

Best Management Practices for New York State Golf Courses



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Authors:

Robert E. Portmess PhD, Department of Horticulture, Cornell University

Jennifer A. Grant PhD, New York State Integrated Pest Management Program, Cornell University

Barry Jordan, RLA, Golf Course Architect

Anthony M. Petrovic PhD, Department of Horticulture, Cornell University

Frank S. Rossi PhD, Department of Horticulture, Cornell University

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FOREWORD

The game of golf provides boundless recreational opportunities and health benefits to millions of golfers worldwide. As both a golfer and a golf course designer, I believe that golf courses should exist in harmony with the natural setting. Therefore, respecting the environment is at the core of everything I do.

When I am involved in a golf course project, such as the construction of GlenArbor Golf Club in Bedford Hills, I require that everyone involved share this respect. At my company, we have particularly focused on one of earth's most precious resources – water. Protecting water quality and conserving water are not only a fundamental responsibility for our industry, but also translates into real cost savings for golf course operations. For these reasons, I am proud to endorse the *Best Management Practices for New York State Golf Courses*. The New York State golf course superintendents associations, researchers at Cornell, and the state and national organizations that have provided additional support should be commended for this effort and making this information so readily accessible to anyone who cares about conserving our natural resources.

- *Gary Player, January 2014*

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This project would also not have been possible without the financial support of a number of organizations in New York State. These partners and supporters include members of the following organizations:

Adirondack Golf Course Superintendents Association
Central New York Golf Course Superintendents Association
Finger Lakes Association of Golf Course Superintendents
Golf Course Superintendents Association of America
Environmental Institute for Golf
Hudson Valley Golf Course Superintendents Association
Long Island Golf Course Superintendents Association
Metropolitan Golf Association
Metropolitan Golf Course Superintendents Association
Metropolitan PGA
New York State Turfgrass Association
Northeastern Golf Course Superintendents Association
Turfgrass Environmental Stewardship Fund
Western New York Golf Course Superintendents Association

Last, this project was reviewed in the draft and draft final stages by members of the partner organizations, members of the golf industry, as well as the New York State Department of Environmental Conservation. We thank the reviewers for the time and effort spent to improve the final products of these efforts.

Acronyms

A	acre
AAPFCO	Association of American Plant Food Control Officials
ABW	annual bluegrass weevils
AI	active ingredient
BMP	best management practice
BOD	biological oxygen demand
BPD	backflow prevention devices
CA	calcium
CaCO ₃	calcium carbonate
CEC	cation exchange capacity
CNMP	Comprehensive Nutrient Management Plan
CO ₃	carbonate
CU	coefficient of uniformity
CWA	Clean Water Act
DAP	diammonium phosphate
DCD	dicyandiamide
DI	deep and infrequent irrigation
DU	distribution uniformity
DULQ	distribution uniformity of the lowest quartile
EC	electrical conductivity
ECe	salt tolerance of turfgrass species
ECL	Environmental Conservation Law
ECw	electrical conductivity of water
EIQ	Environmental Impact Quotient
EPA	Environmental Protection Agency
ET	evapotranspiration
FUEIQ	field use EIQ rating
g/L	grams per liter
GCSA	Golf Course Superintendents of America
GIS	geographic information system
GPS	global positioning system
GUS	groundwater ubiquity score
HCO ₃	bicarbonate
IBDU	isobutylidene diurea
IPM	integrated pest management
IRPeQ	pesticide risk indicator for Quebec
K	potassium
K ₂ O	potassium oxide
K _c	crop coefficient
K _{oc}	soil adsorption
lbs/A	pounds per acre

LF	light and frequent irrigation
LR	leaching requirement
MAP	monoammonium phosphate
MCL	maximum contaminant levels
Mg	magnesium
mg/L	milligrams per liter
MOA	Memorandum of Agreement
mPa	millipascal
MSDS	Material Safety Data Sheets
MU	methylene urea
N	nitrogen
Na	sodium
NBPT	n-butylthiophosphoric triamide
NCDC	National Climate Data Center
NFPA	National Fire Protection Association
NH ₄	ammonium
NH ₃	ammonia
NO ₂ ⁻	nitrite
NO ₃ ⁻	nitrate
NRCC	Northeast Regional Climate Center
NYSDEC	New York State Department of Environmental Conservation
NYS	New York State
NYSDOH	NYS Department of Health
NYS DOT	NYS Department of Transportation
OEHD	Occupational and Environmental Health Department
P	phosphorus
P ₂ O ₅	phosphate
PAWC	plant-available water capacity
Pb	lead
PET	potential evapotranspiration
PIMS	Product Ingredient Manufacturer System
PMEP	Pesticide Management Education Program
PPD	Pesticide Properties Database
PPE	personal protective equipment
ppm	parts per million
PSEP	Pesticide Safety Education Program
RCRA	Resource Conservation Recovery Act
RSC	residual sodium carbonate
S	sulfur
SAR	sodium adsorption ratio
SC	scheduling coefficient
SDS	Safety Data Sheet
SDWA	Safe Drinking Water Act

SEQR	State Environmental Quality Review
SPDES	State Pollutant Discharge Elimination System
SSP	single superphosphate
SWPPP	Stormwater Pollution Prevention Plan
TDS	total dissolved salts
TMDL	Total Maximum Daily Load
TN	total nitrogen
TP	total phosphorus
TSS	total suspended solids
UAN	urea-ammonium nitrate
UF	urea-formaldehyde
USDA	United States Department of Agriculture
USGS	United States Geological Survey
VOC	volatile organic compound
WIN	water insoluble nitrogen
WIN PST	Windows Pesticides Screening Tool
WSN	water soluble nitrogen
Zn	zinc

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1 INTRODUCTION

Golf courses and their supporting industries benefit New York State residents directly and indirectly:

- **Environmental benefits.** Golf courses provide open space, and their well-managed turfgrass protect water and other natural resources.
- **Economic benefits.** The golf industry contributes more than \$3 billion and 50,000 jobs annually to the state's economy. Golf fundraisers also contribute approximately \$100 million annually to charities across the state, funding countless diverse and worthy causes.
- **Recreational and health benefits.** Golf courses provide excellent recreational and health benefits for golfers of all ages. A Swedish study found golfers who walk when playing live five years longer than non-golfers.

As the stewards of golf courses in NY, superintendents are dedicated to protecting New York's natural resources and embrace the responsibility to maintain these facilities in harmony with the natural environment. The golf industry has led the effort in establishing Best Management Practices (BMPs) for golf courses in New York State. These BMPs will help those in the golf industry work in concert with policymakers and regulators in a shared commitment to water quality protection.

Authors from Cornell University have integrated the latest research on BMPs specifically for New York's climate and environment; however, neighboring New Jersey and Connecticut will benefit as well. The research-based, voluntary BMP guidelines are designed to protect and preserve New York's water resources that enhance open space using current advances in golf turf management.

This effort to provide extensive guidance for environmental stewardship is being conducted in the best traditions of golf, as defined by golf's inherent values: honesty, integrity, and fair play (including upholding the rules when no one is watching). These are core values of golf turf professionals and serve as the basis for this innovative environmental effort.

What are BMPs?

BMPs are methods or techniques found to be the most effective and practical means of achieving an objective, such as preventing water pollution or reducing pesticide usage. Many BMPs reduce stormwater volume, peak flow, and nonpoint source pollution through evapotranspiration, infiltration, detention, filtering, as well as biological and chemical actions. This new guidance provides information for using BMPs to prevent or minimize the effects of golf course management on surface and groundwater to insure and enhance public health and environmental quality. Pollution prevention is easier, less expensive, and more effective than

addressing problems “downstream”. Essentially, BMPs are a sustainable approach to providing environmental, economic and social benefits to golf and society.

Why are BMPs important to the golf industry?

Golf courses rely on a healthy environment that includes water and wildlife. It is of paramount importance to enhance and protect water quality. A significant body of research exists that indicates successful implementation of BMPs virtually eliminates the golf course risk to water quality. In fact, several studies have shown that implementing BMPs enhances water quality on its journey on and through the golf course property.

Additional incentives for golf courses in New York State to implement BMPs include the following:

- potential for more efficiently allocating resources by identifying management zones
- cost savings associated with applying less fertilizer and pesticide
- improved community relations
- recognition by club members and the community at large as environmental stewards

Through a cooperative approach between the golf industry and friends and neighbors outside the industry, practices have been developed that benefit all parties.

When should you be aware of BMPs?

BMPs provide a science-based approach to protecting water quality from potential risks. Whether managing an existing course, renovating an existing course or constructing a new course, BMPs can be designed, installed and implemented. For example, golf course renovation and design projects can incorporate landscape BMPs such as vegetated swales, properly sited maintenance and storage facilities and efficiently designed irrigation systems. Specifically, during a renovation or grow-in period, BMPs protect water quality while the site is most vulnerable to soil erosion. For existing courses, the day-to-day management decisions on when, how much and how to apply nutrients provides many additional opportunities to apply BMPs that preserves and protects water quality.

How to align golf course management with BMPs

Successful implementation of BMPs begins with understanding a few basic environmental and water quality concepts associated with land management and water (Chapters 2 and 3). Using these concepts, a thorough site-specific understanding of vulnerable areas can focus BMP implementation in every stage of golf course design, construction, renovation, and maintenance (Chapter 4).

BMPs for irrigation (Chapter 5) and nutrient management (Chapter 6) and the role of turf density (Chapter 7), integrated pest management (IPM) and pesticide management (Chapters 8 and 9) will prevent runoff, leaching, and drift. Golf course managers must understand how

much water is needed and when to apply it; how to select fertilizers and pesticides; and when, how, and where these compounds should and should not be applied. In addition, IPM principles provide alternatives to applying pesticides, as well as justification for using pesticides when necessary. Finally, maintenance facilities should also be properly managed in order to prevent point source release of chemicals that can reach ground or surface waters (Chapter 10).

2 ENVIRONMENTAL CONCEPTS

Understanding the following environmental concepts provide the basis for understanding the role of BMPs in water quality protection:

- concepts related to climate and microclimates
- concepts related to water, such as the hydrologic cycle and watersheds
- concepts related to soils, such as soil texture and soil moisture
- concepts related to geology, such as karst topography

Water, soils, and geology all play a role in environmental fate and transport mechanisms (such as runoff and leaching) that can contribute to water quality impacts. BMPs act on these fate and transport mechanisms to prevent water quality contamination.

2.1 Climate

Projections of a changing climate suggest that rainfall events will become less frequent, but more intense. As a result, a greater volume of the precipitation is expected to run off instead of infiltrating into the soil and replenishing groundwater. Consequently, the need for supplemental irrigation may increase, and superintendents will need to take greater care in the applying fertilizer and pesticides to reduce the risk of runoff. Structural BMPs are also valuable in managing increased runoff. For more information on available climate data for New York, see the Northeast Regional Climate Center (<http://www.nrcc.cornell.edu/>).

Golf courses are diverse landscapes with a variety of microclimates that require site-specific management to maintain uniform playing conditions. Microclimates are created by landforms as well as by vegetation and water bodies. In each case, the golf course superintendent must adapt management programs that address nutrient and pest management needs while understanding the effect these microclimates might have on the fate of applied materials.

2.2 Hydrologic Cycle

The hydrologic cycle is the cyclic movement of water in its various phases through the atmosphere, to the Earth, over and through the land, to the ocean, and back to the atmosphere (Figure 2-1). The sun is the powerhouse for the hydrologic cycle, providing the energy for phase changes of water (evaporation and condensation) and for the storage and release of latent heat. Because water is an efficient solvent, all water-soluble elements follow this cycle at least partially. Thus, the hydrologic cycle is the integrating process for the fluxes of water, energy, and the chemical elements throughout the environment.

Water enters the hydrologic system as precipitation, primarily in the form of rainfall or snowfall. It is then delivered to surface waters from runoff or infiltrates into the subsurface. Water can leave the system via stream flow or runoff, evaporation from open bodies of water, or evapotranspiration (evaporation from soil surfaces and transpiration from the soil by plants).

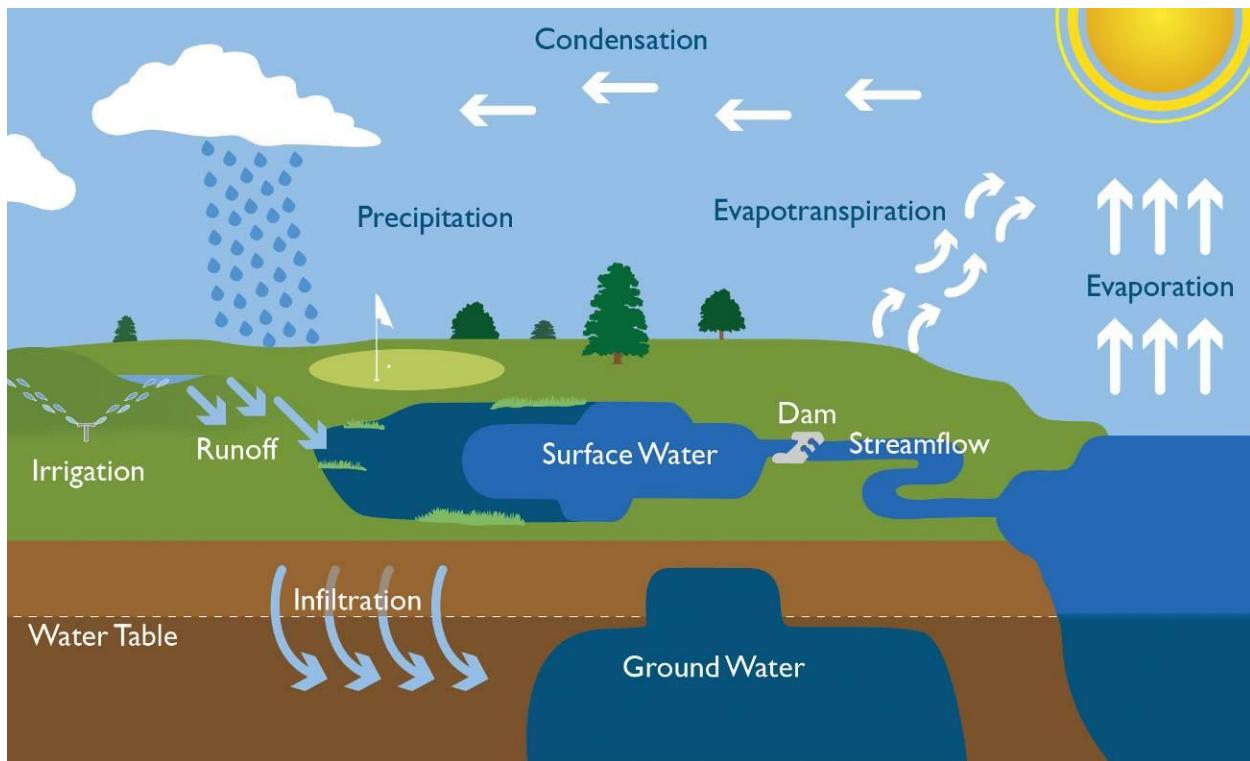


Figure 2-1. The hydrologic cycle.

2.2.1 Groundwater Recharge

Water moves through the surface of the earth, eventually through the soil horizons to natural storage areas below the ground. Depending on subsurface rock formations and overall permeability, the filling of these storage areas or “recharge” can collect water from a few hundred square feet to a few square miles. Groundwater often provides the source of water for perennial stream flow at base flow conditions when there is no precipitation. It is critical to understand the basics of groundwater recharge, both in size and scope, to mitigate potential contamination.

2.2.2 Infiltration and Runoff

The amount of water that infiltrates into the ground from the total run off depends on a number of variables, including the intensity of precipitation or irrigation, soil infiltration capacity, site characteristics, antecedent soil moisture, and season. Water that infiltrates into the soil either is stored within the soil profile or percolates downward toward groundwater, depending on the soil moisture conditions and soil structure. This soil water is then available for evapotranspiration. If the moisture-holding capacity of the soil is exceeded, the excess water percolates downward through the soil profile to groundwater. If the soils are at saturation, any additional precipitation does not infiltrate into the soil and becomes surface runoff instead. It is in this runoff that more soluble compounds applied to turf have the greatest potential to move off site.

Site characteristics including land use, land cover, soils, and topography also influence the amount of infiltration versus amount of runoff. Turf, forests, fields, and other vegetated areas slow down the flow of runoff, filter out sediments, and trap pollutants or break them down biologically. Conversely, hard impermeable surfaces such as buildings, roads, parking areas, and exposed bedrock prevent water from infiltrating into the ground. These hard impermeable surfaces, as well as bare soils, offer little resistance to reduce the velocity of runoff. Similarly, compacted soils and saturated soils retard the infiltration of water and therefore promote runoff. Lastly, steep slopes can increase the rate and amount of runoff.

The amount of runoff versus infiltration at any location also varies seasonally. During the winter, soils in New York are likely to be frozen and impermeable to water. Snowmelt, rain, and low evapotranspiration rates in the spring generate wet soil conditions and downward movement of water to groundwater. The potential for runoff is high because the near-saturated or partially frozen soils have low water infiltration capacities. During the summer, high rates of evaporation and plant water uptake may reduce soil water storage, leaving none to percolate downward. Summer rains only partially recharge the soil profile, and the soil's moisture holding capacity is typically not exceeded. Except for high-intensity thunderstorms, runoff and erosion potentials are generally low during the summer. In the late fall, evapotranspiration rates decrease, and groundwater recharge occurs when the moisture-holding capacity of the soil is exceeded. Runoff and erosion potentials also increase during this period. However, in New York, runoff from turf most often occurs from wet soils and not from high rainfall intensity.

2.3 Watersheds

A watershed is generally defined as an area of land that drains into a body of water, such as a river, lake, estuary, reservoir, sea, or ocean. Thus, all golf courses are in some watershed. A watershed includes the network of rivers, streams, and lakes that convey the water, as well as the land surfaces from which water runs off. Watershed boundaries follow the highest ridgeline around the stream channels and meet at the bottom or lowest point of the land where water flows out of the watershed. The boundary between watersheds is defined as the topographic dividing line from which water flows in two different directions.

Identifying and defining watersheds depends on the scale at which the landscape is examined. A watershed may be small and represent a single tributary within a larger system (such as a subwatershed), or be large and cover thousands of miles and cross numerous state boundaries, such as the Chesapeake Bay watershed. New York State is divided into 17 watersheds (Figure 2-2).



Figure 2-2. Watersheds in New York State.

At a larger scale, the U.S. Geological Survey (USGS) has divided and subdivided the United States into units classified into four levels: regions, subregions, accounting units, and cataloging units. A fifth field of classification (watershed) and sixth field (sub-watershed) are currently under development by USGS. The hydrologic units are arranged or nested within each other, from the smallest (cataloging units) to the largest (regions). Note that watersheds cut across typical regulatory boundaries such as counties and states, which can complicate regulation.

The first level of classification divides the United States into 21 major regions. Regions contain either the drainage area of a major river, such as the Missouri region, or the combined drainage areas of a series of rivers, such as the Texas-Gulf region, which includes a number of rivers draining into the Gulf of Mexico. New York State is situated within the boundaries of three regions: Ohio, Mid-Atlantic, and Great Lakes.

For more information on watersheds, see:

- NY Department of Environmental Conservation (NYSDEC) web site on New York watersheds (<http://www.DEC.ny.gov/lands/60135.html>)
- USGS watershed classification (<http://water.usgs.gov/GIS/huc.html>)

USGS Hydrologic Units Example

Cataloging Unit: French River

Accounting Unit: Allegheny

Subregion: Allegheny River Basin

Region: Ohio

- U.S. Environmental Protection Agency (EPA) Surf Your Watershed (<http://cfpub.epa.gov/surf/locate/index.cfm>)

2.4 Water Conservation

The increasing concentration of the US populations in urban and suburban areas is leading to concentrated demand for water resources. This urbanization has begun to challenge the supply of affordable and plentiful fresh (potable) water for irrigation in New York State. Water suppliers in most of the northeastern US must double the supply capacity to meet demand in the summer, resulting in high infrastructure costs. Therefore, economic, social, environmental, and political pressures dictate that water is used efficiently and conserved on New York's golf courses.

Golf course superintendents can maintain a landscape optimal for play, while conserving water, through effective course design and management. For example, reducing managed turf areas reduces water needs, maximizes rooting in areas that are irrigated, and improves the use of the water applied. In addition, a well designed, properly maintained, and wisely used irrigation system ensures the uniform application of water and minimizes runoff. Many of the BMPs discussed in this manual result in more efficient water usage, such as improving the efficiency of irrigation systems. In addition, superintendents can reduce irrigation requirements by a number of means, such as minimizing maintained areas, maximizing rooting potential, reducing water lost through evapotranspiration, and improving soil water storage where possible on sandy sites.

For general information on water conservation on golf courses, see:

- "Water Conservation on Golf Courses" United States Golf Association (USGA), <http://www.usga.org/Content.aspx?id=25918>
- "Water Conservation" Golf Course Superintendents Association of America (GCSAA), http://www.gcsaa.org/_common/templates/GcsaaTwoColumnLayout.aspx?id=1783&LangType=1033

For specific water conservation measures for golf courses, see:

- Fertilizing for Water Conservation (Cornell research), published in *Golf Course Management*, <http://www2.gcsaa.org/gcm/2000/dec00/pdfs/12fert.pdf>

2.5 Soils

Soil is the growing medium for turf on golf courses. Golf course superintendents must understand the behavior and function of water in the soil, as it assists with determining the potential off-site movement of fertilizers and pesticides.

