of sources. Maximum utility of the CTEEM system will come with future development of computer capability to mesh input and output information. We believe the process has extended application and can have a significant impact on global environmental evaluation, management, and upgrading.

Application of the CTEEM System to a Golf Course

The golf course industry seeks to be environmentally responsible. The burden of meeting this responsibility often falls on golf course superintendents, individuals highly skilled in turf management but not typically trained as ecological scientists. Superintendents already evaluate agronomic indicators on a regular schedule, so adapting to an environmental monitor

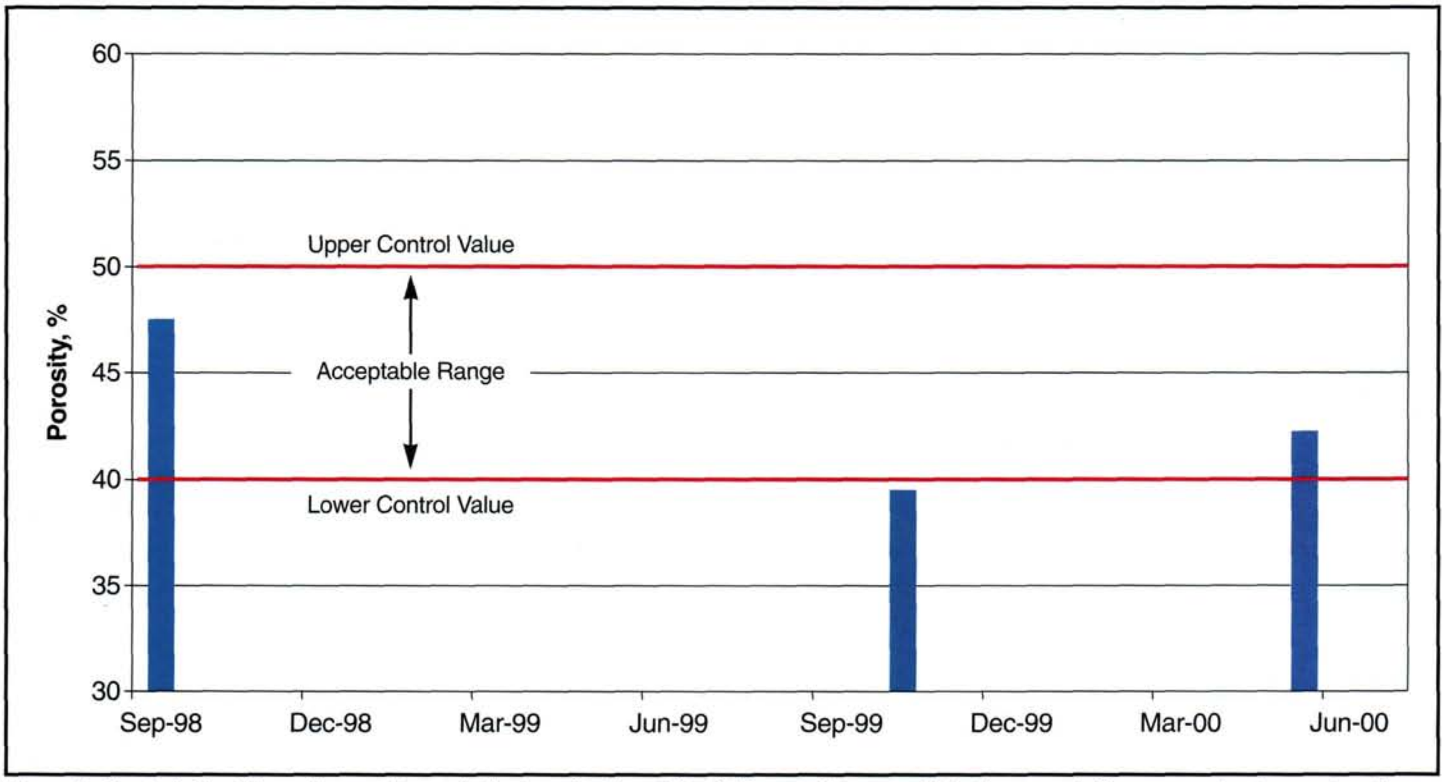

Figure 3. Control chart for soil porosity, an indicator of soil quality. Soil porosity was within the acceptable range prior to construction (Sep-98), but fell below acceptability during construction (Oct-99), causing some sod establishment problems. After one winter of freezing-thawing and wetting-drying, porosity returned to the acceptable range (May-00).

