Remote Water Quality Sensing:

A Tool for Golf Course Irrigation Best Management Practice Validation

A critical component of operating golf courses is water resource management for both ground and surface water sources. By evaluating the local site characteristics, effective water management plans can be crafted for a facility's on- and off-course footprint. While the design and construction of a course is the most effective time to introduce best management practices (BMPs) into the hydrological landscape, there are simplistic solutions that can be implemented to existing course designs. Many facilities continually strive to incorporate BMPs into daily operations, and with the help of digital precision water quality tools, can validate these practices. This can allow for facilities to effectively manage resources for both economic savings and environmental preservation. This effective implementation of BMPs can provide economic savings, creative resource management and solidify facilities as stewards of the environment.

Standard Best Management Practices

The United States Golf Association (USGA) and the Golf Course Superintendents Association of America (GCSAA) have extensive documentation and case studies on BMPs for effective water quality management. Courses can implement many practices throughout all areas of their operation to promote resource management and pollution prevention strategies. A few of the most common across courses include:

- Assessing hydrology and identifying surrounding water tributaries to ensure proper water flow through course design
- Conducting a soil analysis to assess soil fertility to guide precision fertilizer applications to reduce nutrient leaching
- Using targeted chemical applications for weed, disease and insect pest control, while selecting less toxic options to maintain ecosystem balance
- Maintaining, calibrating and sanitizing spray equipment to prevent over-application or contamination of fertilizers and pesticides
- Capturing washed compounds (sprays, oils, grease, etc.) and safe chemical storage to reduce the risk of leaching or off-site movement of chemicals
- Installing natural detention basins or bioswales to capture sediments, remove nutrients and slow water flow to surrounding waterways
- Establishing native areas to remove excess nutrients from runoff and promote local aesthetic for player experience
- Scheduling irrigation and incorporating moisture sensors to efficiently use water around the course
- Conducting irrigation system audits to obtain system precipitation rates for evapotranspiration-based irrigation and maintaining proper irrigation distribution uniformity, both of which reduce under and overwatering of turf

General Water Quality Parameters

The two areas for water resource management include irrigation water and surface water. Some courses irrigate using well or groundwater, while others will use surface water from ponds to be pumped back to the course. Irrigation water should have macro- and micronutrients acceptable for turfgrass tolerance, which requires strategic sampling or real-time monitoring. For example, grasses grown on golf course putting greens are often intolerant of sodium due to the combination of short mowing and frequent irrigation, which can cause stress. General guidelines for irrigation nutrient concentrations can be seen in the table below.

Table 1: Concentration (mg/L) of macronutrients for standard irrigation water.

COMPOUND	LOW	NORMAL	HIGH	CRITICAL
Nitrate (NO_3^-)	< 5	5-50	50-100	> 100
Ammonium (NH_4^-)	< 2	2-75	75-100	> 100
Phosphorus (P)	< 0.01	0.1-0.4	0.4-0.8	> 0.8
Potassium (K)	< 5	5-20	20-30	> 30
Calcium (Ca)	< 20	20-60	60-80	> 80
Magnesium (Mg)	< 10	10-25	25-35	> 35
Sulfur (S)	< 10	10-30	30-60	> 60
METALS	ACCEPTABLE RANGE		MAXIMUM CONCENTRATION	
Iron (Fe)	2.4-4.0		5.0	
Manganese (Mn)	< 0.2		0.2	
Copper (Cu)	< 0.2		0.2	
Molybdenum (Mo)	< 0.1		0.1	
Zinc (Zn)	< 0.3		2.0	
Boron (B)	< 2.0		2.0	

Surface water runoff has different water quality guidelines due to the nature of the water. Irrigation water is seen to be captured on-site by plants and soil infiltration, while runoff water can impact surrounding and downstream ecosystems. The most impactful knowledge for facility personnel is to understand the local watershed and potential sources for nutrient input. For instance, a golf course isolated in a rural area may be on a waterway that only has natural compounds from the landscape, thus making the course a potential major contributor to the watershed. For courses in subdivisions and adjacent to tributaries, runoff from residential homes can be a source of high-concentration nutrients from lawn fertilizers, making course BMPs even more impactful to balance nutrient runoff. In either case, managing the water drainage from courses to waterways is important to preserve downstream ecosystems and is a priority for many golf course BMPs.

Many of the total maximum daily loads (TMDLs) for nutrients are established on a site-by-site basis by the Department of Environmental Quality based on the input source for the facility. This includes nitrogen species, phosphorus, sulfate, chloride and total dissolved solids. The Louisiana Department of Environmental Quality (LDEQ) provides Regulations (LAC Title 33) as a guideline for facilities to understand sources and concentrations of compounds. For example, a major contributor of nutrients, like a wastewater treatment facility, might have a daily TMDL and a monthly average TMDL to ensure proper treatment before discharge. For golf courses, if TMDLs are not established, it is important to monitor sources of discharge to prevent excess nutrients from entering surrounding waterways. The Environmental Protection Agency has listed acceptable levels of nitrates in drinking water to be 10 mg/L, but in the case of environmental systems, any excess nitrogen or phosphorus can lead to algal blooms. It is best to monitor discharge areas, maintain a stable ecosystem and quantify nutrient concentration to avoid excess concentrations. Some water quality parameters, including dissolved oxygen, temperature and turbidity, have estimated ranges for discharge water seen in Table 2. These can be used to help indicate if excess nutrients are present. In the case of low dissolved oxygen, this could indicate that microbes are removing oxygen from the water to process excess nutrients in the system. This could lead to hypoxic conditions for aquatic life and algal blooms. Many of these parameters are easily tested using handheld or remote sensors to best validate current practice.