Water can infiltrate into the soil and then can be held in pores or adhere to soil particles. The infiltration and water holding capacity of a soil involves different forms of energy. Three forces determine the water storage capacity of soil:

- gravitational potential, which draws water down and through the soil profile.
- matrix potential, which is defined by the adsorption of water to the soil particle surfaces. Smaller soil particles, like clay or silt, as well as organic matter, have a greater total surface area than a coarser material such as sand.
- osmotic potential, which is the attraction of water to solutes. The plant root system uses osmotic potential to draw water from the soil across the root membrane.

Downward movement of water through large soil pores or when soil is fully saturated is driven by gravity, hence the term gravitational water (Figure 2-3). When the soil is saturated, some of this water will become groundwater recharge or can enter drainage tiles, if present. The amount of water that remains after gravity has exerted its influence is referred to as the "field capacity" of the soil.

The water content of the soil determines whether plants thrive or wilt. Evapotranspiration from the turf surface draws water from the soil. If this process continues unabated and no irrigation or rainfall occurs, the soil will dry to a point known as the wilting point. The difference between soil moisture content at field capacity and the point at which plants wilt due to lack of moisture is referred to as "plant available water". Often little plant-available water is present in the soil when it reaches the wilting point, which is the point at which the soil holds the water with greater energy force than the plant can exert to extract it.

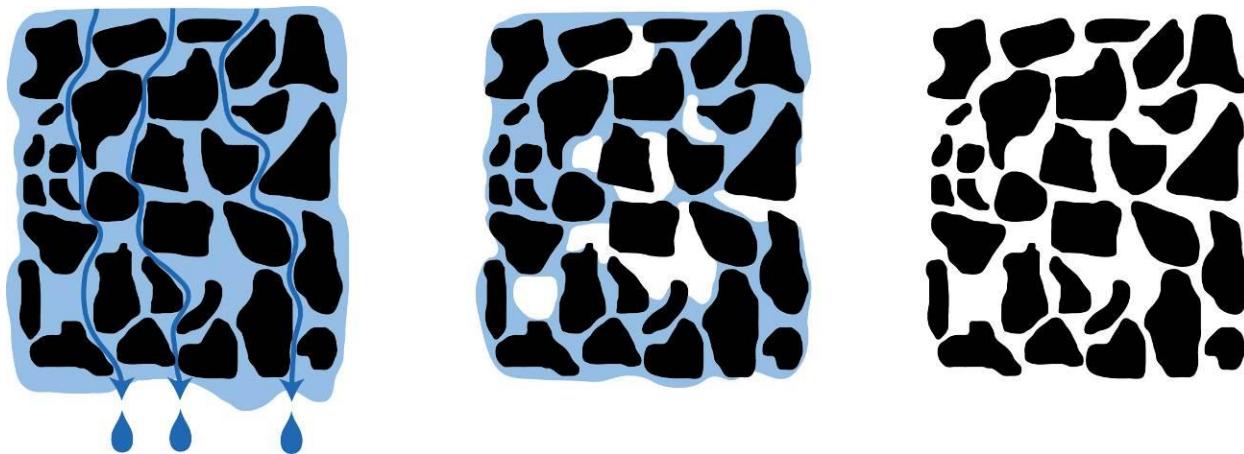


Figure 2-3. Soil water field conditions: saturation (left); field capacity (middle), and wilting point (right).

The amount of plant-available water depends upon the soil structure, texture, and organic matter. The classification of soil structure and textural analysis is shown in the soil texture triangle. (Figure 2-4). Lab analysis can determine the percent distribution of sand, silt, and clay. The amount of plant-available water held by different soils is presented in Figure 2-5. Commercially available moisture meters are able to read soil moisture percentage.

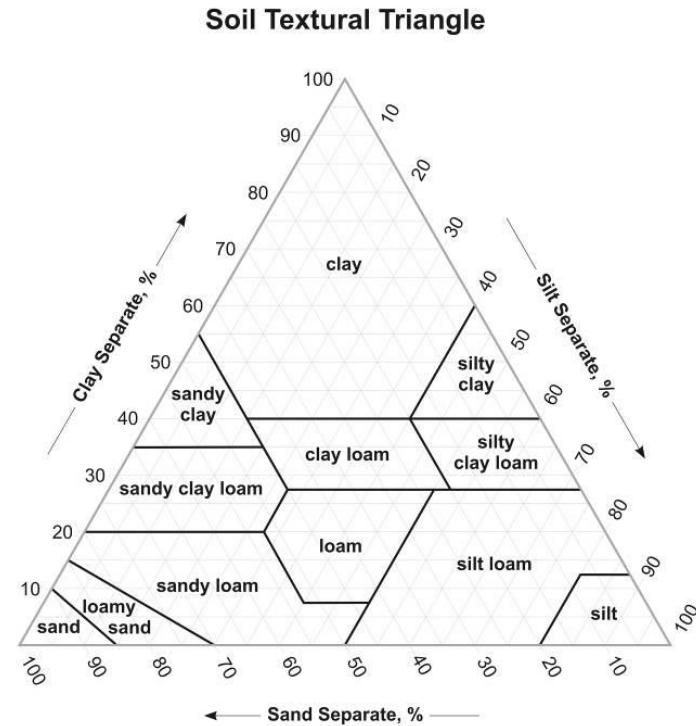


Figure 2-4. Soil textural triangle depicting soil particle distribution for different soils. Soil size definitions are as follows: Clay <0.002mm, Silt = 0.002-0.05 mm, Sand = 0.05 -2.0 mm. Source: USDA.

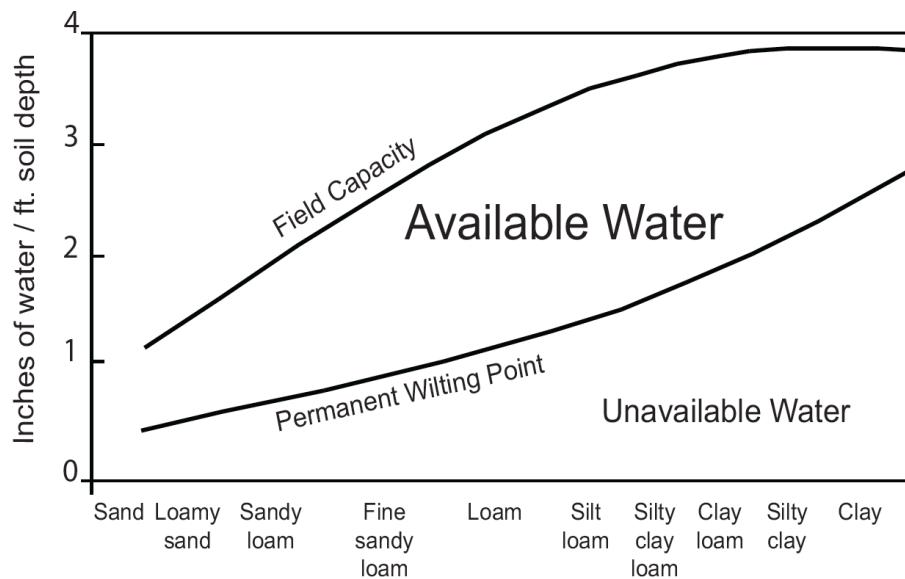


Figure 2-5. Available water by soil type. Source: Ohio Agronomy Guide, 14th edition, Bulletin 472-05.

Adding amendments to sand can dramatically increase the plant-available water capacity (PAWC), as shown in Table 2-1. While peat only slightly increases the PAWC of a 12-inch sand

root zone, adding calcine diatomite and a natural zeolite can double or even triple the PAWC of sand.

Table 2-1. Plant-available water holding capacity for sand and sand with amendments

Material	Plant available water holding capacity (% by volume)
Sand	4
Sand/Calcine clay (90:10)	6
Sand/Calcine diatomite (90:10)	8
Sand/Natural zeolite (90:10)	11
Sand/peat (80:20)	5

For more information on soils in New York, see: <http://websoilsurvey.nrcs.usda.gov>.

2.6 Geology

Golf courses can cover large expanses of land that may vary in geological properties. Understanding these geological properties is critical because these properties can pose risks for ground or surface water contamination.

2.6.1 Surficial Geology

Surficial geology is the study of landforms and the unconsolidated sediments that lie beneath these landforms. The type of surficial geology, along with the type of subsoil and depth to groundwater, can influence the surface water and groundwater interactions that allow contaminants to move from one medium to the other. Soils with hard pans or finer textured horizons in the subsoil may have a greater ability to adsorb contaminants as they leach through the surface horizons. The greatest potential for groundwater contamination occurs where sandy soil overlies porous materials (such as limestone or coarse gravel) with a shallow water table.

For New York State maps of surficial geology, see <http://www.nysm.nysed.gov/gis/#surf>.

2.6.2 Karst Geology

Karst geology (also called karst topography) is a type of surficial geology associated with carbonate bedrock (limestone, dolomite, or marble) and characterized by sinkholes, depressions in the land surface, caves, and underground drainage systems (Figure 2-6).

In New York State, continental glaciation and local stratigraphic and structural conditions have produced karst features, which may affect the quality and quantity of groundwater in the state. Karst features are created over time by rainwater, which dissolves the carbonate bedrock as it drains into fractures, creating channels and openings in bedrock. These channels and openings to the ground surface provide a direct connection between surface water and groundwater; these enhanced connections are known as “focused” or ‘direct’ recharge. Direct recharge quickly replenishes the water supply; however, it also leaves the aquifer particularly vulnerable

to contamination, especially where the topsoil layer is thin and does not filter out potential contaminants.

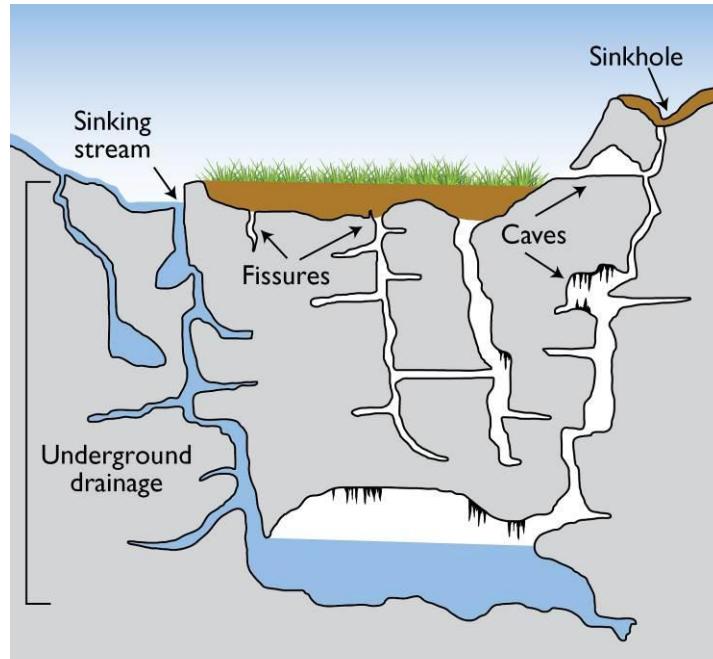


Figure 2-6. Karst geology is characterized by such features as sinkholes, fissures, and caves.

Available bedrock geology maps of NYS identify carbonate bedrock areas that indicate the potential presence of karst features. However, higher resolution maps of the boundaries as well as karst features in these bedrock units would be better suited for site-specific management, but may not be available from other sources.

For more information on karst geology, see:

- Bedrock geology map of NYS: <http://www.agiweb.org/environment/karstmap.pdf>
- “Living with Karst”, American Geological Institute: <http://www.agiweb.org/environment/publications/karst.pdf>
- Fickies, R.H. and Fallis, E., 1996, Rock Type Map of New York State: New York State Geological Survey, Open file Report 1g1222, scale 1:1,000,000.

2.7 Environmental Fate and Transport Mechanisms

Understanding contaminant fate and transport mechanisms will help superintendents to minimize the risk of off-site movement of nutrients and chemical pesticides applied to golf courses. First, research indicates that using BMPs minimizes the chances for movement of potential water quality contaminants into ground or surface water. When BMPs are not properly implemented, however, water quality is at greater risk. These risks are primarily the result of runoff and leaching, which are themselves environmental fate and transport mechanisms:

- Runoff is the movement of water across the turf and soil surface, typically following a storm event or heavy irrigation.
- Leaching is the downward movement of water through the soil and potentially into groundwater.

Additional fate and transport mechanisms for nutrients and pesticides include drift and spills. Drift occurs when pesticides become airborne as dry particles, liquid spray droplets, or vapor. Spills are the unintended releases of chemicals, such as fertilizers, pesticides, hazardous materials, or petroleum products released during transportation, storage, and routine maintenance and facility operations. These releases can be a point source of contamination.

2.7.1 Runoff

Surface runoff is a water flow along the surface of the ground that occurs when the soil is saturated, compacted, high in clay particles, or has lost soil structure (large pores). When runoff flows along the ground, it can pick up contaminants (including but not limited to pesticides, fertilizers, and petroleum) that then become discharge or nonpoint source pollution. The potential for runoff is greater on steep slopes. Research on golf courses has shown that in areas with minimal slopes, runoff on fairways is less than 5% of rainfall (Easton et al. 2005).

2.7.2 Leaching

Leaching refers to the loss of water-soluble plant nutrients or chemicals from the soil as water moves through the soil profile and into the vadose zone (saturated zone). Solute leaching becomes an environmental concern if it contributes these contaminants to groundwater or to surface waters where contaminated groundwater replenishes surface water bodies. Several variables influence the probability and rate of leaching, such as soil type and structure, vegetation, chemical properties, rate of precipitation, and depth to groundwater. When deciding on the rate and timing of fertilizer and pesticide application, it is critical to assess soil moisture status and potential for high infiltration in order to minimize potential losses. In addition, soil texture is a major influence on nutrient and pesticide leaching. For example, three to four times more nitrates have been shown to leach from a bentgrass sand fairway turf than from a sandy loam or silt loam soil (Petrovic 2004).

For more information on leaching see:

- “Loss of Nitrogen and Pesticides from Turf Via Leaching and Runoff”, http://www.usga.org/course_care/articles/environment/pesticides/Loss-of-Nitrogen-and-Pesticides-from-Turf-via-Leaching-and-Runoff/
- Appendix B, Groundwater Quality of Eastern Long Island, NY Golf Courses

2.7.3 Drift and Volatilization

Pesticides can move from the sites where they are applied into the surrounding environment through drift and volatilization. EPA defines pesticide spray or dust drift as “the physical

movement of pesticide droplets or particles through the air at the time of pesticide application or soon thereafter from the target site to any non- or off-target site."

Volatilization occurs when pesticide surface residues change from a solid or liquid to a gas or vapor after a pesticide application. Once airborne, volatile pesticides can come into contact with applicators or move long distances off site. Not all pesticides are volatile, and the higher the vapor pressure of a given chemical, the higher its volatility will be. Appendix C lists all the pesticides registered for use in New York State with the corresponding vapor pressures. Generally, any pesticide with a vapor pressure greater than 1 millipascal (mPa) is deemed to be volatile. For more information on drift and volatilization, see:

- EPA Pesticide Issues: pesticide volatilization
<http://www.epa.gov/pesticides/about/intheworks/volatilization.htm>
- Croplife Foundation, "Minimizing Pesticide Spray Drift"
http://croplifefoundation.files.wordpress.com/2012/05/spray_drift.pdf
- Cornell University Pesticide Application, Turf Spraying web page:
<http://web.entomology.cornell.edu/landers/pestapp/turf.htm>

2.7.4 Sedimentation

A primary benefit of turfgrass or any perennial vegetation is the reduction in sediment and particulate movement, or reduced soil erosion. Precipitation and irrigation can carry soil particles (sediment) in runoff and deposit them into surface waters. Too much sediment can cloud the water, reducing the amount of sunlight that reaches aquatic plants and harming aquatic species. In addition, sediments can carry fertilizers, pesticides, and other chemicals that are attached to the soil particles into the water bodies, causing algal blooms and depleted oxygen. Sedimentation is controlled through BMPs that control the volume and flow rate of runoff water, keeping adequate turf density, and reducing soil transport.

2.7.5 Point Sources

The legal definition of "point source" is provided in 6 NYCRR Part 050-1.2(65) as follows:

The term "point source" means any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, or landfill leachate collection system from which pollutants are or may be discharged. This term does not include agricultural storm water discharges and return flows from irrigated agriculture.

On golf courses, point sources of pollution can originate from:

- storage and maintenance facilities
- the unintended release of chemicals, such as pesticides, fertilizers, or fuel, during transportation, storage, or handling

- drainage discharge outlets (for example, the end of a drainage pipe)

Containment measures can easily prevent chemicals from becoming point sources of pollution during storage and handling. To prevent discharges from contaminating surface waters, the discharges must be diverted away from surface water and onto turf areas or other appropriate areas instead.

3 WATER QUALITY MANAGEMENT

Golf course BMPs are designed to minimize the transport of potential water quality contaminants (such as nitrogen and phosphorus) from the golf course into surface waters and groundwater. A decade of public and privately funded research concerning the fate of fertilizers and pesticides applied to turf has concluded that golf courses using BMPs pose little to no risk of contributing to water pollution. Specifically, several studies investigated the movement of nutrients and pesticides through the perennial turfgrass system and found that maintaining a dense, vigorous turf, identifying environmentally sensitive areas, and recognizing potential risks of certain soils and climatic conditions are essential to protecting water quality.

Regulatory compliance is the first step in aligning golf course management with BMPs. New York has some of the nation's strictest state regulations on pesticides and fertilizers. Golf course superintendents must be aware not only of regulations on the purchase, storage, handling, and application of fertilizers and pesticides, but also of the potential water quality contaminants, sources, and impacts associated with these compounds. The next step in successful BMP implementation is to recognize the many management decisions that involve potential contamination of surface waters and groundwater and address course management practices in a systematic fashion. Once course management becomes aligned with regulations and water quality protection BMPs, additional value can be gained by using water quality monitoring as a final step to assess the actual water quality entering and leaving the course.

3.1 Regulatory Framework

Maintaining water quality is a high public priority, to ensure a safe and abundant public drinking water supply as well as to protect fish and wildlife resources that use State waters and wetlands as part of their habitat. A number of federal and state regulations that apply to both drinking water and surface water quality for the protection of aquatic life are relevant to golf course operations, depending upon the proximity to drinking water sources, and surface waters, and depth to groundwater. These include regulations related to stormwater; wetlands; pesticides and pesticide usage; fertilizers; hazardous materials; and water withdrawal.

Maintenance facilities are likely to be subject to a number of local requirements, which may vary by county or town. Local building inspectors should be consulted during planning for new facilities to outline the permitting process and local requirements. Also, consider meeting with a representative from a NYSDEC regional office and the local fire marshal. The NYSDEC requests a State Environmental Quality Review (SEQR) for new construction, which is administered by local governments. NYSDEC comments on SEQR as well as other interested and involved agencies.

3.1.1 Drinking Water

The Safe Drinking Water Act (SDWA), passed in 1974, is the main federal law that ensures the quality of Americans' drinking water. Under the SDWA, EPA sets standards for drinking water quality and oversees the states, localities, and water suppliers who implement those standards.

SDWA authorizes EPA to set national health-based standards for drinking water, known as the National Drinking Water Regulations, to protect against both naturally occurring and manufactured contaminants. These regulations specify maximum contaminant levels (MCLs) for contaminants, which include nitrates, nitrites, and some pesticide constituents. EPA, individual states, and water systems are compelled to work together to ensure that these standards are met. The New York State Department of Health (NYSDOH) established standards for drinking water quality that are more stringent than EPA standards and must be complied with in the state.

For more information, see:

- Surface Drinking Water Act: <http://water.epa.gov/lawsregs/rulesregs/sdwa/index.cfm>
- National Drinking Water Regulations:
<http://water.epa.gov/drink/contaminants/index.cfm>
- Drinking water contaminants MCLs:
<http://water.epa.gov/drink/contaminants/index.cfm#List>
- NYSDOH drinking water protection program:
<http://www.health.ny.gov/environmental/water/drinking/>

3.1.2 Stormwater

Stormwater is water that originates in some form of precipitation, as either rainfall or snowmelt. Because this water travels along or through the earth's surface, it can collect and carry potential contaminants that could compromise surface waters or groundwater. Therefore, regulations exist that govern the quality of water discharged from runoff sources. NYSDEC has established limits for some chemicals in stormwater, including nitrites, nitrates, and pesticides. NYSDEC has also established a limit for phosphorus levels in stormwater of 0.1 mg per liter.

Individual or general permits for stormwater discharges may be required for activities associated with stormwater discharges, including construction activities. Construction activities disturbing one or more acres of soil must be authorized under the General Permit for Stormwater Discharges from Construction Activities. Permittees are required to develop a Stormwater Pollution Prevention Plan (SWPPP) to prevent discharges of construction-related pollutants to surface waters. The New York State Stormwater Management Design Manual was reissued in 2010 for more information.