ing program should involve familiar practices. Some may, however, be served by technical education and/or consultation in selecting appropriate evaluation criteria, methods, and target control levels; meeting local compliance requirements; database development; and matching remediation options to environmental indicators. Both the GCSAA and USGA have educational and published resources that can meet that demand. The CTEEM system provides the framework these managers need to make environmental stewardship monitoring just as routine as their current agronomic monitoring. It describes environmental evaluation as a series of steps that are easily customized to individual courses. By adopting an environmental evaluation program, superintendents can identify problem areas, be guided toward remediation, and demonstrate progress toward sustainability.

To illustrate how the CTEEM system is being applied to Colbert Hills Golf Course, we have included examples from the soil quality, water quality, and avian ecosystems work in progress.

Soil Quality Example

Movement of air and water into and throughout the soil body easily qualifies as one indicator of critical soil functions like plant growth, optimum microbial activity, and water cycling, to name a few. Soil porosity, or the non-solid volumetric percentage, is one measure of this redistributive process. Porosity can be calculated from soil bulk density, or volumetric mass, which is an easily measured property.

Bulk density, g cm^{-3} = oven-dry mass, g / sample volume, cm^3

Porosity, % = [1 - (bulk density / particle density*)] × 100

*Particle density for most mineral soils is assumed to be a constant 2.65 g cm^{-3}

The USGA[12] recommends that sand-based golf green rootzones have a porosity between 35 and 55 percent. Finer-textured fairway soils typically have a narrower porosity range in which plant growth is optimized, making a range of 40 to 50 percent porosity our target LCL and UCL for fairway and rough regions. These latter limits correspond to values of 1.59 g cm^{-3} and 1.33 g cm^{-3}, respectively, on the control chart for bulk density (Figure 3). Data show that bulk density was within the sustainable range prior to construction but rose into the degraded range during construction (note that a rise in bulk density causes a fall in porosity). At this stage, this indicator would skew the soil quality segment of the spider radar graph (Figure 2) and alert the superintendent to apply some management strategy, perhaps selecting core aeration based on experience, or accessing an available database or linked website for additional options. Further monitoring would determine the effectiveness of the applied management.

Water Quality Example

Several physical and chemical indicators relate surface-water quality to stream life, biological diversity, and suitability for conversion to human consumption. One indicator monitored in this study was the total nitrogen concentration. Nitrogen occurs in various forms in soil, plant residue, and wildlife excrement. It is commonly applied to turfgrass to stimulate growth. Federal regulations are in the planning stage to establish nutrient criteria in streams that would minimize the adverse effects on humans, livestock, and aquatic life.[13] At this point, we have adopted our lowest detection level (shown as zero on graphs) as the LCL and set the total nitrogen UCL at 3 mg/L for this water quality indicator.[13,14]

Between April and June 1999, surface water leaving Colbert Hills Golf Course exceeded the UCL 6 times (Figure 4). The surface water entering the Colbert Hills site did not exceed the UCL (Figure 4). An increasing index, or one that exceeds the UCL, alerts the superintendent to evaluate management activities that might be a contributory cause. Suggestions linked to excessive nitrogen levels may include fertilizer rate adjustment, change in fertilizer form, timing of application, widening of buffer zones around surface water bodies, etc. Course construction was occurring between April and June 1999, so much of the time the soil surface was bare in preparation for sodding. It is likely that the excessive nitrogen observed in the stream was a product of high erosion rates associated with the unprotected soil surface.[15]

Viewed with other indicators on the composite spider radar graph (Figure 2), total nitrogen in the surface water for this date skews the radar images (i.e., lies outside of the sustainable range) and would need remedial management. Spider radar graphs can also show a time sequence of data for a single indicator (Figure 5). In this case, some total nitrogen levels in stream water fall outside of the control zone and produce some skewing of the radar image over the times indicated. This condition would signal an indicator in need of remedial management, and the cause may be linked to other dated episodes.

Avian and Mammal Ecosystems

The quality of wildlife habitat is being assessed with Habitat Suitability Index (HSI) models.[16] Developed by the U.S. Fish and Wildlife Service and applied to hundreds of species, HSI models quantify relationships between key environmental variables and habitat suitability for a target species. HSI models assign values ranging from zero (totally unsuitable) to 1.0 (provides all needs of the species).