Drainage from courses into surrounding waterways is a common practice and a potential area for water resource management. Photo by M.P. Hayes

Table 2: Standard acceptable ranges for water quality parameters.

PARAMETER	TYPICAL ACCEPTABLE RANGE
Turbidity	25-50 NTU
Temperature	29.4 C-35.0 C for freshwater
Dissolved Oxygen	4-5 mg/L
pH	6-9

Technology Adoption

Water Quality Sensors

For facilities to have more accessibility to real-time data, adopting technology like handheld or deployable water quality sensors can be a practical and economic solution to monitoring runoff and validating BMPs. There are many variations of water quality sensors on the market, but the key to finding the one that fits your facility is to determine the usage frequency and parameters of interest. This type of technology is often overlooked due to the technical nature of calibration and software, but companies make these processes user-friendly with video series for maintenance, calibration and troubleshooting. For individual parameters like conductivity, pH or dissolved oxygen, it may be more feasible to buy a multiparameter handheld, which will allow personnel the ability to take single-point samples and log the data manually for daily measurements. This would be a great option for introductory measurements or determining water quality at a single point for a few days throughout the year. This could be used to ensure irrigation salinity is in the correct range with conductivity readings, or test for low dissolved oxygen around ponds to predict blooms.

Another option is deployable long-term sensors sometimes known as sondes, which can provide continuous data in intervals as frequent as 15 minutes. These sondes are useful in situations when courses want to actively monitor water discharge or pumping areas to better validate practices or quantify pulses of nutrients. In many cases, a deployable sonde can measure between three and seven parameters, which allow for a range of water quality variables to be tested. At a discharge location, a course could put a sonde to actively measure nutrients in the form of nitrate and ammonium, pH, dissolved oxygen, temperature, conductivity and chlorophyll for real-time data on ecosystem imbalance. These sondes will be higher priced than the handheld units but can provide advanced data sets and be paired as a network for comprehensive water management.

Water quality sondes have the capability to be submerged for long periods of time and monitor data in various time intervals using optical sensors. Photo by M.P. Hayes

Uncrewed Surface Vessels

Water quality sensors can be paired with other technologies for digital precision water management around golf courses. Uncrewed surface vessels (USV) are the terrestrial version of drones and can be used in tandem with water quality sensors to map ponds or waterways to better understand impairments. An example of this is the BlueBoat, which can be outfitted with a multiparameter sonde to measure various water metrics, including dissolved oxygen, ammonium, nitrate, pH, turbidity and temperature. The vessel has a handheld GPS for data collection, a ping sonar for depth readings and a long-range antenna for full pond surveys. USVs can be set for a manual mission with a person controlling vessel or a recurring automated mission. The software allows for easy mission design by drawing the USV map into the program. The boat will then provide real-time surface water scans that can

Advancements in digital precision water sensing provides unique opportunities like allowing uncrewed surface vessels to conduct validation of course BMPs. Photo by M.P. Hayes be translated to contour plots using GPS data for a more comprehensive understanding of water systems. The vessels are lightweight and easily operated for a unique approach to environmental sustainability. Courses that implement this advanced digital precision water technology will be at the forefront of BMP validation and water resource management.

Potential Uses for Digital Precision Technology

1. **Budgeting nitrogen for reclaimed irrigation water:** For courses that use pond or surface water for irrigation, water quality sensors can be used to establish total concentration of nitrogen species and determine if nitrogen in the water can offset fertilizer cost. In sources surrounded by residential homes, the input from lawn fertilizer can add high values of nitrogen to pond water.

   For example, a pond containing 5 mg/L nitrate-N and 2 mg/L ammonium-N delivers approximately 0.036 pound of N per 1,000 square feet per acre-inch applied, or roughly 1.6 pounds of N per acre per acre-inch applied.

2. **Monitoring salinity from well or city water:** When water quality for irrigation is an issue from the ground or city water supply, handheld or deployable sondes can be used to test conductivity of water. This measurement can be calculated into salinity to ensure water supply will not stress turfgrasses around the course.

3. **Tracing algal blooms in ponds:** Coupling water quality sensors with USV, courses can use real-time parameters to determine chlorophyll levels that may lead to algal blooms. During spring and summer, these blooms can cause issues with course aesthetics, drainage, smells and water quality impairments. Algal blooms can best be managed with water circulation, nutrient reduction and aeration.

4. **Identifying areas for BMPs:** USVs can trace ponds to determine areas of high concentration nutrients or low dissolved oxygen. These areas can be due to course drainage (i.e. landscape or impervious surfaces), total volume or runoff source. By mapping various water bodies around the course, these areas can be identified for natural-based solutions, like planting native grasses or adding bioswales to reduce nutrients. This can also be a tool to alter irrigation scheduling or change fertilizer spray patterns.

Areas with sloped banks and exposed soil can increase the nutrient or sediment concentration in ponds around the course. Photo by M.P. Hayes

5. **Validating BMPs:** When courses have effective BMPs, digital precision water technology can be used to actively track the progress and benefits of implement projects to justify savings and broaden the knowledge for other golf course professionals. In many cases, continuous data from deployed sensors or pond mapping can be promoted as success stories for BMPs to advocate for facilities making positive contributions to the surrounding environment and becoming stewards of local watersheds.

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