The concentration of activities in and around maintenance facilities may increase the levels of chemical residues susceptible to runoff from heavy precipitation. Stormwater collection areas may need to be established to capture runoff in accordance with NYSDEC specifications.

For more information see:

- NYSDEC's "Stormwater" page: www.dec.ny.gov/chemical/8468.html
- NY Stormwater Design Manual: <http://www.dec.ny.gov/chemical/29072.html>

3.1.3 Surface Water

The goal of all surface water quality protection programs is to ensure that all waters of the State meet water quality standards. The Federal Clean Water Act required states to classify all of the waters of the State according to their best uses and to adopt water quality standards in order to protect those best uses. NYSDEC uses the best uses and standards so established to regulate surface waters, land use associated with tidal and freshwater wetlands, and dams. Specifically, NYSDEC is charged with identifying impaired surface water bodies (i.e., waters not meeting water quality standards), recommending mitigation, and establishing guidelines for enhanced protection through a variety of regulatory programs.

For surface waters in New York not meeting the established State water quality standards, NYSDEC establishes total maximum daily loads (TMDLs) for the pollutant of concern causing the impairment (such as nitrogen, phosphorus, or sediments). NYSDEC has completed TMDLs for many water bodies in New York State, including Long Island Sound, Lake Champlain, waters of the Croton River watershed, and a number of lake watersheds. EPA may also require localities to develop Comprehensive Nutrient Management Plans (CNMPs) for activities in those impaired watersheds. Currently, CNMPs are focused on agricultural land use specifically related to the New York City Watershed Memorandum of Agreement (MOA). Note that state, federal, and local water quality regulations can change—remain informed on local, regional, and national policies and regulations.

For more information, see:

- NYSDEC Division of Water Regulations: <http://www.NYSDEC.ny.gov/regs/2485.html>
- NYSDEC TMDLs: <http://www.NYSDEC.ny.gov/chemical/23835.html>
- EPA's National Assessment Database: <http://www.epa.gov/waters/305b/>

3.1.4 Groundwater

NYSDEC regulates groundwater, including setting groundwater quality and effluent standards. For more information, see NYSDEC Division of Water Regulations: <http://www.dec.ny.gov/regs/2485.html>.

3.1.5 Freshwater Wetlands

Article 24 of New York Environmental Conservation Law requires permits to conduct activities within a wetland and an adjacent area bordering the wetland. Physical disturbance, as well as application of chemicals (pesticides, herbicides, fungicides, even fertilizer), requires an Article 24 permit if the action is done in a state-regulated wetland or within the regulated adjacent area (typically 100 feet from wetland boundary).

3.1.6 Fertilizers

A growing number of states have enacted regulations that restrict fertilizer sale and application. For example, Minnesota and Wisconsin enacted specific legislation that restricts the application of phosphorus containing fertilizer unless a soil test indicates need. Additionally, Minnesota

requires education and certification of applicators to ensure that applicators understand environmental aspects of fertilizer application.

In New York, the Dishwater Detergent and Nutrient Runoff Law became effective in January 2012. This law prohibits the use of phosphorus-containing fertilizers with a phosphate (P_2O_5) content greater than 0.67%, unless:

- soil tests show a phosphorus deficiency
- the fertilizer is being used to establish new seeded or sodded turf
- the fertilizer being used is an organic compost
- the fertilizer is derived from litter

The law prohibits application of fertilizer onto impervious surfaces. Fertilizer should not be applied within 20 feet of any surface water, modified to 10 feet if the buffer has vegetative cover. An exception to the buffer requirement exists if the spreader guard, deflector shield or drop spreader is at least three feet from surface water. Finally, the law prohibits the application of fertilizers on lawns and non-agricultural turf between December 1 and April 1.

In addition to state regulations, turf managers should review their county and town ordinances to determine if stricter restrictions apply to phosphorus fertilizer use and application. For example, a few counties have extended the phosphorus-containing fertilizer restriction from November 1 or November 15 to April 1. Currently, local laws enacted to reduce phosphorus include ones adopted in Westchester, Nassau, Suffolk and Chautauqua counties and the Village of Greenwood Lake.

In addition to restrictions on the use of phosphorus-containing fertilizers, CNMPs for those NY counties required to submit plans for impaired waters may restrict the use of nitrogenous fertilizers. Turf managers should consult with the local County Cooperative Extension Office, SWCD Office, or County Water Authority to learn if any restrictions apply.

For more information, see:

- NYSDEC Dishwasher Detergent and Nutrient Runoff Law web page:
<http://www.dec.ny.gov/chemical/67239.html>
- Minnesota legislation: <https://www.revisor.mn.gov/statutes/?id=18C>
- Westchester County local regulation:
http://www.westchestergov.com/pdfs/ENVFACIL_2008LawnFertilizerLaw.pdf
- Nassau County local regulation:
<http://www.nassaucountyny.gov/agencies/legis/documents/locallaw11-2009.pdf>
- Suffolk County local regulation: <http://legis.suffolkcountyny.gov/resos2007/i2117-07.htm>
- Chautauqua County local regulation:
http://www.planningchautauqua.com/?q=watershed/Phosphorus_Law.htm

3.1.7 Pesticide Use Regulations

The New York State Environmental Conservation Law (ECL), Article 33, Part 325, establishes statutory authority to the New York State Department of Environmental Conservation to regulate pesticides and pesticide use. These regulations are covered in detail in Chapter 9, Section 9.1. of this document.

3.1.8 Aquatic Pesticide Applications

The application of any pesticide to water, such as an aquatic herbicide used to control vegetation in golf course ponds, or mosquito or other insect control applied to water, must be covered under a SPDES General Pesticide Permit. For more information, see: <http://www.dec.ny.gov/chemical/70489.html>.

3.1.9 Maintenance Facilities

Every golf course has a central area for the maintenance and storage of equipment and supplies. These areas can potentially become point sources of pollution because of unintended releases of chemicals such as pesticides, fertilizers, or fuel during storage or handling of these materials. Maintenance and storage facilities are high priority areas to address in protecting water quality. Containment measures in these areas can easily prevent chemicals from becoming point sources of pollution. More information on regulatory considerations related to maintenance facilities and potential hazardous materials is provided in Section 10.1 of this document.

3.2 Potential Water Quality Contaminants

Fertilizers and pesticides maximize productivity and performance in a variety of agricultural and horticultural settings, including golf turf management. In addition to regulations on applying these compounds, their storage and handling is also regulated. Although application practices can affect water quality, the environment is typically at the greatest risk from spills of larger volumes of the concentrated chemicals used to mix fertilizers and pesticides for application. Regardless of how the chemicals are released into the environment, superintendents should understand the fate of these inputs as well as other potential sources of contamination in order to prevent or to mitigate any potential effects on water quality.

3.2.1 Fertilizers

Of the many nutrients applied to golf turf, the primary contaminants of concern in fertilizers are nitrogen and phosphorus. These nutrients can leach into groundwater or be carried in runoff into surface waters after applications. New York's Environmental Conservation Law (ECL) narrative standards state that no nitrogen and phosphorus are allowed in runoff that contribute to algal growth, weeds, or the impairment of the water.

3.2.2 Pesticides

Pesticides may be toxic to aquatic and terrestrial systems. The varying chemical properties of pesticides—for example, their solubility, toxicity, and chemical breakdown rate—determine the

potential impact to water quality. Pesticide safety and management is covered in Chapter 9 of this document.

3.2.3 Sediments

EPA defines suspended and bedded sediments as follows:

“...particulate organic and inorganic matter that suspend in or are carried by the water, and/or accumulate in a loose, unconsolidated form on the bottom of natural water bodies. This includes the frequently used terms of clean sediment, suspended sediment, total suspended solids, bedload, turbidity, or in common terms, dirt, soils, or eroded materials.”

Increases in sediment loading can compromise the ecological integrity of aquatic environments, affecting water quality physically, chemically and biologically. In addition, sediments often carry organic matter, nutrients, chemicals (such as pesticides), and other wastes. For example, phosphorus is immobile in most soils and concentrates in the top few inches of the soil, where it is very susceptible to erosion and thus likely to be present in sediment.

3.2.4 Hazardous Materials

Other potentially hazardous materials, such as fuels and paints that are used in everyday operation and maintenance, can contaminate water quality if accidentally released, especially in large quantities. BMPs followed for maintenance operations can prevent contamination from accidental releases.

3.2.5 Waterfowl

The deposits of fecal matter by resident and migrating waterfowl (Canada Geese, mute swans, and others) may contribute to water quality impairment through nutrient enrichment. The overall impact of bird feces on water quality, however, depends on numerous factors, such as the size, depth, and natural chemistry of the water body; avian populations and behavior; and the rate at which other nutrient sources enter the water body (Unckless and Makarewicz 2007). On golf courses, shallow ponds with significant populations of waterfowl are most likely to be affected. In these cases, annual phosphorus loading by waterfowl can be calculated using the days per year that each species spent on any lake or reservoir.

3.3 Potential Water Quality Impacts

If water quality contaminants reach surface waters or groundwater, the potential water quality impacts can include the following:

- drinking water impairment, if nitrogen as either nitrate (NO_3) or nitrite (NO_2) is present at levels above health-based risk values in drinking water
- nutrient enrichment of surface waters
- sedimentation due to eroding soils

- toxicity to aquatic life

3.3.1 Drinking Water Impairment

The presence of nitrogen as either nitrate (NO_3) or nitrite (NO_2) at levels above health-based risk values in drinking water may adversely affect health. MCLs established by EPA are 10 mg/L for nitrate and 1 mg/L for nitrite. Phosphorus contamination of drinking water has not been directly linked to human health problems, although increased levels may affect water taste and odor and, in some cases, enhance the growth of toxic algae. MCLs have been established for some pesticides or pesticide constituents in drinking water, such as glyphosphate.

Although drinking water impairment from golf course management activities is possible, research indicates that this is uncommon. Seventeen studies (36 golf courses) were reviewed by Cohen et al. (1999) and were incorporated into a detailed data review. A total of 16,587 data points from pesticide, metabolite, solvent, and NO_3 analyses of surface water and ground water were reviewed. Approximately 90 organics were analyzed in the surface water database and approximately 115 organics in the ground water database. The results of the analysis indicated that widespread and repeated water quality impacts by golf courses were not observed at the golf course study sites. None of the authors of the individual studies concluded that toxicologically significant impacts were observed, although health advisory levels, MCLs, or maximum allowable concentrations were occasionally exceeded.

3.3.2 Nutrient Enrichment

Nutrient enrichment of surface waters is widespread across the state of New York in large part because of the prevalence of sources of phosphorus and nitrogen, including the following:

- municipal wastewater treatment plant discharges
- urban runoff from impervious surfaces such as parking lots, rooftops and roads
- agricultural activities
- flow from inadequate onsite septic systems
- home lawn and other fertilization practices
- atmospheric deposition

Nutrient enrichment can lead to eutrophication, the process by which a body of water acquires a high concentration of nutrients, which promotes excessive growth of algae (called algal blooms). As the algae die and decompose, oxidation of the organic matter and respiration by the decomposing organisms can deplete dissolved oxygen in the water, in turn causing the death of aquatic organisms such as fish and invertebrates.

Although both phosphorus and nitrogen must be managed to prevent eutrophication, nitrogen is the higher priority for marine environments, while phosphorus is more important in fresh waters. In Long Island Sound, nitrogen fuels the growth of excessive amounts of planktonic algae. In the Sound, the eutrophication process results in hypoxia (very low levels of dissolved

oxygen in the water column) each summer, especially in the western half of Long Island Sound. In marine systems, the eutrophication process can also alter the habitat for submerged aquatic vegetation and marine life, reducing the size and diversity of the ecosystem and fisheries. Some algal blooms, often referred to as red or brown tides, can also be toxic to crustaceans, fish, and humans. In freshwaters, phosphorus fuels the growth of excessive amounts of algae that also results in reduced amounts of dissolved oxygen available to freshwater aquatic organisms. Phosphorus levels of 0.035 to 0.10 mg/L have been linked with increased levels of algal growth in rivers, lakes, and estuaries.

In addition to excessive algae growth, nutrient enrichment can contribute to the excessive growth of vascular aquatic plants. Excessive aquatic plant growth can alter the aquatic plant community, deplete oxygen, impact fish communities, restrict recreational use, and cause odors during die off.

For more information, see:

- NYSDEC "Nutrient Loadings and Eutrophication" fact sheet: http://www.dec.ny.gov/docs/water_pdf/top10nutloading.pdf
- NYSDEC "Aquatic Weeds and Invasive Species" fact sheet: www.dec.ny.gov/docs/water_pdf/top10invasives.pdf
- EPA Nutrient Pollution web page: <http://epa.gov/nutrientpollution/>

3.3.3 Sedimentation

Sedimentation is the process whereby water that is carrying sediments from eroding soil slows long enough to allow soil particles to settle out. The smaller the particle, the longer it stays in suspension. Larger, heavier particles such as gravel and sand settle out sooner than smaller, lighter particles such as clay (which may stay in suspension for long periods and cause water turbidity). The effects of sedimentation are generally site specific and depend on a number of variables including sediment grain size and type, and hydrological conditions; water quality impacts can include increased turbidity, impairment of aquatic habitats, and filling in of water bodies. In addition, sediments can also affect water quality if they contain other contaminants such as organic matter, nutrients, pesticides, or other chemicals. Sedimentation is only likely to occur on golf courses during construction and major renovations when soils are disturbed.

3.3.4 Toxicity to Aquatic Life

Pesticides applied to golf courses can be harmful to fish and wildlife. Herbicides used to control weeds can be transported to ponds and streams where they can be harmful to aquatic vegetation and algae. Insecticides, including some of the products used for adult mosquito control, also tend to be toxic to fish and aquatic life, and if transported off treated areas by runoff, fish and invertebrates in adjacent waters can be harmed. Fortunately, turf tends to hold water and retard runoff, greatly reducing the pesticide load transported to adjacent water bodies, particularly compared to pesticide treatments on bare ground or agricultural fields. To ensure the protection of aquatic life and compliance with pesticide regulations as described in Section 9.1 of this document, close attention should be paid to all of the instructions listed on the

pesticide label. Carefully following label instructions is the best way to insure that a pesticide application will not be harmful to fish and wildlife.

3.4 Water Quality Monitoring

Aligning management programs with established, research-based BMPs is the first step to ensuring water quality protection. Water quality monitoring can confirm the effectiveness of a BMP-based program. Golf course superintendents wanting to develop and implement a water quality monitoring program to document the water quality conditions should first review available baseline water quality data. Baseline data can be assessed to determine the likely origin of contaminants, measure the extent of sedimentation and nutrient inputs, and estimate the potential impacts to surface water and groundwater. Following implementation of BMPs, routine monitoring can be used to measure water quality improvements and identify any areas where corrective actions should be taken.

Water quality monitoring can also demonstrate the presence of water quality issues inherent in water as it enters a golf course property. For example, in Suffolk County extensive laboratory testing for contaminants has shown that groundwater entering the golf course already has extremely high nitrate levels (near or greater than the regulatory limit; see Appendix B) The county also collects surface water samples and shares the test reports with superintendents.

3.4.1 Sources of Existing Information

Several sources of existing surface and groundwater monitoring data may be available, including:

- Soil and Water Conservation Districts – Comprehensive water quality management programs; may be willing to test surface water and assist in installation of groundwater monitoring wells. SWCD listings for NYS are available at: http://www.nyssoilandwater.org/contacts/county_offices.html
- NYSDEC - Conducts a groundwater monitoring program in coordination with USGS. http://www.dec.ny.gov/docs/water_pdf/top10nutloading.pdf/lands/36117.html
- USGS - Reports results of groundwater monitoring and compares to EPA and NYSDOH standards. The USGS has completed testing and published reports for most of the major watersheds in the state. <http://ny.water.usgs.gov/projects/305b/>.
- County Water Authorities - Maintain and test community water wells and may have additional test data from other points within the watershed.

3.4.2 Developing a Water Quality Monitoring Program

Developing a water quality monitoring program can include both groundwater monitoring and surface water monitoring. The data from this periodic monitoring can be used to identify issues that may need corrective actions. In addition, water quality monitoring of irrigation sources (particularly water supply wells and storage lakes) provides valuable agronomic information

that can inform nutrient and liming programs. A water quality monitoring plan should identify appropriate sampling locations, frequency, and monitoring parameters.

Groundwater monitoring from wells located at the hydrologic entrance and exit from the course may be the best way to evaluate a golf course's impact on water quality. If groundwater monitoring data from these locations are not available from existing sources, monitoring wells can be installed by private companies. Installing groundwater monitoring wells can be relatively expensive, but the expense may be justified in certain cases where the origin of contamination needs to be determined through comparison of water quality entering and exiting the property. To identify the appropriate site for monitoring wells, groundwater flow is required. In some areas of New York, groundwater flow maps have been developed, but may not be available at a fine enough scale for an individual golf course. Experienced environmental engineering firms or USGS can assist in determining suitable monitoring well locations. Testing protocols can be simplified to test only those parameters that are directly influenced by course management, including organic and inorganic levels of nitrogen and phosphorus and a pesticide screen for certain pesticides used on the course. NYSDEC pesticide reports provide the necessary documentation for pesticides used. The USGS also offers contract services to advise on sampling and testing of water samples. SWCD offices can also provide guidance on groundwater testing programs.

Surface water monitoring can include the laboratory testing of a number of different physical and chemical parameters to assess water quality. In addition, the sampling of macrobenthic invertebrates can be used as a relative assessment tool for stream health. Sampling of surface waters can be conducted by golf course staff or volunteer monitoring groups (Figure 3-1).



Figure 3-1. Golf course staff can easily sample surface water. Source: Ken Benoit

A number of references for detailed information on planning a water quality monitoring program on golf courses can be used to plan a site-specific water monitoring program:

- *Environmental Stewardship Guidelines* (Oregon GCSA, 2009) includes a highly detailed chapter on water quality monitoring specific to golf turf.
<http://www.ogcsa.org/Pages/environmental/ogcsa-guidelines.html>
- *Environmental Best Management Practices for Virginia's Golf Courses* (Virginia GCSA, 2012) includes a detailed chapter on water quality monitoring and an example water quality monitoring report appendix. <http://www.vgcsa.org/view.asp?id=373&page=68702>
- *A Guide to Environmental Stewardship on the Golf Course* (Audubon International, 2002)

BMP Statements

- Assess current surface and groundwater quality.
- Conduct water quality assessment using accepted standards.
- Use an accredited laboratory for water quality assessment.

4 SITE ANALYSIS AND WATER QUALITY PROTECTION

Site analysis is the first and most important step in aligning golf course management with research-based BMPs designed to protect water quality and ecosystem integrity. A site analysis describes site maintenance areas, chemical storage and handling practices, equipment cleaning, and other priority areas on the golf course associated with topography and environmental sensitivity. Following this thorough assessment the feasibility of land use, structural, and management BMPs should be considered to ensure reasonable water quality protection.

The BMPs discussed in this chapter can be incorporated into design for a new course or course renovation. For an existing golf course, the golf course superintendent can undertake a site analysis to identify specific areas of interest to focus the implementation of BMPs. For a new golf course development or a renovation project, the state of New York requires that a licensed golf course designer guide the site analysis process to ensure compliance with relevant regulations. Designers and others involved in golf course development are encouraged to work closely with local community groups and regulatory bodies during planning and siting and throughout the development process. For every site, local environmental issues and conditions must be addressed.

The first step in a site analysis is to develop a better understanding of how a golf course fits into the landscape. The site assessment begins with identifying high priority areas and the current potential for water quality impacts. Note that the high priority areas are more often located where equipment is cleaned and fertilizer and pesticides are stored and handled because these areas have the potential for large volume releases.

4.1 Identifying Priority Areas

Understanding the golf course landscape is the first step in assessing potential water quality issues. Areas to identify first are the environmentally sensitive areas such as wetlands, surface water bodies and shorelines, steep slopes to surface water, and areas with shallow depth to ground water or that are located in a critical groundwater recharge zone (especially true for Long Island, due to its sandy soils). In addition, identify relevant geological characteristics such as karst topography, which leaves groundwater vulnerable to contamination.

On golf courses, point sources of pollution should be identified as priority areas for water quality protection. Specifically, these point sources can originate from storage and maintenance facilities and as the unintended release of chemicals, such as pesticides, fertilizers, or fuel, during transportation, storage, handling or cleaning of mowers and pesticide application equipment. Containment measures can easily prevent chemicals from becoming point sources of pollution, as described in Chapter 10.

The goal of the site assessment process is to identify priority areas, beginning with determining the following:

- the golf course's position relative to its position in the watershed

- drainage basins
- environmentally and ecologically sensitive areas
- management zone boundaries

Watershed drainage basins. Drainage basins on the property should be identified on both topographic maps and routing plans. Identifying drainage basins also helps to determine the approximate area of greens, tees, fairways, and roughs in each drainage basin.

Environmentally sensitive areas. Environmentally sensitive areas are those areas with natural resources susceptible to changes that can alter ecosystem structure or function (such as wetlands), or areas that might be home to an endangered, threatened, rare species, or species of special concern. Information on the presence of endangered species can be obtained from New York's Natural Heritage Program (see <http://www.dec.ny.gov/animals/31181.html>).