To develop the most meaningful assessment without indexing all species in this complex avian and mammalian ecosystem, the study site was first stratified into vegetative communities. Then, key Great Plains Region species were selected as indicators of each type of site. Suitability of the area for birds will be judged using the meadow lark or field sparrow HSI model in areas that are primarily grassland, the downy woodpecker or black-capped chickadee model for wooded regions, and a brown thrasher or northern bobwhite quail model for shrub-dominated areas. Mammalian habitat assessment will use the HSI model for the eastern cottontail in grasslands, the fox squirrel in wooded areas, and the bobcat in shrub-dominated sites.

Selecting HSI models most appropriate for the geographical region and vegetative composition of the ecosystem being studied will provide the most meaningful assessments. A mix of HSI models can customize assessment to any local interest. For example, if wetland sites were included, HSI models for the mink or muskrat could be used for mammals and the bullfrog or newt models for amphibians.

Generally, an HSI value less than 0.8 reflects environmental conditions (food sources, nesting sites, brood habitat, escape cover, etc.) that will not sustain wildlife populations. Therefore, HSI values of 0.8 and 1.0 constitute the lower and upper control values for this study.

Conclusions

Managing the environmental quality of an ecosystem requires consideration of a spectrum of environmental indicators. An evaluation program using a customized set of indicators applied to control charts can establish whether environmental processes are operating within an acceptable range. Presenting several indicators on normalized spider radar graphs allows for a simplified, composite visualization of environmental quality. Appropriate linking of these evaluation charts to remedial management databases can assist golf course superintendents and managers of other lands of any scale, toward establishing and maintaining a sustainable ecosystem. These studies on a newly constructed golf course are guiding researchers in the development of an environmental evaluation tool with application to a wide range of ecosystems.

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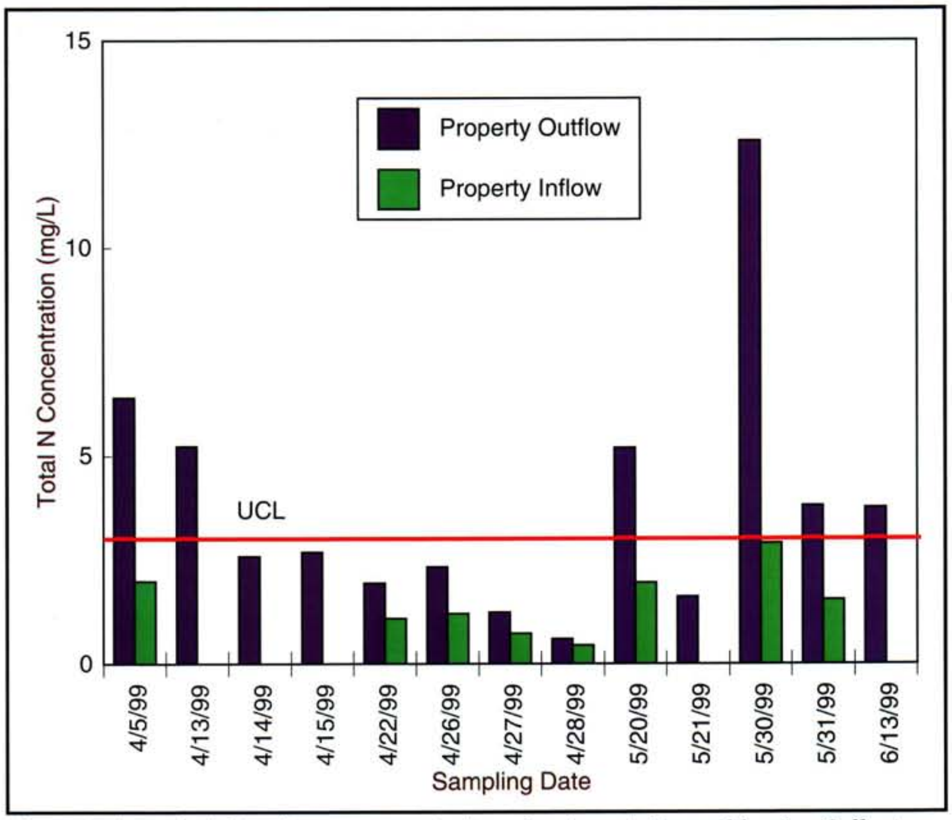

Figure 4. A graph of the nitrogen concentration of water entering and leaving Colbert Hills Golf Course. Water entering the property never exceeded the upper control value, but water leaving the property did exceed the UCL six times, which alerted the superintendent to evaluate management activities that might cause the problem.