One of the objectives of BMPs is to provide the necessary protection for these environmentally sensitive areas by design and operation of the golf course and maintenance facilities.

Superintendents can protect these areas through BMPs, careful selection of pesticides and fertilizers, restrictions on the use of certain materials in sensitive areas (for instance, "no spray" zones), and proper construction. These practices minimize the potential for point and nonpoint source pollutant input to sensitive areas within the management zones at the course.

Management zones. In order to manage a golf course in an environmentally sensitive and responsible manner, establish management zones throughout the course. Management zones are defined as areas that have distinct management practices based on the area's position in the watershed and the drainage basin analysis conducted for the watershed. Management zones work hand-in-hand with BMPs and IPM. Management zones include the following:

Management Zone A: These zones may or may not be part of the playable area AND are considered to be of the highest risk for water quality issues. Therefore, any management of these areas should be focused on minimizing any chemical use, preventing direct discharge into water bodies, and maximizing resident time for water moving along the surface in this zone.

Management Zone B: These zones are part of the playable area and therefore require an increased level of maintenance, but pose significantly less risk than in Zone A. Additionally, when wind speed is greater than 10 mph, a shroud should be used on spray equipment to avoid drift. Therefore, management of these areas should allow for additional chemical use while still minimizing the potential for movement into surface or groundwater.

Management zones should be clearly marked on course maps and the maintenance crew should be familiar with these areas. The use of GPS/GIS systems for precision mapping of these zones and identifying boundary locations can assist the crew in following the management zone guidelines.

4.2 The Broader Golf Course Landscape

Adjacent ecosystems form complex and diverse mosaics on the landscape. Forests, wetlands, bottomland hardwoods, agricultural fields, streams, rivers, and lakes, combine to form biologically diverse and ecologically complex watersheds.

When designing and managing golf courses as ecosystems, do not override or alter natural processes, but rather work to maintain naturally occurring processes. For example, chemical cycling is constantly occurring and it is a key to ecosystem stability. Losses of essential elements are controlled by complex feedback loops involving plants, animals, soil microorganisms, decaying litter, and soils. Natural ecosystems function because of their complexity, which builds stability in these systems.

Chemicals can have an important part impact on the ecosystem. Ecosystems use energy to assimilate chemicals into new biological structures, decompose dead materials, and recycle mineral nutrients. Introduction of chemicals such as pesticides into the system need not upset the natural balance. However, golf courses must be careful not to override the natural cycling processes or to introduce toxic materials where they can harm organisms or ecologically sensitive areas. The best approach is to avoid or minimize problems by using BMPs. These practices may include the sensible use of pesticides, emphasizing localized applications that act quickly and effectively without any appreciable impact on the natural system.

4.3 Water Quality Protection Systems

Using BMPs and management zones, turfgrass management can coexist in harmony with nature. The quantity and quality of water generated within the property boundaries can be protected by appropriate watershed controls and management practices. Because water is the primary movement mechanism for contaminants, protection of water resources also provides protection for sensitive areas and species. Surface water is the focus of watershed protection because recent research on the environmental impact of nutrients and pesticides applied to golf courses has indicated that for the majority of the acreage under turf management, surface runoff is a much greater concern than leaching. While leaching of certain materials does occur at low levels and under specific environmental and climatic conditions, more materials are transported in surface runoff than through leaching (Baris, R.D. et al. 2010). However, certain areas of New York have a history of groundwater contamination problems.

Preventive measures must be in place to keep potential contaminants from entering surface waters. The building blocks of water quality protection include preventive measures (source prevention) or nonstructural practices that minimize or prevent the generation of runoff and the contamination of runoff by pollutants. Structural controls that are part of the design and engineering of the course are capital improvements designed to remove, filter, detain, or reroute potential contaminants carried in surface water. The most effective way to manage surface water is by using a comprehensive systems approach that includes integration of preventive practices and structural controls (Eaker 1994).

This comprehensive systems approach, which should be used throughout the golf course property, should stress optimum site planning and the use of natural drainage systems. Livingston and McCarron (1991) suggest that a stormwater management system might be considered as a "Best Management Practices (BMP) Train" in which the individual BMPs are considered the cars. In most cases, the more BMPs incorporated into the system, the better the performance of the treatment train. The first cars might include BMPs to minimize generation of runoff (for example, irrigation management) and pollutants (such as IPM) and the final car could include a retention pond.

4.3.1 Preventive Strategies

At any golf course, preventive strategies should include combinations of land use controls and source prevention practices. An integrated water quality protection system is based on a tiered concept as follows:

- prevention - prevent problems from occurring
- control - have safeguards in place to control any problems
- detection - consider a monitoring program to detect changes in environmental quality

Preventive measures are categorized as either land use BMPs or source prevention BMPs. Land use BMPs are engineered and incorporated into the course during golf course design and construction. Land use BMPs protect natural resources through primarily mechanical methods, as described in the remainder of this chapter. Source prevention BMPs are implemented during golf course operation to prevent or preclude the possibility of movement of sediment, nutrients, or pesticides from the property or from toxic materials being introduced into ecologically sensitive areas. Source prevention BMPs include the use of management zones as described in Section 4.1 and IPM strategies, as described in the later chapters.

Land use BMPs are incorporated during design for construction activities that affect drainage, surface water, sedimentation and erosion control, and ecologically sensitive areas. Examples of land use control BMPs include

- settling and filtering processes for removing sediment and pollutants that are bound to sediment particles associated with surface runoff
- subsurface drainage, infiltration, and use of land absorption areas (vegetated filter strips) to detain water, allow it to be filtered prior to groundwater recharge
- grassed waterways or outlets
- critical area planting to stabilize highly erodible areas

Other land use BMPs are structural, such as quality basins, infiltration basins, and catch basins that detain water to reduce runoff quantity and nutrient and pesticide discharge.

4.3.1.1 Vegetative Practices

Vegetative Filtration. Common examples of vegetative filters that can be used throughout the golf course are conservation areas or buffers, land absorption areas (vegetated filter strips) and swales (diversions, berms). Vegetative filters act as natural biofilters to reduce storm water flow and pollutant load, and turf areas are effective filters.

Turf uses the natural processes of infiltration, filtration, and biological uptake to reduce flows and pollutant loadings. Vegetated filter strips remove sediment and attached chemicals, organic material, trace metals, and nutrients (nitrogen and phosphorus). Sediment removal rates are generally greater than 70% and nutrient removal is typically greater than 50%.

Maintenance of vegetative filters requires management to achieve dense, hearty vegetation. Where changes in vegetative cover must be made, these changes are normally established in low maintenance ground covers. This practice may include the use of native or naturalized plants, including low maintenance turfgrasses. When turf is used as the filtration medium, cultural activities should focus on producing healthy turf with a minimum of maintenance activities.

Turf should be allowed to grow to the highest end of the optimum range for more effective filtration. Fertilizers and pesticides are usually not applied in these areas except sparingly (sometimes during establishment to reduce erosion and runoff problems much faster) or after a risk assessment has determined that application of certain materials will have no impact in adjacent areas. Establishing these buffers reduces erosion and sediment loss decreases. Buffers also protect surface waters by attenuating pollutants in surface runoff.

Soil surface runoff may also be moderated, reducing the impact on receiving water bodies and streams. The greatest benefit is the protection of adjacent ecologically sensitive areas—potential pollutants are simply not introduced, or are introduced on a limited basis compared to more highly maintained turf areas. Figure 4-1 shows several examples of vegetated buffers.

Conservation Areas or Buffers. These are areas where it is critical to establish and maintain perennial vegetative cover to protect resources. The most sensitive portions of watercourses are the areas immediately adjacent to the water. Disturbance within and adjacent to watercourses can degrade water quality by increasing the availability and transport of pollutants. Therefore, retaining vegetated buffers along watercourses is one of the most effective practices used to protect water quality and should be designed to handle the anticipated runoff. If the area is a state or locally designated wetland, a buffer may be required and the width of the buffer specified by the regulating authority.

Critical Area Planting. Planting vegetation on highly erodible or critically eroding areas also protects water quality. The greatest amount of soil erosion and sediment delivery to surface waters occurs when large areas are graded during the construction phase, which requires phased construction to minimize the amount of bare land. Quickly establishing vegetation

reduces the movement of materials in runoff, as plants take nutrients in the soil and reduce the amount that can be washed into surface waters or leach into groundwater, as well as trap particulates.



Sodding is an important consideration in these areas since it provides instant ground cover and rooting can occur rapidly for permanent establishment. In certain instances, strip sodding rather than solid sodding can be used if the slopes are not too steep and the strips are wide enough to adequately handle the sediment carried in the runoff. However, sod production systems that use inputs can potentially contribute to water quality issues after installation; pesticides have been found in groundwater monitoring wells on very sandy sites following sodding.

Grassed Swales or Berms or Diversions. Channels constructed across a slope with a supporting ridge on the lower side are another effective control. These channels stabilize a runoff area and reduce sheet and rill erosion by reducing the length of slope. These measures also eliminate vertical channeling and large gullies, which reduces the amount of sediment and related pollutants delivered to the surface waters.

Berms direct water into specific areas to allow vertical filtration rather than allowing surface runoff. Vegetated swales are used to permit filtering and infiltration of storm water. The grasses for these swales should be water tolerant and erosion resistant (rapid germination and establishment to form dense sod). These types of swales are used on gentle slopes where slower velocities enhance the filtering and infiltration processes.

Swales are also effective in routing water to maximize contact time of water and vegetation. An example in which swales are helpful is the routing of water from the underdrains of greens. Filtration can be greatly increased by carefully choosing the route of water from the underdrain. If space is limited, drainage water could be directed to flow along a path that maximizes the distance of contact with vegetation, rather than choosing the shortest route to the lowest elevation. The effectiveness of swales in reducing flows and pollutants is similar to that of filter strips.

Vegetated Filter Strips. Filter strips are manmade or naturally occurring flat areas established at the perimeter of disturbed or impervious areas to intercept runoff as sheet flow and remove particulate matter and contaminants. Either grassed or wooded areas can function as filter strips.

Grassed Waterways. These natural or constructed channels are shaped, graded, and planted to ensure the stable flow of runoff. This practice reduces erosion in a concentrated flow area, such as in a gully or in ephemeral gullies, and reduces sediment and substances delivered to receiving waters. Vegetation may also filter some of the sediment delivered to the waterway; however, filtration is a secondary function of a grassed waterway.

Any chemicals applied to the waterway in treating the adjacent areas may wash directly into the surface waters when runoff occurs shortly after spraying. If standing water is present, applications of fertilizer or pesticides should also be avoided.

Turfgrass used as a Vegetative Filter. One of the most effective BMPs for protection of surface water is use of turf as a vegetative filter in swales and filter strips. Turfgrass areas are extremely effective in reducing soil losses compared to other cropping systems. In a comparison of soil loss from conventional agriculture with soil loss from turf, measured soil loss from tobacco production (4210 lbs/acre) was 842 times higher than from turf areas (5 lbs/acre), even with a slope of 16% on a silt loam soil.

Where polluted runoff from agricultural areas has occurred, establishment of turf buffer strips of only 15 feet have been shown to improve water quality. Studies at Oklahoma State University have shown that turfgrass buffers of 16 ft effectively reduce concentrations of chemicals in runoff. Other studies noted that in cases where water quality has declined due to agricultural practices that lead to loss of nutrients and erosion, grass buffer strips placed between treated fields and surface waters significantly reduce the problem (Cole et al 1997). This result is related to the architecture of the turf canopy, the fibrous turf root system, and the development of a vast macropore soil structural system that encourages infiltration rather than runoff.



Figure 4-1. Grasses filter strips discharging into water filtration basins. Source: Robert Alonzi.

Turf density, leaf texture, rooting strength, and canopy height physically restrain soil erosion and sediment loss by dissipating impact energy from rain and irrigation water droplets. These turf features also provide resistance to surface movement of water over turf. Additionally, turfgrasses have an extensive fibrous root system, with 80% of the root mass found in the upper 4 inches of the soil profile. The combination of turf canopy and root mass has a strong soil stabilizing effect.

4.3.1.2 *Structural BMPs*

Structural BMPs include water quality basins, infiltration basins, and catch basins to regulate or impound runoff. These structures detain and filter water through plant material prior to discharge and can reduce runoff quantity as well as nutrient and pesticide discharge. See Appendix D for renderings of structural BMPs.

Subsurface Drainage. Subsurface drainage directs drainage water and can reduce runoff and leaching. Subsurface drainage is also installed to control a water table or to interrupt subsurface seepage or flow. Where possible, directing this drainage into vegetative areas for biological filtration or infiltration basins helps to control the potential loss of nutrients and pesticides from the golf course, rather than directly draining it into surface water.

Water Quality Basins. These basins are designed to capture the "first flush" runoff and provide water quality treatment primarily through physical settling of sediment-based pollutants. These basins can be constructed by excavation or embankment (or both) to create a ponding area sufficient to handle the required water quality volumes. Planting wetland species in the bottoms

of these basins achieves additional quality control through biological filtering and uptake. The discharge system for basins can include a gravel underdrain layer with a small diameter perforated drainage pipe to slow dissipation of runoff over an extended period. Gravel underdrains without an outlet can also provide a measure of infiltration and groundwater recharge where appropriate. Finally, higher intensity storms can be routed through water quality basins for proper flood control and flow attenuation.

Wet Ponds. These ponds are earthen embankments or a combination ridge and channel generally constructed across the slope and minor watercourses to form a sediment trap and water retention basin. Wet ponds are one of the most effective structural BMPs for protecting water quality. Wet ponds at the golf course use a permanent water surface to achieve a high removal rate for sediment, nutrients, and metals. Aquatic plants and biochemical processes within the ponds enhance the removal of nutrients, metals and other pollutants. Secondary benefits include recreation, aesthetics, and wildlife habitat.

Pollutant removal efficiencies of wet ponds vary based on the pollutant of concern and the size of the permanent pool. The highest removal efficiencies are achieved in larger ponds at the golf course, where the ratio of basin volume to the volume of runoff from the average storm is greatest. Wet ponds are also effective in reducing peak discharges, downstream flooding, and stream bank erosion at the golf course.

This feature traps and removes sediment and sediment-attached substances from runoff. Trap control efficiencies for sediment and total phosphorus transported by runoff may exceed 90% in silt loam soils. Dissolved substances, such as nitrates, may be removed from discharge to downstream areas because of the increased infiltration. Where geologic conditions permit, the practice leads to increased loadings of dissolved substances toward groundwater. Water temperatures of surface runoff, released through underground outlets, may increase slightly because of longer exposure to warming surfaces during its impoundment.

Infiltration Controls. Infiltration controls are a general category of structural BMPs that maintain or enhance the ability of water to percolate through the soil profile. Infiltration generally improves water quality by allowing natural physical, chemical, and biological processes to remove pollutants. Pollutant removal in an artificial media or natural soil profile occurs through filtration, absorption, and oxidation by soil microorganisms.

Catch Basins. Catch basins are used primarily as a pretreatment device for the removal of coarse grit, sand, and debris. This pretreatment extends the life and performance of the other BMPs. From the catch basins, runoff is conveyed to the other water quality BMPs.

Wetland and Riparian Zone Protection. Wetlands and riparian areas are often continuums along rivers, streams, and coastal waters and are particularly sensitive to landscape changes and fragmentation. These areas play a critical role in attenuating nonpoint source pollution by intercepting runoff, subsurface flow, and certain groundwater flows and then removing, transforming, and storing pollutants (such as sediment, nitrogen, phosphorus, and certain

heavy metals). In addition, they provide aquatic habitat, stream shading, flood attenuation, shoreline stabilization, and groundwater recharge. Wetlands and riparian areas are often highly regulated by the state and local regulatory authorities.

Constructed Wetlands. Constructed aquatic ecosystems features poorly drained soils and rooted emergent hydrophytes, which simulate the role of natural wetlands in water purification. These structures efficiently remove certain pollutants (nitrogen, phosphorus, metals, sediment, and other suspended solids) and can treat wastewater, such as discharges from equipment wash pads. Once these areas are constructed, however, they are considered wetlands and regulated as such.

4.3.2 Effectiveness of BMPs

The effectiveness of pollutant removal by land use BMPs is a function of the following:

- physical, chemical, and biological processes
- the fraction of runoff treated by the BMP
- the nature of the pollutant being removed

Thus, an effective BMP train is one that treats 100% of runoff by physical, chemical, and biological processes. Table 4-1 shows relative removal efficiencies of infiltration basins, vegetated filter strips, grass swales, wet ponds, and storm water wetlands for five variables (total suspended solids, total phosphorus, total nitrogen, pesticides, and chemical oxygen demand). By including as many removal mechanisms as possible, the probability of success for removal of a particular pollutant is increased. These factors should be considered as follows:

1. BMPs that use settling and filtering processes are relatively effective at removing sediment and pollutants that are bound to sediment particles.
2. Turf buffers are very effective filters that allow drainage of water from the course and, at the same time, effective filtering to improve water quality.
3. Turf density, leaf texture, and canopy height are physical factors that restrain soil erosion and sediment loss by dissipating impact energy from rain and irrigation water droplets providing a resistance to surface movement of water over turf.
4. Ponds and infiltration BMPs can achieve 60 to 100% removal efficiencies for sediment.
5. Infiltration BMPs are capable of similar removal efficiencies for sediment, but are subject to clogging if sediment inputs are excessive.
6. Wet ponds and extended-detention ponds with shallow marshes have a moderate to high capability for removing both soluble and particulate pollutants because they use settling and biological uptake and degradation of pesticides.

Table 4-1. Stormwater pollutant removal efficiencies, urban BMP designs (Sources: Schueler 1987 and NYSDEC, 1993)

BMP/Design	TSS*	TP	TN	Zn	Pb	BOD
Extended Detention Pond						
"First flush" runoff volume produced by 1.0 inch storm, detained for 24 hours	75%	50%	35%	55%	55%	40%
Runoff volume produced by 1.0 inch storm detained for 24 hours or more with shallow marsh added in bottom stages	80%	70%	55%	75%	75%	50%
Wet Pond						
Permanent pool equal to 0.5 inch of runoff per watershed acre	55%	35%	25%	25%	45%	25%
Permanent pool equal to 2.5 times the volume of runoff from the mean storm (0.5 inch)	75%	55%	40%	40%	70%	40%
Water Quality Basin						
Infiltration basin which exfiltrates "first flush" of 0.5 inch runoff/ impervious acre	70%	50%	50%	50%	50%	70%
Filter Strip						
25 to 50 foot turf strip	40%	20%	20%	40%	40%	20%
100 foot wooded strip	90%	50%	50%	90%	90%	70%
25 to 50 foot wooded strip	80%	40%	40%	80%	80%	60%
Grassed Swale						
High slopes with check dams	20%	20%	20%	10%	10%	20%
Low gradient	30%	30%	30%	20%	20%	30%

*TSS= Total Suspended Solids; TP=Total Phosphorus; TN= Total Nitrogen; Zn=Zinc; Pb=Lead; BOD=Biological Oxygen Demand

4.3.3 Maintenance of Structural BMPs

Periodic long-term inspection and maintenance of the structural BMPs are essential to ensure that they function as designed. The superintendent and maintenance crews should be responsible for the inspection and maintenance of the BMPs for the golf course. Best practices for maintenance of these structures are described below.

4.3.3.1 Water Quality Basins

Inspections: Ponds should be inspected on a regular basis to ensure that the structure operates as designed. When possible, inspections should be conducted during wet weather to determine if the pond is meeting the targeted detention times and include checking:

- any evidence of subsidence, erosion, cracking or tree growth on the embankment
- condition of the emergency spillway
- accumulation of sediment around the riser
- adequacy of upstream/downstream channel erosion control measure
- erosion of the pond's bed and banks
- modifications to the pond or its contributing watershed that may influence pond performance

Inspections should be carried out with as-built pond plans in hand (Schueler 1987). Repairs should be made when the need for them is observed.

Mowing. The upper stage, side slopes, embankment, and emergency spillway of an extended detention dry pond must be mowed at least twice a year to discourage woody growth and control weeds. The use of water-tolerant, hardy, and slow-growing native or introduced grasses is recommended.

Debris and Litter Removal. Debris and litter should be removed during regular mowing operations.

Erosion Control. The pond side-slopes, emergency spillway and embankment may periodically suffer from slumping and erosion and require regrading and re-vegetation. However, slumping and erosion should not occur often if the soils are properly compacted during construction.

Sediment Removal. If properly designed, significant quantities of sediment can accumulate in the detention pond. This sediment should be removed periodically in order to preserve the available stormwater management capacity and to prevent the outlet or filter medium from becoming clogged. In addition, accumulated sediment may become unsightly. While more frequent sediment removal may be needed around outlet control structures, the lower stage of a detention pond should be cleaned manually typically every 5 to 10 years.

4.3.3.2 Grassed Swales

Swale maintenance keeps the grass cover dense and vigorous through periodic mowing, occasional spot re-seeding, and weed control. Watering may also be necessary during a

drought, particularly in the first few months after establishment. In addition, excessive sediment buildup behind check dams should be removed as necessary.

4.3.3.3 Vegetative Filter Strips

The maintenance required for a filter strip depends on whether or not natural vegetative succession is allowed to proceed. Maintenance tasks and costs are both sharply reduced for "natural" filter strips. However, corrective maintenance is still needed around the edge of the strip to prevent concentrated flows from forming.

Shorter filter strips must be managed as a lawn or short grass meadow and therefore should be mowed at least two or three times a year to suppress weeds and interrupt natural succession. Periodic spot repairs, watering, and fertilization may be required to maintain a dense, vigorous growth. Accumulated sediments deposited near the top of the strip need to be manually removed over time to keep the original grade.

All filter strips should be inspected on an annual basis. Strips should be examined for damage by foot or vehicle traffic, encroachment, gully erosion, density of vegetation, and evidence of concentrated flows through or around the strip. Extra watering, fertilization, and re-seeding is also usually needed in the first few months and years to make sure the strip becomes adequately established (Schueler, 1987).

4.3.3.4 Catch Basins

Catch basins should be cleaned out at least twice a year. Inlet structures usually are cleaned out with a vacuum pump. The resulting slurry of water, sediment, and other contaminants can be transported to a treatment plant or approved landfill for disposal. An alternative disposal method involves carefully siphoning out each chamber without creating a slurry and allowing it to infiltrate over a nearby grass area. The remaining grit and sediment can be removed and trucked to a landfill for final disposal. Maintenance records and clean-out schedules should be kept as part of the maintenance process.

4.3.3.5 Dry Wells

Dry wells rapidly take excess surface water and transport it to the subsoil that recharges groundwater. In areas where groundwater contamination is a problem, such as sandy areas of Long Island, the use of dry wells should be discouraged. Dry wells bypass the biofiltering capacity of the surface turf ecosystem and thus can inadvertently allow nutrients and pesticides to potentially contaminate groundwater. If they are used, the dry wells should be covered when fertilizers and pesticides are applied to prevent direct contamination of the dry wells. Applications of fertilizers and pesticide should also be avoided during wet periods when the dry wells are collecting water to prevent groundwater contamination.

Preventive Maintenance. Maintenance of infiltration facilities ensures their continued effectiveness. Preventive maintenance practices identify areas of erosion in the contributory

drainage and stabilize those areas. For example, if suspended solids are not identified and removed, void areas in the stone reservoir of an infiltration trench may become clogged.

Inspections. Logs should be maintained for each BMP structure, recording the rate of de-watering after large storms and the depth of sediment buildup in the well for each observation. Once the performance characteristics of the structure have been verified, the monitoring schedule can be reduced to an annual basis unless the performance data indicate that a more frequent schedule is required.

BMP Statements

- Properly assess maintenance sites and golf course for priority areas related to water quality protection.
- Determine most effective structural or vegetative BMP strategy, if needed.
- Assess effectiveness of implemented BMP strategy.

5 IRRIGATION

Water is a fundamental element for physiological processes in turf such as photosynthesis, transpiration, and cooling, as well as for the diffusion and transport of nutrients. Golf turf quality and performance depend on an adequate supply of water through either precipitation or supplemental irrigation. Too little water induces drought stress and weakens the plant, while too much causes anaerobic conditions that stunt plant growth and promote disease. Excessive water can also lead to runoff or leaching of nutrients and pesticides into groundwater and surface water.

Precise water management is arguably the single most important turf practice for maintaining high quality golf turf. When the amount of water lost from the turf system by evapotranspiration (ET) exceeds amount supplied by rainfall, the turf must be irrigated. Courses should maximize water use efficiency through proper irrigation, as this conserves water and decreases the likelihood of water quality impacts from runoff or leaching. Deliberate use includes using an efficient irrigation system and ensuring the system's proper function, using only the amount of irrigation water needed to maintain healthy turf in playing areas, and incorporating cultural practices that increase the water holding capacity of soil.

5.1 Irrigation Water Supply

5.1.1 Irrigation Water Sources

Irrigation water can come from several sources:

- surface water from ponds, lakes, or stormwater detention ponds
- groundwater from wells
- recycled water sources
- any combined supplemental sources from rainwater and stormwater collection

Regardless of the source, irrigation water must be dependable, reliable, and of sufficient quantity and quality to accommodate turf grow-in needs and ongoing maintenance.

In the northeast, irrigating with recycled water may become more common as the cost of water increases and availability of fresh water decreases, especially in large metropolitan areas. Recycled water is defined as any water that has been treated after human use and is suitable for limited reuse, including irrigation; this water is also referred to by other names such as reclaimed water, wastewater, and effluent water. Using recycled water may also be part of a nutrient reduction strategy to meet TMDLs in impaired watersheds.

For more information on the use of recycled water on golf courses, see:

- Appendix E, *Guidelines for Using Recycled Wastewater for Golf Course Irrigation in the Northeast*
- Environmental Institute for Golf, "Using recycled water on golf courses"
http://www.stma.org/sites/stma/files/pdfs/gcsaa_recycledwater_leaflet-1.pdf

5.1.2 Irrigation Water Quality

Water quality used for irrigation turf on golf courses must be suitable for plant growth and pose no threat to public health. Nonpotable water irrigation sources (such as recycled water or storage and detention ponds) should be tested regularly to ensure that the quality is within acceptable limits to protect soil quality and turfgrass performance. In addition, wells along the shore that supply potable water might need to be tested for salt water intrusion. Summarized below is a brief description of water quality parameters of greatest interest for irrigation water (nutrients and salinity issues); additional parameters such as pH and micronutrients may be valuable for detailed evaluations of water quality.

For more information on irrigation water quality, see:

- “Understanding Water Quality and Guidelines to Management”
<http://gsr.lib.msu.edu/2000s/2000/000914.pdf>
- “Irrigation Water Quality Guidelines for Turfgrass Sites” at
<http://plantscience.psu.edu/research/centers/turf/extension/factsheets/water-quality>

5.1.2.1 Nutrients

Irrigation water may contain macronutrients, including phosphorus and nitrogen, as well as other nutrients that should be accounted for in nutrient management programs to avoid over fertilization. Irrigation water, especially reclaimed, recycled, or effluent water, should be tested frequently. Excess nutrients may accumulate to levels that are toxic to plants, potentially influencing aquatic plant growth in rivers, lakes, and estuaries and contribute to a variety of soil-related problems. For example, irrigation water high in sodium and low in calcium and magnesium applied frequently to clay soils can break down soil structure, cause precipitation of organic matter, and reduce permeability. Table 5-1 presents the potential for problems at various nutrient levels in irrigation water. Conversion factors and an example for calculating pounds nutrient per acre-foot of irrigation water are provided in Appendix F.

5.1.2.2 Salinity

Recycled waters usually contain higher amounts of dissolved salts than other irrigation water sources within a specific geographic region (Harivandi 2007). Water quality analyses may report salinity using a number of parameters (Appendix E). Dissolved salts in recycled water tend to reduce the number of cation exchange sites, reducing the nutrient holding capacity of the soil. Deflocculation causes the breakdown of clayey soils and reduces the porosity of the soil. Accumulations of salt in the soil are also phytotoxic.

Table 5-1. Summary of Irrigation Water Quality Guidelines. Source: Duncan, R. R., Carrow, R. N., & Huck, M. T. (2009).

Water Parameter	Units	Desired Range	Usual Range	Average Domestic	Average Reclaimed
General Water Characteristics					
pH	1-14	6.5-8.4	6.0-8.5	7.7	7.1
Hardness	mg/L	<150	---	---	---
Alkalinity	mg/L	<150	---	---	---
Bicarbonates (HC0 ₃)	mg/L	<120	<610	174	194
Carbonates (C0 ₃)	mg/L	<15	<3	3.0	0
Total Salinity					
ECw	dS/m	0.40-1.20	<3.0	0.8	1.1
TDS	mg/L	256-832	<2000	617	729
Sodium Permeability Hazard					
SARw	meq/L	<6.0	<15	1.9	3.1
RSC	meq/L	<1.25	---	-2.3	-1.88
ECw	dS/m	>0.40	---	---	---
Specific Ion Impact on Root Injury of Foliar Uptake Injury					
Na	mg/L	<70	---	---	---
Cl	mg/L	<70	---	---	---
B	mg/L	<0.50	<2.0	0.17	0.44
Specific Ion Impact on Direct Foliar Injury					
Na	mg/L	<70	---	---	---
Cl	mg/L	<100	---	---	---
HC0 ₃	mg/L	<90	---	---	---
Selected Nutrients/Elements					
N	mg/L	<10	<2.2	---	---
P	mg/L	<0.1	<0.66	---	---
K	mg/L	<20	<2.0	4.0	26
Ca	mg/L	<100	<400	67	64
Mg	mg/L	<40	<60	24	23
SO ₄	mg/L	<90	<960	171	196
Fe	mg/L	<1.00	---	0.16	0.20
Mn	mg/L	<0.20	---	0.01	0.03
Cu	mg/L	<0.20	---	0.04	0.03
Zn	mg/L	<1.0	---	.012	0.08
Na	mg/L	<120	<920	70	114
Cl	mg/L	<70	<1062	82	130

Considerations for irrigation water with higher concentrations of salts (total dissolved salts (TDS) > 500) include irrigation duration and frequency, drainage, and turfgrass species selection. Generally, if the amount of water applied to soil (irrigation and precipitation), exceeds ET, salt movement is downward through the soil profile. Conversely, salts move upward in soils if ET exceeds the amount of water in precipitation or irrigation applied to soil. In the latter case, salt drawn to the soil surface gradually accumulates to levels that are toxic to plants (electrical conductivity (EC) > 3 ds/m). This basic process combined with the type of grass grown determines how severe the problem can potentially become and whether it will ultimately affect the playing quality of the turf. Perennial ryegrass and tall fescue are relatively tolerant to salinity compared to annual bluegrass, bentgrass, and Kentucky bluegrass (Table 5-2).

Precipitation levels in New York State are generally great enough to naturally flush soils, thereby controlling salinity levels in soils. If precipitation is not enough to flush soils, leaching fractions can be used to calculate the amount of water needed to flush the soil of salts. The formula for calculating the leaching requirement (LR) is as follows:

$$LR = \frac{EC_w}{5(EC_e) - EC_w}$$

where:

EC_w = Electrical Conductivity of Water

EC_e = Salt Tolerance of Turfgrass Species

Table 5-2. Relative salt tolerance of turf species in NYS. Source: Harivandi 2011.

Sensitive (<3 dS/m)	Moderately Sensitive (3-6 dS/m)	Moderately Tolerant (6-10 dS/m)	Tolerant (>10 dS/m)
Annual Bluegrass	Annual Ryegrass	Perennial Ryegrass	None in NYS
Colonial Bentgrass	Creeping Bentgrass	Tall Fescue	
Hard Fescue	Slender Creeping, Red, and Chewings Fescues		
Kentucky Bluegrass			

The sodium (Na) concentration and the quantity of other salts in the irrigation water can affect the permeability (the ability of water to infiltrate into the soil and move through the profile) in clay soil. When irrigation water has Na levels $> 200 \text{ mg L}^{-1}$, Na may build up over time and affect permeability. Calcium, which is important to soil structure stability, is displaced by sodium, which in turn causes the soil structure to break down, and results in reduced water and oxygen infiltration and percolation. This problem can become a more serious problem on fine-texture clayey soils than sand-based systems (see Table E in Appendix E).

Residual sodium carbonate (RSC) values are used to assess the sodium permeability hazard. RSC is a measure of the influence of bicarbonates and carbonates as compared to the calcium and magnesium concentration. The total salt content of the water (EC) and the sodium adsorption ratio (SAR) must be considered together when determining irrigation water restrictions due to the sodium permeability hazard (Table 5-3). RSC levels below 1.25 meq/L are safe to use for irrigation.

Table 5-3. Irrigation water restrictions related to soil water infiltration. Source Harivandi 2011.

SAR	None	Slight to Moderate	Severe
	EC (mmhos/cm)		
0-3	>0.7	0.7-0.2	<0.2
3-6	>1.2	1.2-0.3	<0.3
6-12	>1.9	1.9-0.5	<0.5
12-20	>2.9	2.9-1.3	<1.3
20-40	>5.0	5.0-2.9	<2.9

5.1.3 Irrigation Water Requirements

Seasonal and bulk water requirement analysis can be conducted to determine water requirements. The seasonal bulk water requirement analysis verifies the suitability of a water source and irrigation system to supply irrigation water under normal conditions. The maximum seasonal bulk water requirement analysis is a worst-case scenario estimate to simulate extended drought conditions, calculated by not allowing for effective rainfall. The National Climate Data Center (NCDC) provides historical climate data as far back as 1895 as well as statistics on precipitation across ten regions in New York. The NCDC uses Palmer Indices, which summarize data for precipitation, evapotranspiration, and runoff, which can be used to calculate the average number of weeks in a statistical year with a water deficit, the average values of the deficits, and the peak evapotranspiration losses assuming no precipitation. For more information, see:

- NCDC data: <http://www.ncdc.noaa.gov/>
- Calculating water requirements: Chapter 3, "Environmental Best Management Practices for Virginia's Golf Courses" at <http://www.vgcsa.org/BMPs>.

5.1.4 Water Withdrawal

NYSDEC requires water withdrawal reporting for any system capable of withdrawing more than 100,000 gallons groundwater or surface water per day. In accordance with the recently enacted water quality standard for flow, any withdrawal must also ensure that the existing best use of the waterbody from which the water is taken, such as protection of aquatic life, is not impaired.

For more information on water withdrawal reporting and regulations in New York, see: <http://www.dec.ny.gov/lands/55509.html>.

5.2 Irrigation System Design and Performance

5.2.1 Design

Irrigation systems should be designed to be efficient, distribute water uniformly, conserve and protect water resources, meet state and local code, and meet site requirements. Site specific characteristics and incorporation of water conservation practices and technologies should be evaluated in the design. The Irrigation Association lists 25 design-oriented BMPs. Figure 5-1 includes several examples of irrigation site-specific designs to conserve water.



Figure 5-1. Irrigation site-specific designs and technologies help to conserve water. Source: Frank Rossi.

5.2.1.1 Site Considerations

The design and operation of an irrigation system must be tailored to conditions on the course. Planning should account for different soil types, areas of irrigation, and turf species. Soil conditions dictate how much water is needed to complete deep and infrequent cycles to replenish water in the root zone. The areas of irrigation may also vary in their water requirements depending on site characteristics such as aspect to the sun, hill slopes, and degree of shade. For example, wind-exposed areas have greater transpiration losses than sheltered areas and therefore greater water requirements.

5.2.1.2 Infrastructure

Infrastructure design considerations include sprinkler and piping placement, sprinkler coverage and spacing, and communication options and serviceability. An irrigation system must be designed to match peak demand. The capacity to deliver more water in a short interval of time can be increased up to, but not exceeding, the infiltration rates of the soils. Any increase beyond the infiltration rate results in runoff.

The type of system used for irrigation influences the efficiency and effectiveness of water usage. Single head systems irrigate the areas closest to the head more than areas farther out. The difference in distribution uniformity presents a serious problem, as achieving planned water replacement on the outer reaches of the head results in excess water being applied in the middle and increases the risk of runoff. Double-row systems offer an improved efficiency over single-row coverage, although manual watering or other types of supplemental watering may be needed outside the fairway area and into the extended rough. Multi-row sprinkler systems provide the best method to control and conserve water, with the ability to respond to specific moisture requirements of a given fairway area. In addition, newer designs are available with multiple nozzle configurations, back and front, that provide the flexibility to more precisely size the system and improve distribution uniformity.

Advanced irrigation control systems are recommended when possible because they provide precision irrigation control. These systems provide specific schedules for each green, tee, and fairway and allow course managers to make adjustments for differences in microclimates and root zones. Weather stations can be integrated to calculate and automatically program water replacement schedules. Additional features may include rain stop safety switches that either shut down the system in the event of rain or adjust schedules based on the amount of precipitation. Advanced systems can connect soil moisture meters, temperatures gauges, and salinity probes installed on the course.

5.2.2 Performance

Properly working systems are necessary for efficient irrigation. Irrigation audits can be conducted to assess the system function, ensuring that the irrigation system works reliably and cost effectively. The Irrigation Association has published irrigation audit guidelines (http://www.irrigation.org/Resources/Audit_Guidelines.aspx). The following are common measures of system performance used in irrigation audits:

Coefficient of Uniformity (CU). CU measures

system performance by how widely a system varies in distribution. A CU of 100% means that a system is uniform. A CU of 84% or better is considered acceptable for high value products.



Figure 5-2. Regular irrigation system maintenance helps to conserve water. Source: Frank Rossi.

Because the CU is calculated with the absolute value of the deviations, the score does not indicate whether the system is over- or under-watering. In addition, the score does not indicate what section of the area tested is not performing.

Distribution Uniformity of the Lowest Quartile (DULQ). The most commonly used calculation to determine uniformity of a sprinkler layout, DULQ is the ratio of the average measurements in the lowest 25% of samples to the overall average of all samples expressed as a percentage. For example, a DULQ of 60% means that the lowest 25% of the samples measured only received 60% of the average water applied. Some resources suggest that a DULQ of 65% or less is poor, 75% is good, and 85% or more is excellent.

Scheduling Coefficient (SC): measures the average water applied to the driest, most critical areas of an area under test and compares to the average. An SC of 100% implies the distribution is uniform. An SC of 120 % indicates that the average was 120% more water applied than the driest area. The SC is often used to adjust run times to ensure that the driest areas receive the required scheduled water replacement. The disadvantage of this method is that all other areas receive 20% too much water, increasing the risk of runoff and leaching.



Figure 5-3. Regular irrigation system auditing ensures uniform application. Source: Frank Rossi.

5.3 Irrigation Management Decisions

Irrigation should be scheduled when soils reach 50% of the plant available water point and the amount of water should replenish the root zone to field capacity. The infiltration rate, effective root zone depth, and estimated ET demand determine irrigation frequency and soak cycle needs. Turfgrass species also affects irrigation frequency, since some turfgrasses more effectively resist drought than others.

5.3.1 Infiltration Rate

Infiltration rates depend on soil texture. Sandy soils have higher porosity and greater infiltration rates than silty or clayey soils. The matrix potential of the finer particle soils increases the time to wet the soil. Figure 5-2 shows the time and area wetted for two different soils: a 15 minute irrigation cycle on a sandy loam penetrates and wets to a depth of 12 inches and a 40 minute cycle wets nearly 36 inches of sandy loam, while clay loam soil requires hours of irrigation to wet the same profile.

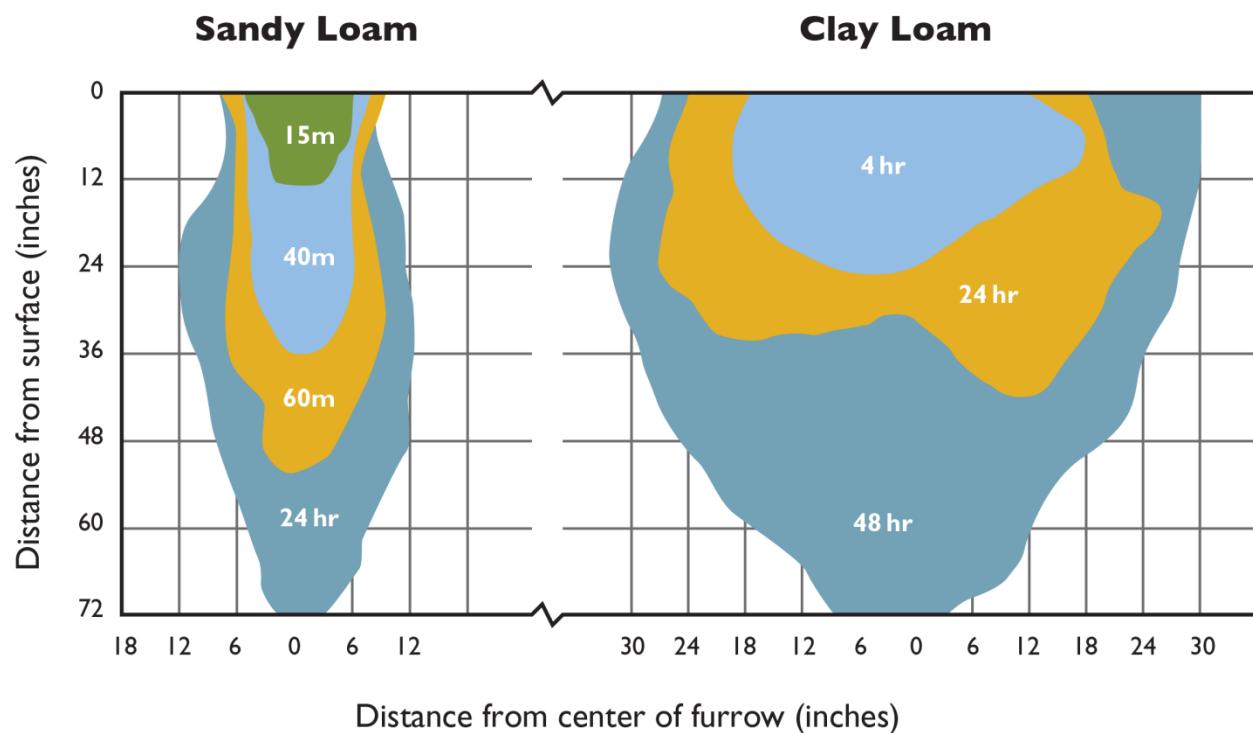


Figure 5-4. Infiltration of two different soil types measured in time and area wetted.