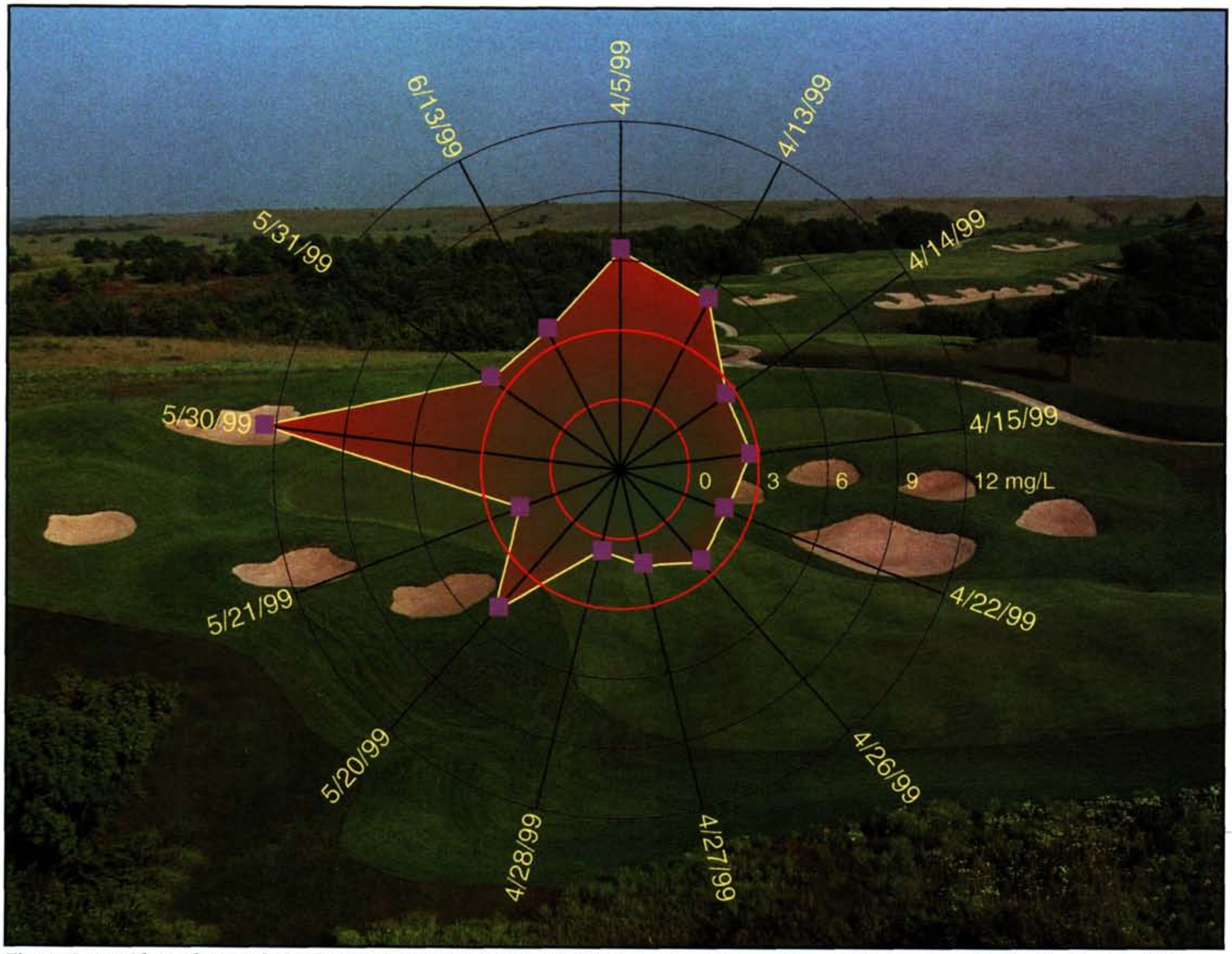

Figure 5. A spider radar graph displaying daily average of total nitrogen concentrations in runoff water on episodic days in April, May, and June, 1999, where Little Kitten Creek exits Colbert Hills Golf Course. The upper control limit (larger red circle) is set at 3 mg L^{-1} and the lower control limit (smaller red circle) is set at 0 mg L^{-1}.

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