Soils develop unique characteristics called preferential flows that, in some cases, influence or accelerate flow through the profile downward towards groundwater. Examples of preferential flow are as follows:

- Macropores created by larger size particulate, gravel, or wormholes, create channels of preferential flow that direct water downward (Figure 5-3).

- Uneven mixes of soil types can result in veins of sandier soil that are more conductive than finer particle soils.
- Organic matter, organic residues, and subsurface layers of mixed densities may restrict and direct flow in unique patterns or fingers.
- Finger flow in sand, which acts like a large channel, allows water to rapidly flow through the profile along with any soluble compounds (fertilizer and pesticides).
- Hydrophobic soils repel water and thus the water must find another pathway, flowing (by runoff) towards areas that are wettable or into cracks in the soil.

Preferential flow and restrictions can lead to non-uniform moisture distribution in the root zone. Some areas of turf may be drier and other areas may be wetter, even saturated.

Superintendents can develop better and uniform soil conditions by managing the soil compaction and organic matter content or thatch, such as by frequent aerification and top-dressing to provide better root-zone profiles. The use of water dispersants may be required to help water move through hydroscopic soil conditions associated with localized dry spot. Wetting agents, and in some cases organic amendments, may be needed to increase water holding capacity of some soils, particularly sandy soils.



Figure 5-5. Preferential flow in soils. Source: Cornell, Soil & Water Lab.

5.3.2 Root Zone Depth

The depth of the root zone (the depth to which 90% of the root system penetrates) must be determined onsite with a soil probe or spade. The soil type and root zone depth together are used to estimate the soil water-holding reservoir available to the root system.

5.3.3 ET Demand

ET describes the water lost through soil evaporation and plant transpiration and is influenced by the climate conditions on any given day. Hot, windy days with low relative humidity have higher rates of ET than cooler calm days with low relative humidity. At the wilting point, ET has depleted the available water and the plant begins to show stress. Irrigation scheduling needs to periodically refill the soil reservoir to avoid wilting and can be scheduled by calculating the potential evapotranspiration (PET).

5.3.3.1 Calculating PET

The Northeast Regional Climate Center (NRCC) provides estimates of PET based on climate data from every regional airport in New York State. An ET rate of 0.20 is considered high. Conversely, an ET rate of 0.05 is considered moderate. Calculating PET requires a crop coefficient (K_c), which varies by plant species, the leaf area characteristics, and density of the canopy. The K_c typically used for turfgrass management is 0.80. PET estimates should be factored by the crop coefficient to calculate the water replacement to be scheduled.

$$\text{PET} \times K_c = \text{Adjusted PET for Turf}$$

$$\text{Precipitation} - \text{Adjusted PET for Turf} = \text{Water Deficit}$$

In 2012, New York State experienced three successive seasons that challenged turf managers with very hot and dry periods. Using NRCC data, the 2012 PET deficit for each week is shown for Syracuse Hancock Airport in Figure 5-3. During the 2012 season, ET exceeded precipitation for 17 weeks, exposing turf to drought stress. The total deficit was 10.18 inches of water. Replacing 80% of the PET deficit would have used 11.9 million gallons of water to irrigate 54 acres, the average number of irrigated acres on an 18-hole golf course in the Northeast (Throssell et al 2009).

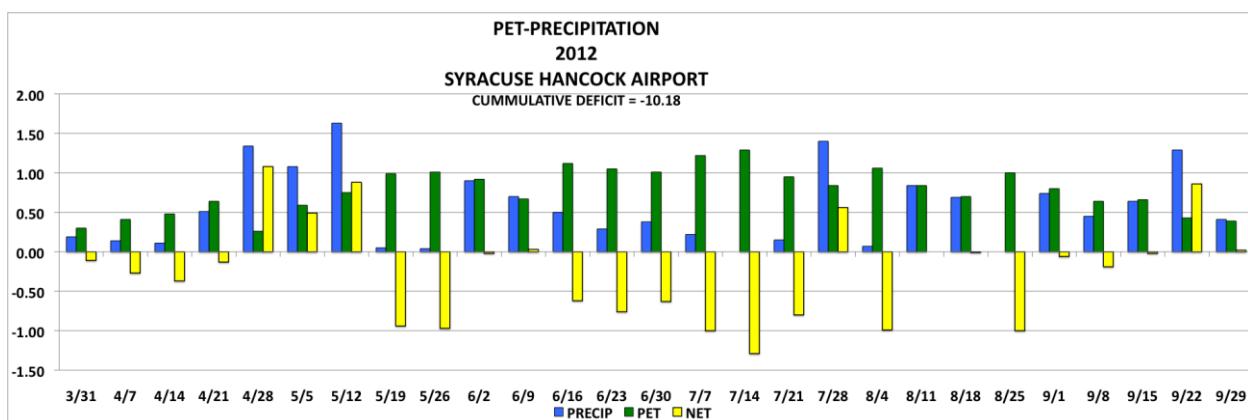


Figure 5-6. Cumulative weekly evapotranspiration deficit (Precipitation - PET) for Syracuse Hancock Airport, New York.

The NRCC provides historical data and ET forecasts at <http://www.nrcc.cornell.edu/grass/>.

5.3.3.2 Using PET

Information from onsite weather stations or PET data from the NECC can be used at a golf course scale or at a smaller scale to adjust for microclimates and conditions. Meaningful ET occurs from April through October in most cases in NY, so rainfall and ET is useful for this period. A few well-monitored golf courses in NY have demonstrated the importance of factoring in the soil water holding capacity to calculate the amount of irrigation. As shown in Figure 2-6 in Chapter 2, the soil texture determines water supply and frequency of irrigation. For example, a typical 12 inch USGA sand root-zone green will have only about 0.75 inch of

plant available water stored. Any daily rain events greater than 0.75 inch need to be reduced to 0.75 inch in the PET calculation (rainfall-ET). Also, to avoid drought stress in turf, irrigation should be at 50% of the PAW, or in the case of the sand green, about 0.20 inch of PET. On very dry days, this value could mean irrigating daily or every couple of days, depending on the weather. At the smaller scale, irrigation should be adjusted in areas with lower PET, such as shady areas. If an on-site weather station is not an option, at the least a rain gauge should be used to collect rainfall due to localized summer storms.

5.3.4 Monitoring Soil Moisture

The NRCS provides a guideline for estimating the soil moisture content of soil by touch (<http://nmp.tamu.edu/content/tools/estimatingsoilmoisture.pdf>). The turf industry, however, offers tools to more precisely measure soil moisture content. Several handheld and portable instruments can be used to spot check areas (Figure 5-7).



Figure 5-7. Root zone moisture, temperature, and salinity meter (left) and portable moisture meter (right). Source: John J. Genovesi, Maidstone Club

Programs are also available to map moisture content using global positioning system (GPS) positioning. Maps can be compared between different times of day, different seasons, and different management routines to compare soil moisture conditions. Irrigation system suppliers now offer in ground moisture meters to provide continuous data input to their controllers to adjust irrigation rates based on soil moisture.

5.3.5 Deep and Infrequent Versus Light and Frequent Irrigation

Several studies have compared deep and infrequent irrigation (DI) to light and frequent (LF) schedules. DI was applied at signs of wilting and the soil was wetted to a depth of 9.5 inches. LF treatments watered daily to replace the ET lost and generally wetted the top 1.5-3.0 inches of soil. Both treatments were syringed as required to cool turf on hot days. The turf treated using DI had increased root and leaf carbohydrates, larger and deeper root masses, reduced thatch, and better overall quality throughout the season ((Fu, J., and Dernoden, P. H. 2008; Fu, J., and Dernoden, P. H. 2009a; Fu, J., and Dernoden, P. H. 2009b). This particular study only considered physiological factors and did not assess the risks of leaching. Soils should not be

wetted much below the root zone because this practice increases the risks of pushing nutrient and pesticide residues closer to groundwater.

Other studies have demonstrated that turf pre-conditioned with deficit irrigation for a period of 7 to 14 days withstands periods of drought and has a quicker recovery. Pre-conditioning improves stomatal conductance, transpiration rates, and photosynthetic capacity in subsequent periods of stress. However, letting soils dry completely has a negative effect on plants. Creeping bentgrass, Perennial ryegrass, and tall fescue can be pre-conditioned replacing 60-80% of the water deficit. Kentucky bluegrass has much higher sensitivity to drought stress and should only be watered at 100% of deficit. Cool season turfgrass should not be watered below 40% of deficit. Even though Kentucky bluegrass has the greatest sensitivity to deficits, it has the highest resiliency to recover.

BMP Statements

- Design and maintain irrigation systems to uniformly apply water to the intended area of management.
- Determine accurate supplemental water needs based on appropriate climate and soil data.
- Assess system efficiency through regular audits of application rate and uniformity.

6 NUTRIENT MANAGEMENT

Although nutrients are present in the soil as well as in all forms of turfgrass and other plant material waste, turfgrass management requires the use of fertilizer to meet turf nutrient needs. Understanding the role of plant and soil nutrients as well as applied nutrients is essential to minimizing off-site movement of these compounds that could contaminate surface and groundwater. Because of this potential for off-site contamination, New York State and some local agencies regulate aspects of the use of fertilizers, as discussed in Chapter 3.

6.1 Nutrient Use in Plants

All plants require nutrients to sustain growth and development. Certain essential nutrients are classified as either macro- or micronutrients, based on the amount needed by plants rather than their importance for plant growth. Macronutrients include nitrogen, phosphorus, potassium, calcium, sulfur, and magnesium. Micronutrients include iron, zinc, copper, chlorine, nickel, molybdenum, boron, and manganese (a known issue on higher pH sands in NY).

Micronutrients are required in significantly lower amounts than macronutrients; however, a deficiency or excess of these micronutrients can have a profound influence on plant growth.

Proper nutrient management usually includes the following steps:

1. Determine plant needs (such as light levels, traffic levels, irrigated or not, and expected visual quality).
2. Assess the soil reservoir for availability (soil testing).
3. Determine nutrient needs and select the proper source of nutrient fertilizer (most are combination products).
4. Decide the rate, timing, and frequency of application.

6.2 Soil Testing

Soil testing is the beginning of precise nutrient management programs for all nutrients other than nitrogen as it can be used to determine nutrient levels, make fertilizer recommendations, and in some cases diagnose the cause of poor performing turf. Assessing the existing reservoir of available nutrients in the soil can minimize the need for supplemental applications of fertilizer, which saves money while protecting the environment. Soil nutrient analysis aids in determining if nutrient deficiencies exist, as many soils have various levels of nutrient holding capacity, often referred to as cation exchange capacity (CEC). For example, sand-based systems, which have only a limited amount of stored minerals, may demand more mineral additions.

Determining supplemental nitrogen needs are typically not based on soil tests as the method of extracting N and the subsequent calibration with plant growth have not been established.

Soil tests are required by the NYS Dishwasher Detergent and Fertilizer Law to confirm a need for phosphorus fertilization prior to its application. Research at Cornell University, however, concluded that no correlation exists between soil test phosphorus levels and runoff until

phosphorus levels are 50 fold greater than the sufficiency level. A survey of soil test submissions to the Cornell University Nutrient Analysis Lab found that less than 3% of all submitted samples over a 5 year period had phosphorus values at these levels.

6.2.1 Soil Sampling

General guidelines for soil sampling are as follows:

- Sample when soils are biologically active. Fall sampling is most common and allows time to review results and apply lime and nutrients in advance of spring growth and to develop a season-long plan.
- Do not sample within the two months following heavy fertilizing or liming; sampling around frequent, light applications (spoon feeding) is acceptable.
- Test soils at the same time of year to allow for comparison of results from year to year.
- Because soils exhibit significant spatial variability, take a number of samples, combine, and then subsample. As a rule, a minimum of ten sample locations should be sampled per acre.
- Sample areas with different soils and drainage separately, for instance, sample sand-based greens and tees separately from fairways and roughs.
- Take the sample from the root zone (typically 4-6 inches deep) typically by removing the grass mat from the top of the sample.

6.2.2 Laboratory Analysis

Soil test methods vary in a number of respects:

- the type of chemical extractant used to measure the nutrient that can be released or dissolved into solution
- the ratio of soil to solution
- laboratory methods

Some methods are more suitable for one type of soil than another; therefore different labs use different tests. For example, soil labs at universities in the northeast use the Morgan or Modified Morgan test, which is appropriate for the acidic soils found in this region. Other test methods, such as the Bray-1, the Olsen, and the Mehlich-3 tests, use very different extracting solutions, different soil to solution ratios, and processes and are more appropriate for other types of soils. The Olsen test is specifically designed for calcareous soils (soils that contain calcium carbonate). The Mehlich-3 provides reliable results across a wider spectrum of soil pH. Results vary depending on the test method and even when using the same method, can vary widely from one lab to another due to variations in lab procedures. Consistently use the same laboratory to perform soil test in order to compare results over time.

On sand-based areas of golf courses with low CEC (<6 cmol/kg), soil testing has limited utility. Test results in these areas are often low due to the soil's low nutrient holding capacity. On such sites, test only for pH, CEC, soluble salts, organic matter, phosphorus (to adhere to regulatory requirements); if the pH is above 7.5, also test for calcium and magnesium.

6.2.3 Interpreting Test Results

Soil nutrient analysis provides information on the levels of macronutrients (phosphorus, potassium, calcium, and magnesium) and typical micronutrients (iron, zinc, copper, and boron) present in the soil, as well as the soil pH. In addition to standard pH and nutrient information, additional soil test data, such as CEC, soil organic matter content, and total soluble salts, can be requested and may prove valuable in the management of putting green soils in particular. Soil test results may include N levels, however because nitrogen constantly fluctuates between plant available and unavailable forms, it is unclear whether this information is useful.

Laboratories report results for nutrients as either parts per million (ppm), pounds per acre (lbs/A), or as a predictive index (lbs/A can be converted to ppm by dividing the lbs/A reported by two and ppm can be converted to lbs/A by multiplying by two). Most laboratories report a rating indicating the relative status for each nutrient, such as Very Low, Low, Medium, High, or Very High. Test results provide recommended nutrient (including nitrogen) and lime application levels and frequency of application. Soil test results form the basis for nutrient management planning for selection of nutrient sources, rates of application, and appropriate timing to meet site specific needs for greens, tees, fairways, and roughs.

6.2.4 Supplemental Plant Tissue Analysis

Plant tissue analysis is a useful diagnostic tool when samples are collected over a season in which levels can be correlated with environmental, biological, and fertilizer events.

Occasionally sampling provides little information regarding nutrient management when tissue levels are not properly correlated with fertilizer need. Therefore, tissue testing is not considered a reliable means of establishing a nutrient management program on its own. Used in conjunction with soil tests, analyzing plant tissues over time can be used to observe trends that can be correlated to environmental and management factors. Tissue testing may be best used on sand-based areas and when the majority of nutrients are going to be applied in fertigation (the application of nutrients through the irrigation system) or in small amounts (spoon feeding).

6.3 Nutrient Availability and pH

The pH of a soil influences the entire soil chemical environment and fundamentally determines nutrient availability, fertilizer response, and soil biology. In general, a neutral pH is considered adequate for most turfgrass needs; however, slightly more acidic pH can allow for increased levels of metal ions to become soluble and is often favored as a means of increasing the competitiveness of creeping bentgrass and fine fescue over annual bluegrass (Figure 6-1). Soil pH can be manipulated with a variety of fertilizer sources such as ammonia sources of nitrogen that have a slight acidifying effect as ammonium is processed by microbes. In addition, various types of liming materials such as calcium carbonate or dolomitic (higher Mg) lime supply nutrients can raise the soil the pH. Salts can also raise pH.

Efforts have been made to reduce soil pH with elemental sulfur to address calcareous soil issues with pH in excess of 7.3. Due to the high buffering capacity (the ability of soils where calcium or magnesium is a parent material to resist a pH change) of soils with pH greater than 7.3, the use of elemental sulfur results in little change. This result is especially true for limestone based soils in great lakes region of the state.

Soil pH profoundly influences phosphorus (P) availability and can influence movement on and through the soil profile. Soil available P or P fertilizer added is either fixed by adsorption to soil particles or retained without precipitating into secondary P minerals. The amount of fixation and retention depends on a wide array of factors, pH being one of the most significant. Precipitation increases as iron or aluminum precipitates at acid pH or as calcium precipitate at alkaline pH. The pH equilibrium between these precipitation extremes is between 6.0 and 7.0.

6.4 Critical Plant Nutrients

Golf course managers must ensure that all supplemental fertilizer is handled and applied to maximize plant response and minimize off-site movement. Nitrogen and phosphorus are the most important macronutrients to manage correctly because they are critical to both plant health and water quality.

6.4.1 Nitrogen

Nitrogen (N) is the most important managed nutrient for both plant growth and health. Insufficient N limits growth and plants' ability to withstand stress. For example, sufficient nitrogen is required for root growth; insufficient amounts may result in a weaker root system and lower reserves. Conversely, excessive N can lead to excessive shoot growth at the expense of root growth and result in a weaker plant structure. Providing sufficient quantities of nitrogen, consistently over time, maintains turf density, quality, and function.

The source, rate, and timing of nitrogen fertilization influence the turfgrass response. For example, soluble N sources provide quick green up but often do not sustain this response for more than a few weeks (depending on rate). These factors also have a significant influence on the fate of nitrogen applied into the environment (Figure 6-2).

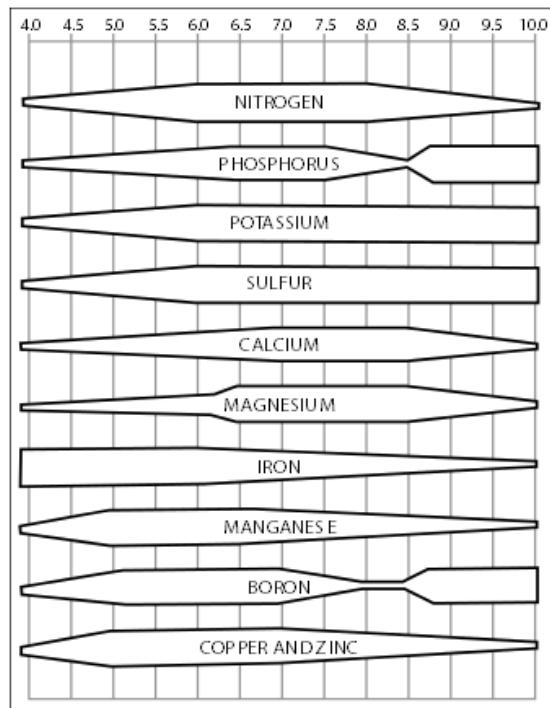


Figure 6-1. Relative soil nutrient availability as influenced by pH. Source: Virginia Turfgrass.

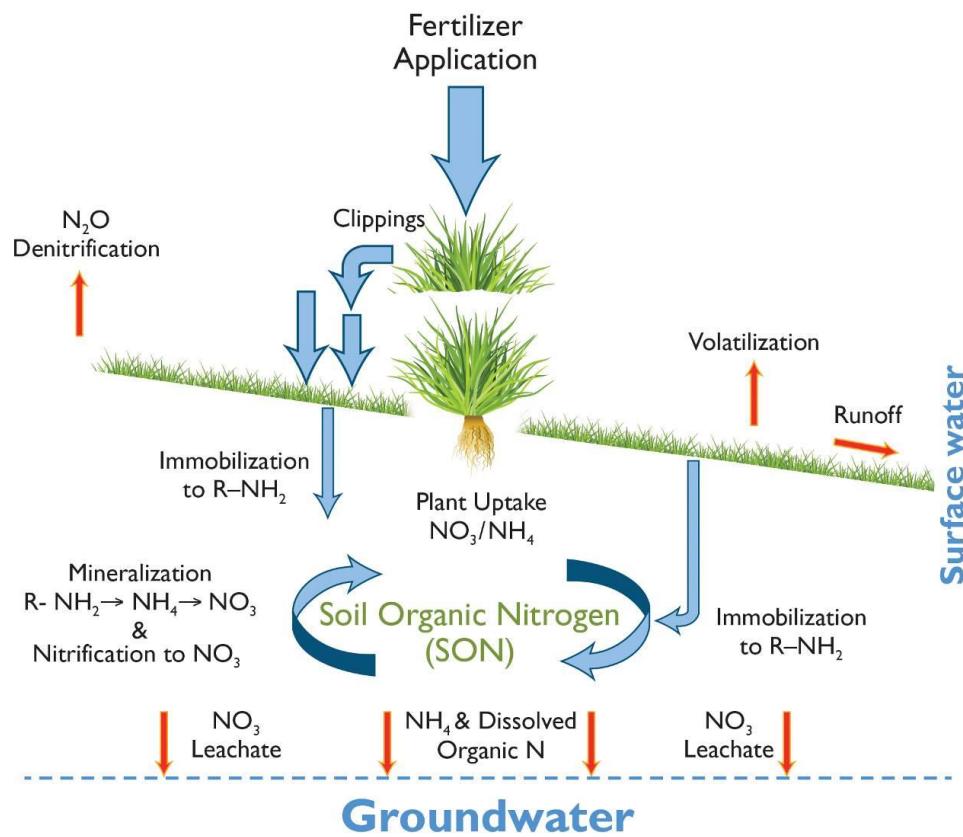


Figure 6-2. Nitrogen cycle.

6.4.2 Nitrogen Fertilizers

Many types of nitrogen fertilizers are available and vary by source, percentage of nutrient, and formulation. The fertilizer industry has standardized labeling to represent the “N” in the “N-P-K” label to represent the percent elemental N regardless of the form, while the P and K represent the percent of phosphate (P_2O_5) and potassium oxide (K_2O), respectively.

It is critical to understand the form of nitrogen supplied in a fertilizer and distinguish which forms have the lowest risk of contaminating groundwater, while still providing a consistent release of nitrogen over time. Additionally, it is critical to understand the environment that the nitrogen fertilizer is being released into to ensure minimal off-site movement.

6.4.2.1 Nitrogen Management Checklist

Using the right product, at the right time, and at measured rates of application maximizes plant use of the fertilizer and minimizes the risk of nutrient leaching or runoff. However, determining these best practices requires an understanding of other important factors.

Soil Issues

- **Soil Type:** Well-drained soils with coarse textures and high percolation rates have lower water holding capacity, greater infiltration, and higher risks of leaching.
- **Organic Matter:** Soils with low amounts of organic matter have lower biological capacity to assimilate nitrogen and are more susceptible to leaching.

Plant Issues

- **Growth Phase:** Newly seeded areas pose higher risks of leaching and runoff than well-established stands of turfgrass. Once established, the increased density of root mass increases nitrogen uptake while reducing the risk of leaching. Turfgrass in early stages of growth (1 to 20 yrs or more, depending on the organic matter starting point) has increasingly greater capacity to store and release nitrogen, reducing fertilizer requirements. The lower the amount of organic matter present in turfgrass, the longer the period of storage will be. As the site matures and the amount of organic matter accumulates (20 to 50 yrs), it poses a higher risk of leaching than younger turf.

Product Characteristics and Application

- **Product:** The best strategy for use of water soluble fertilizers is light rates of 0.5 lbs n/1000 sq. ft in general; 0.4 lbs n/1000 sq. ft on sand; and no more than 0.7 lbs n/1000 sq. ft on other soils (assuming no heavy rain events) and more frequent applications. This practice more closely matches plant uptake and ensures minimal leaching past the turf root zone. Water insoluble or slow release products, including organics or stabilized products, used properly, have a lower risk of impairing water quality through leaching and runoff. Release rates of combined fertilizer sources and applications can increase or "stack" the amount of available nitrogen. The combined total nitrogen can possibly leach nitrogen even if individual products would not.
- **Fertilizer Rate:** Excessive applications of any nitrogen-based fertilizer product can create high soil nitrate levels (>1.0 ppm) susceptible to leaching.
- **Timing:** Application of any nutrient to saturated soil or prior to heavy rainfall can lead to significant off-site movement. Applications made too early in the spring or too late in the fall result in higher soil nitrate levels, posing a greater risk to groundwater quality. Similarly, applications should be reduced during summer decline when plant uptake decreases. Research has not shown an appreciable difference in turf quality using different schedules of application. Applications made every month compared with split schedules of spring and fall, spring only or fall only show reasonable consistency. Light-frequent applications may provide the most consistent quality and limit the susceptibility of losses to leaching and runoff. Low rates of N associated with light-frequent applications may require that applications be made using spray equipment to uniform coverage and response.

6.4.2.2 Nitrogen Fertilizer Use

Water Soluble Sources

Water-soluble nitrogen (WSN), including inorganic N and synthetic organic urea, are released quickly into the soil, which can increase the risk of leaching at high rates. Inorganic sources include ammonium nitrate, ammonium sulfate, potassium nitrate, calcium nitrate, and mono-di-ammonium phosphate. Nitrate ($\text{NO}_3\text{-N}$) and ammonium ($\text{NH}_4\text{-N}$) are the principle sources of inorganic nitrogen that plants absorb. Plants generally grow best with a combination of $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$. NH_4 is best absorbed at a pH around 7.0 and less absorbed at more acidic pH. Conversely, $\text{NO}_3\text{-N}$ is best absorbed at an acidic pH.

Urea is a common and inexpensive water-soluble form of nitrogen. Urea can burn turf at high rates, but it has a lower burn potential than other inorganics. Losses due to volatilization may also be high when applied as a dry material on days that are hot ($>80^\circ\text{F}$) and humid. Lightly watering in urea solutions (when possible) reduces the amount of volatilization.

Slow Release Sources

Urea is also available coated in sulfur or a polymer for slow release with less volatilization and leaching. In other variations, urea and urea-ammonium nitrate (UAN) are also available with urease inhibitors, n-butylthiophosphoric triamide (NBPT), and nitrification inhibitors, dicyandiamide (DCD). Inhibitors reduce volatility losses and slow the rate of nitrogen release. These coated and stabilized nitrogen fertilizers are effective at reducing the risks of contaminating groundwater and increase the utilization of nitrogen applied.

Other forms of urea include methyleneureas (MU), ureaformaldehyde (UF), triazone, and isobutylidene diurea (IBDU). The MU and UF fertilizers are available in short or long chain C-H or methyl links. Shorter chains have higher salt indexes, increase the burn potential, and release N quicker. The long chain formulations releases over a longer period with lower burn potentials. The products are grouped according to their "fraction". These distinctive fractions have characteristic water solubility and release rates.

The Association of American Plant Food Control Officials (AAPFCO) requires that ureaformaldehyde products be defined to contain at least 35% N-nitrogen, largely as insoluble but slowly available products with a water insoluble nitrogen (WIN) content of at least 60%. A ureaform produced with a 1.3:1 ratio of urea to formaldehyde contains 38% N of which 65-71% is WIN. A methylene urea product with a 1.9:1 ratio contains 39% N of which 36% is WIN. Products are often produced with a mixture of other water-soluble nitrogen sources and a percentage of WIN ureaformaldehyde. Course managers must understand the product being used, the percentage of water solubility, and the release rates in order to use these products effectively.

The UF and MU fertilizers require microbial activity to release their N. A urease enzyme hydrolizes the urea to NH_4 and bacteria nitrify the NH_4 to NO_3 . Like the organic fertilizers, little

N is released unless the soil temperature is over 50° F. As the soil warms, and microbial activity increases, more N is released.

IBDU, typically 31% N, does not require microbes because it is slowly hydrolyzed by water. IBDU is available in two grades: a coarse grade that is 90% WIN and a fine grade (greens grade) that is 85% WIN. The finer grade releases quicker and is less likely to be collected during mowing. Acid soils also increase the N release rate.

Liquid "Foliar" Sources

Almost any source of nitrogen can be applied in a liquid form and, depending on how much water is used when applying, the nutrient can be absorbed foliarly. Foliar products are available using combinations of urea and other inorganic nitrogen compounds. The product is typically sprayed to coat the leaf surface. Plant uptake is generally 10-70% of the fertilizer applied, which can be higher than the amount absorbed by the roots.

6.4.2.3 Release Rates

Research often evaluates different forms of fertilizers, rating each product according to turf quality, color, and clippings as a measure of growth. While these comparisons are important, knowing the portion of the fertilizer's nitrogen content that is "immediately available" and its release rate can help in selecting products and balancing rates with plant requirements. Controlling the amount of available nitrogen also reduces the risk of excess nitrates being leached from the soil.

Biologically active soils may react quickly to release the water insoluble portion of the fertilizer adding more nitrogen that is available to the plant or movement into ground water. A series of studies confirmed that, under active growing conditions, perennial ryegrass, Kentucky bluegrass, tall fescue, and creeping bentgrass assimilate nitrogen, as either nitrate or ammonium, within 48 hours of applications (Bowman et al 1989a). The results suggest that using prudent rates of application, the plant can quickly absorb and use the immediately available nitrogen that has been applied.

6.4.2.4 Organics Versus Synthetics

Several types of fertilizers have been measured for the losses associated with runoff and leaching of phosphorus, nitrate, and ammonium. Research has determined that once turf was established, natural organics lost 3-6% of the nitrogen applied as $\text{NO}_3\text{-N}$ leachate compared to 8.6-11.1% lost for synthetic organics (Easton and Petrovic 2004). Little difference was found between sulfur-coated urea and the immediately available urea or ammonium phosphate fertilizer. Natural organics, notably dairy and swine composts, increased the percentage losses of phosphorus partially due to more P being applied at the same N amount of the synthetic fertilizer.

6.4.2.5 Water Solubility

Water solubility can potentially increase the risk of leaching. While ammonium cations (NH_4^+) can be held within the soils cation exchange sites, some soils, especially sandy soils, have too little cation exchange capacity to hold ammonium or other cations like potassium or calcium. Nitrates are freely solubilized and mobile in the soil solution. Slow release fertilizers can be used on sites with higher leaching risks to decrease the risks to groundwater. Slow release fertilizers can be applied at a rate of 2-3 lbs N per 1000 sq. ft. per year in split applications. Applications should not be made in late fall (November or later). Since much of the water recharging groundwater occurs during the late fall, winter and early spring, Late fall N applications can result in leaching for two reasons: (1) increased precipitation and groundwater recharge during the period from late fall to early spring and (2) reduced plant uptake of N during winter dormancy.

Timing

Leaching studies conclude that applying fertilizers during clear weather can prevent episodic losses of nitrates to groundwater. The use of quick release, water soluble, immediately available nitrogen sources is an acceptable practice when properly applied. Conversely, over-application or applications that are stacked due to short interval application schedules using some slow-release products can increase the risk of leaching. Precipitation events and excessive irrigation can also drive the nitrates deeper into the soil profile. Testing has shown that applications should be limited so that the water-soluble, immediately available, and released fraction of fertilizer additions does not exceed 0.5 lbs N per 1000 sq. ft., 0.4 on sand, and no more than 0.7 on other soils (assuming no heavy rains in the next several days).

6.4.3 Off-site Movement of Nitrogen Fertilizer

A variety of chemical and environmental factors influences the potential for off-site movement of nitrogen through leaching and runoff.

6.4.3.1 Nitrogen Leaching

All applied N eventually becomes the ammonium or nitrate form of N (or soluble organic N in some cases). Ammonium (NH_4) is rapidly converted in soils to nitrate (NO_3). Ammonium is also tightly held in the clay or organic profile of a soil, typically within the upper 0 to 2-inch layer. Studies typically report only trace amounts of NH_4 in leachate even under high fertilization and irrigation schedules (Bowman et al 1989b; Frank et al 2005).

Excluding the effects of runoff, nitrate ($\text{NO}_3\text{-N}$) presents leaching concerns for groundwater quality. Any fertilizer with solubility greater than 30 mg/L (or 30 ppm) can pose a risk for leaching and groundwater contamination. Leaching flow has been measured highest in winter and spring when plant water use is low and little N is taken up by the grass. However, "episodic" leaching events have been observed in the growing months when precipitation (or irrigation) is greater than the amount of water held in soils plus the amount used by plants.

6.4.3.2 Nitrogen Runoff

Runoff losses have been found to be five times greater on the lower slope than the upper slope in a study conducted on a 6-8% slope with sandy loam to loam soils (Easton and Petrovic 2005). The greater losses at the bottom of the slope were associated with higher clay accumulation, lower infiltration rates, wetter soils, and reduced lateral flow. The losses in the lower slopes are indirectly noted by higher saturation levels.

In general, runoff from turf during non-frozen soil conditions is due to saturation excess, not due to infiltration excess. Slope profiles in the topography of a site can lead to accumulated saturation zones that are prone to runoff. Such areas may also have shallow profiles with clay, bedrock, or other compacted soil layers (sometimes seen from construction activities) that creates or restricts lateral flow. The restrictions increase runoff losses in that area. The creation of shallow lateral flow channels tends to carry losses to other areas, including groundwater recharge.

For newly seeded sites, infiltration rates in turfgrass systems increase with age. Infiltration rates increase with increased shoot density through establishment. As infiltration rates increase, runoff decreases. Within a year after seeding, the infiltration rate can increase from 0.1 inch/hr to over 4 inches/hr. The frequency, duration, and intensity of irrigation or precipitation events can be overriding factors in ground saturation and runoff.

6.4.4 Phosphorus

Phosphorus is a critical nutrient for turfgrass growth and development, playing important roles in energy transformations in plant cells and root development. Therefore, P enhances turfgrass establishment and is the most important nutrient in 'starter fertilizers'. On soils low in P, most of the enhanced establishment is from the N. Phosphorus management is focused on maximizing plant response to supplemental phosphorus, when required as based on soil test results, while minimizing offsite movement.

In the soil, P is generally in complex with other elements and is an insoluble (plant unavailable) nutrient. Phosphorus is slowly made available to plants on an 'as needed' basis by chemical reactions in the soil that convert it to either of two anionic forms, dihydrogen phosphate ($H_2PO_4^-$) or hydrogen phosphate (HPO_4^{2-}).

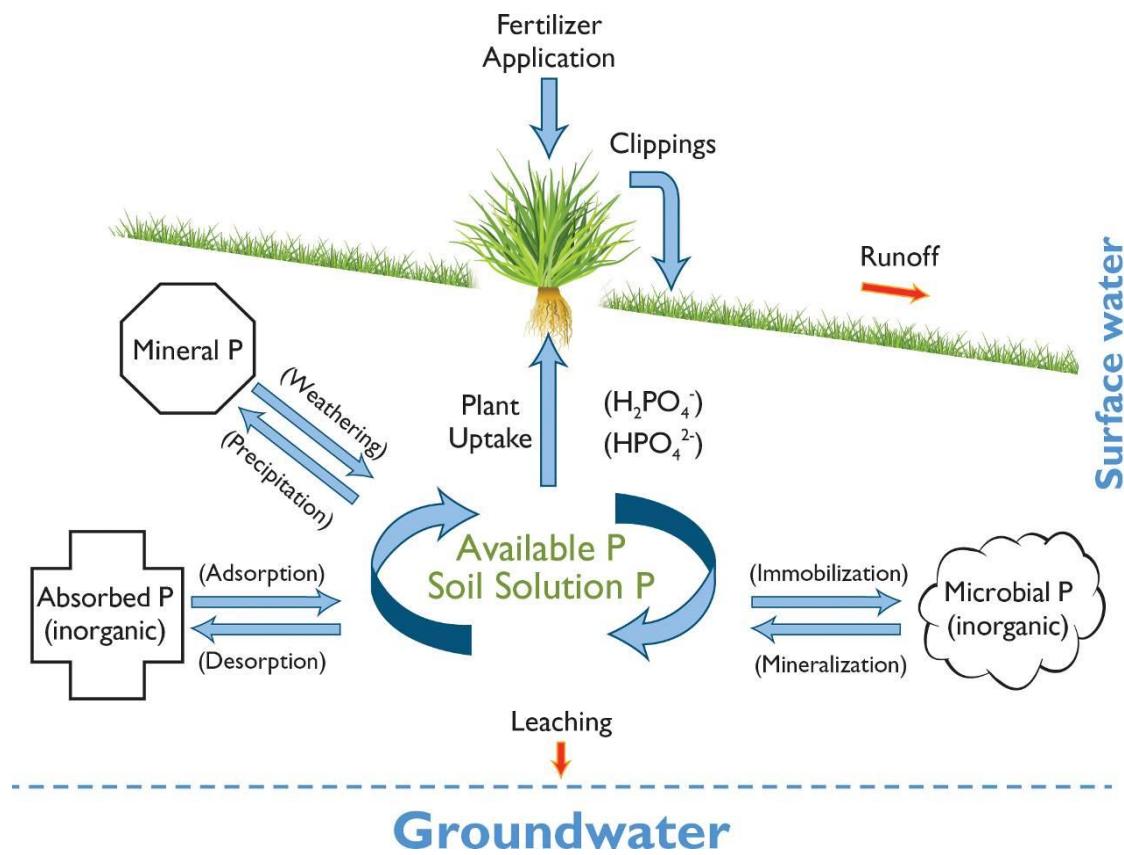


Figure 6-3. Phosphorus cycle.

A soil is considered to have a phosphorus deficiency if it is at or below the medium sufficiency level. Research has often found that turfgrass shows signs of distress at P levels of 5 to 11 ppm (Mehlich III), a range considered Low or Very Low. The medium sufficiency ratings for each test method are shown in Table 6-1.

Table 6-1. Medium sufficiency levels by test method. Source:
<http://nmsp.cals.cornell.edu/software/Morganequiv7.xls>

Test Method / Extractant	Medium Sufficiency	
	ppm	lbs/acre
Mehlich-3	26-54	52-108
Bray P1	15-30	30-60
Olsen	12-28	24-56
Morgan (for agronomic crops)	10-20	20-40
Modified Morgan/Cornell (for turf)	< 2	1-4

Testing labs provide recommendations for the amount of phosphorus fertilizer needed to correct the deficiency. Recommendations are made separately for fertilizing established turfgrass or for pre-plant fertilization to establish a new stand of turf with either seeded or sodded turfgrass (Table 6-2).

Table 6-2. Phosphorus fertilizer recommendations for turfgrass (Petrovic 2012).

Established Turfgrass	Current Recommendations		P ₂ O ₅ Recommended lbs/acre
	Morgan lbs/acre	Mehlich-3 lbs/acre	
Low	< 1	< 3	80
Medium	≥ 1	≥ 3	40
High	> 4	> 12	0
Newly Seeded or Sodded Turfgrass	< 1	< 3	140
	≥ 1	≥ 3	100
	≥ 4	≥ 12	60
	≥ 8	≥ 24	40

6.4.5 Phosphorus Fertilizers

Phosphorus fertilizers are processed from rock phosphate mined from apatite mineral deposits around the world. The processing increases the availability of reactive and water-soluble P content. Many products formulations are available. The P content of any fertilizer is listed in the N-P-K ratio on the label as the percent P₂O₅.

Water solubility is a measure of the fertilizer's ability to dissolve into the soil solution. Some of the water-insoluble fraction of the fertilizer P can be extracted by citric acid. The remaining P is citric insoluble and remains in the soil until soil processes mineralize the insoluble P. The water soluble fraction and the citric acid soluble fraction comprise the total plant available P. The formulas to convert these factors are based on the molecular weight:

$$\%P = \%P_2O_5 \times 0.43$$

$$\%P_2O_5 = \%P \times 2.29$$

Using a higher solubility fertilizer, while perhaps best for the plant, increases the risk of leaching or runoff contamination. Phosphorus fertilizers are listed in Table 6-3 with the corresponding fraction of Total Plant Available P (water soluble and citric soluble fractions).

Table 6-3. Phosphate fertilizers (Tisdale, 1993; Turgeon, 1985)

Fertilizer	%N	% P ₂ O ₅	%P	% Total P Available	Cold Water Solubility (g/L)	Salt Index
Rock Phosphate	---	27-41	12-18	14-65	---	---
Single Superphosphate	---	16-22	7-9.5	97-100	20	0.4
Triple Superphosphate	---	44-52	17-23	97-100	40	0.2
Monoammonium phosphate (MAP)	11-13	48-55	21-24	100	230	2.7
Diammonium phosphate (DAP)	18-21	46-53	20-23	100	430	1.7
Ammonium polyphosphate	10-15	34-37	15-16	100	---	---
Urea ammonium phosphate	28	27	12	100	---	---
Nitric phosphates	14-28	14-28	6-10	80-100	---	---
Potassium phosphates	---	41-51	17-22	100	---	---
Sewer Sludge	4	6	0	0	---	---

6.4.5.1 Phosphorus Management Checklist

Soil Issues

- Phosphorus fixation increases with increasing clay content in the soil. The larger amount of surface area associated with clayey soils and the Al-Fe minerals in the lattice help adsorb more P than other soils. In calcareous soils, the adsorption is associated with calcium carbonate (CaCO₃).
- Larger fertilizer additions are required to maintain a level of plant available P in finer soils compared to that in coarser, sandy soils. The risk of leaching P is highest in sandy soils.
- The rate of biological activity, and therefore P mineralization, increases with increasing temperatures. Fertilizer applications should only be applied to active soils when soil temperatures are above 50°F.
- Liming acid soils increases the P solubility in acid soils, but over-liming can reduce P solubility. Sorption also occurs to calcium cations (Ca²⁺) but only at pHs up to 6.5. At higher pH values, Ca-P precipitates form.
- Incorporating P into the soil when possible increases adsorption and reduces the amount of plant available P. Broadcasting P fertilizer on the surface leaves the fertilizer susceptible to runoff.

Plant Issues

- Returning clippings to the turf is a practical method of returning organic P back to the soil. Clippings may account for 0.10 to 0.35 lbs P per 1000 sq ft. If clippings are removed, the loss of P depletes available P for plant uptake.

Other Sources Issues

- Foliar applications at light rates may increase plant uptake. Unabsorbed foliar P, however, remains at risk for episodic losses due to runoff caused by heavy precipitation or excessive irrigation. A light irrigation after P fertilizer application has been shown to reduce P runoff.
- Phosphanate fungicides are chemically different from phosphanate fertilizers in that the fungicide provides a phosphite ion ($H_2PO_3^-$) having one less oxygen atom. Potassium phosphite, also labeled as mono and di-potassium salts of phosphorus acid, Aliette, and Chipco Signature are the most common examples of a phosphanate fungicides. No evidence suggests that the phosphite ion is used in the plants metabolism. Regardless, the amount of P supplied in any fungicide application is negligible.

6.4.5.2 Phosphorus Fertilizer Use

Rock Phosphate

Rock phosphate can be used as a P fertilizer on soils with a pH of 6 or less. It is not soluble in water. The mineralization of P is a slow process, typically over a period of years depending on soil properties. If used, it should be finely ground and incorporated into the soil. If a soil test indicates a severe deficiency, others sources may be best for the short term. However, rock phosphate could be used as a long term source.

Single and Triple Superphosphates

Single superphosphate (SSP) has 16 to 22% P_2O_5 (7 to 9.5%P). The fertilizer is 90% water soluble and is all plant available P. SSP also contains 12% sulfur (S).

Triple superphosphate has 44 to 52% P_2O_5 (17 to 23%P). The fertilizer has a very high water soluble fraction. It is only available in granular form.

Ammonium Phosphates

Studies suggest that there is increased plant uptake of the P in ammonium phosphate fertilizers due to the presence of ammonium (NH_4^+). Monoammonium phosphate (MAP) and diammonium phosphate (DAP) are water-soluble. MAP and DAP are granular products (Tisdale 1993).

Monoammonium, diammonium, and ammonium polyphosphate are typically used for foliar P applications.

Biosolids

Another source of P comes from the use of biosolids as an organic fertilizer. Milorganite is a popular example containing 6% nitrogen and 4 % P₂O₅. Release of the N and P fractions is by microbial mineralization.

Other P Sources

Phosphorus may be an integral by-product of other soil amendments, natural organic fertilizers, and bio-stimulants. The most notable additions come from the use of composts as soil amendments or nitrogen sources and the use of recycled water.

- **Manure & Composts:** Fertilizers that are produced as by-products of the livestock or poultry industry can be classified as composts or manure. Phosphorus in these products exceeds the 0.67% limit stated in the Dishwater Detergent and Nutrient Runoff law, but have been exempted. Manure and composts are often used to improve soil structure or as sources of nitrogen fertilization. Applying dairy composts incorporated into the top 6 inches of soil at rates of 600 to 1,200 lbs per 1,000 sq ft introduces 5 to 10 lbs P per 1,000 sq ft. Dairy compost, at approximately the same rates, introduces 4 to 8 lbs P per 1,000 sq ft. The use of compost as a soil amendment has been shown to greatly increase the stratification of P in the upper soil profile and the risks of runoff contamination.
- **Recycled Water:** Recycled water used for irrigation has been reported to contain a range of 3 to 10 mg/L of inorganic PO₄-P and 10 to 15 mg/L of NO₃-N and NH₄-N each. The nutrients can be used for plant growth.

6.4.6 Off-site Movement of Phosphorus Fertilizer

Similar to nitrogen fertilization, a variety of chemical and environmental factors influence the potential for off-site movement of phosphorus. The primary means of off-site movement is by runoff due to phosphorus content at or near the soil surface. Improper handling of organic waste, notably clippings, can also be a significant source of phosphorus movement off-site, and thus clippings should not be placed in or near storm water treatment structures or wetlands. Finally, phosphorus leaching can occur, but only under very specific soil and chemical situations.

6.4.6.1 *Phosphorus Runoff*

Turfgrass, like other untilled systems, accumulates higher concentrations of soil P in the upper soil profile (0 to 2 inches) compared to lower depths. Frequent P fertilization, especially at higher rates, substantially increases the soil P levels in this upper profile. Consequently, P in fertilizer can be lost in runoff, as much as 20% of P fertilizer. Runoff can also wash away soil sediment and plant debris with mineral P and organic P. The runoff risks are very high during turfgrass establishment due to limited plant utilization and more runoff present than in established turf.

6.4.6.2 Phosphorus Leaching

In its rare anionic form, phosphorus can leach and is a concern for water quality issues. P leaching potential is best managed by applying P based on soil test results. When phosphorus is complexed with other elements in the soil, however, it has a low leaching potential unless it has been over applied for many seasons. Sandy soils, on the other hand, often have a low potential to fix (tie up) P and therefore are more likely to have a P leaching problem.

6.5 Fertilizer Applications

Proper application of fertilizers is possible only with accurately calibrated sprayers or spreaders. Incorrectly calibrated equipment can easily apply too little or too much fertilizer, resulting in damaged turf, excess cost, and contamination of the environment. Therefore, sprayers and spreaders should be calibrated at first use and after every fourth application. The time it takes to calibrate application equipment is returned many fold in improved results. An excellent resource for spreader care and calibration can be found on the Penn State Plant Science website (<http://plantscience.psu.edu/research/centers/turf/extension/factsheets/calibrating-spreader>). Spreaders should also be thoroughly cleaned after use due to the high salt content that corrodes metal parts. However, the wash water will likely contain N or P and should be disposed of properly (see Chapter 10).

6.5.1 Granular Fertilizer Application

Fertilizer is applied to turf in both granular and liquid forms. When applied in a granular form, it is distributed with a drop, rotary, or pendulum-type spreader. The drop, or gravity-type, spreader has a series of openings at the bottom of the hopper through which the fertilizer drops a few inches to the ground directly beneath. The rate of application can be changed by adjusting the size of the openings. Drop spreaders distribute fertilizer precisely and uniformly.

Drop spreaders are usually two feet wide, but wider models are available. Drop spreaders are normally preferred for the application of fine or very light particles such as ground limestone or granular pesticides that must stick to the foliage. Too much overlapping or misses between application swaths can result in streaking because of uneven nitrogen distribution.

Rotary spreaders are also called centrifugal, broadcast, or cyclone spreaders. Most have a plate, called an impeller, which is attached beneath the hopper and spins as the spreader wheels turn. When fertilizer drops through the adjustable openings at the bottom of the hopper, it falls onto the rotating impeller and is thrown away from the spreader in a semicircular pattern. Rotary spreaders broadcast granular materials over a wider area and faster than the drop type. The spreading width normally ranges from 6 feet for small spreaders to 60 feet for very large ones. Streaking is less likely with rotaries because the swaths are overlapped and the edge of the distribution pattern is not as sharp as that produced by a drop spreader. Rotary spreaders do not provide as accurate and uniform an application as drop spreaders, but the distribution can be satisfactory if the proper overlap is used. Spreading mixed materials of different sizes is a problem because larger, heavier granules are thrown farther than smaller, lighter particles and

ground limestone often drifts when applied with a rotary spreader. The speed at which the spreader is pushed or driven has a major impact on application rate.

Pendulum-type spreaders have a spout that moves from side to side. They are pulled by a tractor or turf vehicle, have a large hopper capacity, and can throw dry materials a great distance when the spout moves rapidly.

6.5.2 Liquid Fertilizer Application

Liquid fertilizer applications allow for lower rates and more precise applications than granular application. Liquid application is usually less expensive than granular applications, though the initial cost of the sprayer equipment is high compared to the cost of a spreader. If not expecting foliar uptake of nutrients, a minimum two gallon spray volume of the fertilizer-water mixture is applied per 1,000 ft² to ensure that fertilizer washes into the root zone.

Fertigation is the application of nutrients through the irrigation system. Minute amounts of fertilizer are regularly metered into the irrigation lines and distributed along with the irrigation water through the sprinkler heads. For fertigation, the irrigation system must be capable of distributing water uniformly. The advantages of fertigation include a more efficient plant use of nutrients, a steadier growth rate, and a savings on labor costs. Fertigation is not widely used yet on NYS golf courses, but could significantly improve nutrient application efficiency and water quality protection. So far, it has been most widely used during grow in to aid establishment, or for applying about half of the total yearly amount of N.

BMP Statements

- Recognize all organic waste generated on golf course contains nutrients that are potential contaminants.
- Determine accurate supplemental nutrient needs based on soil chemical and physical analysis. On sand based areas, consider foliar testing as a diagnostic tool.
- Supplement soil with appropriate rate and source of nutrients to maintain optimum availability and minimum off-site movement.
- Assess application efficiency through regular equipment calibration.

7 CULTURAL PRACTICES

Cultural practices support turfgrass density and therefore play an important role in preserving and protecting water quality. This chapter provides specific recommendations for ensuring that the turf is properly adapted and has adequate infiltration, yet sufficient water and chemical holding properties to minimize effects on water quality.

7.1 Turfgrass Selection

The increased availability of improved turfgrass species and varieties provides an excellent opportunity to select the most well adapted turf to site conditions (Figure 7-1 and 7-2). Well adapted species require reduced amounts of inputs of supplemental fertilizer and pesticides, and if selected for drought tolerance, requires less water to survive and maintain playability.



Figure 7-1. It is critical to keep abreast of the latest developments in turfgrass breeding when selecting the best species and varieties. *Source: Frank Rossi.*



Figure 7-2. Attending field days offers great opportunities to interact with turfgrass scientists on the latest in turfgrass species and variety developments. *Source: Frank Rossi.*

7.1.1 Climate

Highly specific and often less than ideal microclimate conditions challenge many superintendents. A common microclimate is a putting surface location with light deficits and restricted air movement. In these situations, limited options exist for proper turf selection, as these climates simply cannot sustain any turf without significant inputs. Typically, in northern climates, these adverse site conditions lead to increases in weedy species such as annual bluegrass.

7.1.2 Choosing the Right Grass

The perennial nature of golf turf implies that when you do establish or renovate a new turf area it is critical to choose a well-adapted species and variety. Of course putting surfaces are unique growing environments, but larger areas such as fairways could have grasses adapted to reduced nutrient levels, and traffic tolerance potentially reducing the nutrient loading. This is an important BMP for nutrient management. Additionally, natural areas that serve as Landscape BMP's also require careful attention to finding a well-adapted species. Certain grasses adapted to low inputs, reduced mowing, even submersion tolerance could be part of the selection criteria. Ultimately, it is vital to start out with a well-adapted species that will thrive, meet the functional and visual quality expectations, and be sustained using BMPs.

7.1.3 Annual Bluegrass Invasion

Over time, annual bluegrass becomes the dominant species in turf. This invasiveness is a result of the highly adaptive and prolific reproductive capacity of annual bluegrass that favors its competitive ability over other cool season turfgrass. Therefore, regular surface disruption when desirable turf is not actively growing selects for the invasive annual bluegrass.

Eventually, every course faces the choice to renovate or manage, invariably when there is catastrophic failure. Renovation eradicates and then manages to exclude annual bluegrass, hopefully with proper site modifications to allow perennial species to thrive. Conversely, others choose simply to manage the annual bluegrass type that has colonized the location. This is a "pay me now or pay me later" situation where management is less disruptive, but the inputs required to sustain adequate turf are costly.

Research shows that annual bluegrass requires significantly more inputs to provide acceptable quality golf turf, especially on putting greens, than more perennial species such as bentgrass or fescues.



Figure 7-3. Annual bluegrass invasion into existing bentgrass putting green. Over time, the continued surface disruption and shift in maintenance will lead to increasing populations of this invasive species. *Source: Frank Rossi.*



Figure 7-4. Annual bluegrass is very susceptible to winter damage, especially from ice accumulation. Note the live bentgrass amongst the dead annual bluegrass. As the turf thins, the potential for off-site movement of inputs increases. *Source: Frank Rossi.*

7.1.3.1 Annual Bluegrass and Water Quality

For water quality protection, the answer seems obvious that the less annual bluegrass being managed, the fewer inputs required, and the lower the risk to water quality. While this solution may not be as practical on putting surfaces, the putting surfaces comprise less than 10% of the managed turf. It is fairway, rough, and tee areas where annual bluegrass challenge water quality preservation with large tracts of land being treated to sustain a weedy species.

Why do courses not simply renovate to more perennial creeping bentgrass species? Because renovation is disruptive and preventing annual bluegrass re-invasion is difficult. The re-invasion often occurs because of managers' reluctance to alter site conditions, but also because restricted play in cold periods (when bentgrass is damaged) allows annual bluegrass to thrive. As a result, mixed stands of annual bluegrass with perennial grasses such as bentgrass, fescue, ryegrass, and Kentucky bluegrass must be managed. The recommended BMP is to favor the competitive ability of the perennial species in management practices in hopes that the annual bluegrass will adapt and tolerate the management. The better adapted the perennial turf is to the site and management, the better it competes with the annual bluegrass.

7.2 Turfgrass Establishment

At times, effective golf turf management requires renovating an existing stand or establishing new turf. Renovation can be ideal for including the genetically improved turfgrasses, which are well-suited to modern golf turf management. Also, the latest genetic material often requires significantly fewer inputs, further reducing the need for fertilizer, pesticides, and water.

Establishing new turfgrass areas or renovating existing stands can create significant risk to water quality. During establishment, soil is exposed prior to seeding or sodding to ensure effective contact for water transfer from the soil to the plants. Therefore, practices should be implemented that reduce establishment time to full turfgrass cover and protect the soil from being transported in rain events during establishment. These practices can include sodding heavily sloped areas or mulching new seedlings.

Minimizing the amount of fertilizer and chemicals used during the establishment phase is critical, as the establishing turf does not provide the needed uptake to prevent runoff and leaching. For example, a Cornell University study found that using fungicide-treated seed instead of a granular fungicide at establishment significantly reduces the risk of leaching.

Newly establishing areas, especially from seed with soil exposed, should be irrigated carefully. Light, frequent amounts of water to keep the seedbed moist will encourage germination and seedling development. Once the turf density reaches 60 to 70%, cover irrigation can be reduced to more normal levels, as turf will begin to root and extract water and nutrients from the soil.



Figure 7-5. The use of sod can limit the species and varieties used, but significantly reduces the risks associated with new establishment. Source: Frank Rossi.

7.3 Turfgrass Density and Runoff

Turfgrass runoff research consistently concludes that maintaining high shoot density turf is the most effective means of reducing runoff volume. The tortuous path travelled by rainfall or irrigation water increases as the number of shoots per unit area increases. In addition to the reduced runoff, the fibrous root system of turf has been shown to increase infiltration. The longer the water deposited on the turf surface is delayed from runoff, the more likely that proper infiltration will occur. The combination of reduced runoff volume and increased infiltration is a primary aspect of water quality protection, thus maintaining a dense turf is vital. In addition, denser turf also provides a better playing surface.

7.3.1 Mowing

A turf is defined as low growing vegetation maintained under regular mowing and traffic. Conversely, areas not regularly mowed are not considered turf. Mowing is a significant selection tool and one that, when done properly, has a profound influence on turf density.

7.3.1.1 Mowing Height

Mowing practices require decisions regarding type of mower, height, frequency, and clipping management. Individually and collectively these practices, when performed properly, maximize turf density.

Height of cut is often determined by the function of the site, with additional emphasis on visual quality. A close cut turf is often viewed as more aesthetically pleasing. However, lower heights of cut, especially at turf heights below 1.5 inches, require more maintenance to maintain turf density.

Mowing height significantly affects rooting depth because the lower the turf is mowed, the shorter the root system, and therefore the greater concentration of surface rooting. Additionally, the lower height of cut requires more frequent mowing as leaf extension accelerates when turf is cut lower and tissue must be removed more frequently.

Ultimately, every turfgrass species has an ideal mowing height range and a mowing range that the species can tolerate. Maintaining turf within the ideal range maximizes density. As long as mowing heights remain within the tolerance range, however, adequate density is possible when other maintenance factors such as water and nutrients are provided in the optimal range.



Figure 7-6. Proper mowing adjustment, especially reel mowers, ensures maximum turf performance while minimizing stress that leads to reductions in turf density. Source: Frank Rossi.

7.3.1.2 Mowing Frequency

The turf growth rate and height of cut dictate mowing frequency. As mentioned previously, the lower the cut, the more frequently mowing is required. In general, increasing mowing frequency increases turf density.

Little evidence supports the accepted rule that no more than 30% of the leaf tissue should be removed in a single mow. Instead, significant evidence indicates that some turf species such as tall and fine fescue and perennial ryegrass can have between 50 and 75% of the tissue removed before any turf thinning occurs. Ultimately increasing mowing frequency positively effects turf density, but will increase the energy consumption of the maintenance program.

7.3.1.3 Mower Selection

Mower selection is based on the expected height of cut. Mowing heights at or below 1.5 inches are typically best achieved with a reel-type mower. Reel mowers allow for rapid clipping of turfgrass tissue at practical operating speeds with minimal turf damage (when properly

adjusted). Mowing heights above 1.5 inches are best achieved with rotary impact mowers, also when blades are sharpened and properly balanced.

Any mistake in mower set up from blade sharpness to bedknife alignment can lead to increased stress from wounding and reduction in turf density. Therefore, the mower must be properly adjusted and set up to minimize leaf shredding and wounding for pathogens. Reel and rotary mower blades are shown in Figures 7-7 and 7-8.

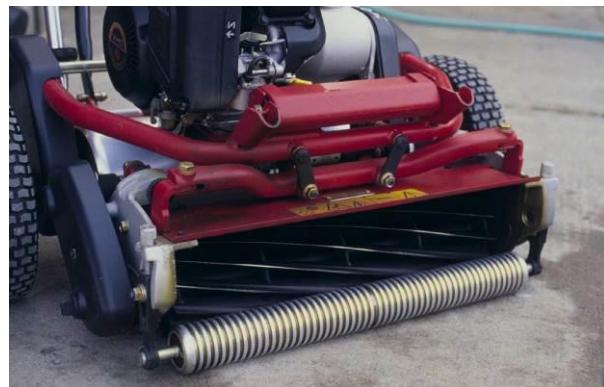


Figure 7-7. Reel mowers are ideal for golf turf mowed under 1" height of cut. *Source: Frank Rossi.*



Figure 7-8. Rotary mowers are best used for height of cuts above 1". Blades should be sharpened after every 10 hours of use. *Source: Frank Rossi.*

7.3.1.4 Clipping Management

Clipping management is the decision to let the clippings fall back to the turf canopy or remove them in a bucket or bag. From a water quality perspective, grass clipping are a nutrient rich resource and should be viewed as fertilizer and handled and applied with similar precaution. Accumulated clippings distributed over a relatively small area can significantly increase nitrate leaching. Some courses will remove clippings from fairways. Distributing these clippings to driving ranges, clubhouse lawns or simply stockpiled as organic waste. Excessive clippings aggregation has been shown to increase soil nitrate levels from less than 2.5 mg N kg⁻¹ to a range of 15-30 mg N kg⁻¹ across the 3-12 inch profile in areas that received four times the amount of normal clippings return. (Bigelow et al. 2005).

Removal of clippings should only be performed if the function of the site dictates removal (such as ball roll on a putting surface). If clippings are left on the site, they must not be allowed to discharge into adjacent water bodies or to clump on the surface and shade the turf (Figure 7-9 and 7-10).

Several research experiments have investigated the effect of long-term clipping management on turf fertilization. In general, clipping removal mines the soil for nutrients and takes them to another location. Thus leaving the clippings on the site as the turf ages assists in sustaining the nutrient content of the soil and reduces the reliance on supplemental fertilizer.

In summary, a properly mowed turf maintains a high shoot density that limits surface water movement. A properly mowed turf sustains an adequate underground biomass to retain additional water and nutrients that infiltrate. Finally, when managing clippings consider them a nutritional resource and leave them on site if possible. Use care in removing or discharging in order to preserve water quality (for instance, do not put clippings in or near storm water treatment structures or wetlands).



Figure 7-9. Clipping removal is only recommended on surfaces where they disrupt the function of the sites, such as putting surfaces. Source: Frank Rossi.



Figure 7-10. Clippings left on turf after mowing can lead to shading of the turf below and heat stress from microbial activity generated in the piles. Source: Frank Rossi.

7.4 Organic Matter

Turf is a perennial plant system that increases biomass as a result of growth and management. Biomass accumulates at the surface from the development and deposition of plant parts such as leaves, stems, and roots. Aboveground plant parts such as leaves and stems are often removed and regrown as a result of frequent mowing. Underground plant parts such as stems (rhizomes) and roots cycle as living, dead, and decomposing organic matter.

The accumulation of organic matter in the top 3 to 6 inches of a turf system provides nutrient and water holding as well as cushioning and insulation. When organic matter accumulates at a rate greater than it degrades, however, it can restrict infiltration of water and gas exchange between the atmosphere and the soil air space in pores.

Excessive organic matter at the surface can become hydrophobic and increase runoff from the turf surface, which may also reduce the effectiveness of fertilizer and pesticides. Furthermore, excessive surface organic matter can promote surface rooting that interferes with the turf's use of water and mineral nutrients, which leads to increased potential for off-site movement of chemicals applied to turf. Figures 7-11 through 7-13 illustrate the problems resulting from the accumulation of surface organic matter.



Figure 7-11. Excessive surface organic matter can lead to anaerobic conditions that encourage diseases such as black layer. *Source: Frank Rossi.*



Figure 7-12. Soil layering leads to impeded drainage, increasing surface moisture that can lead to runoff. *Source: Frank Rossi.*

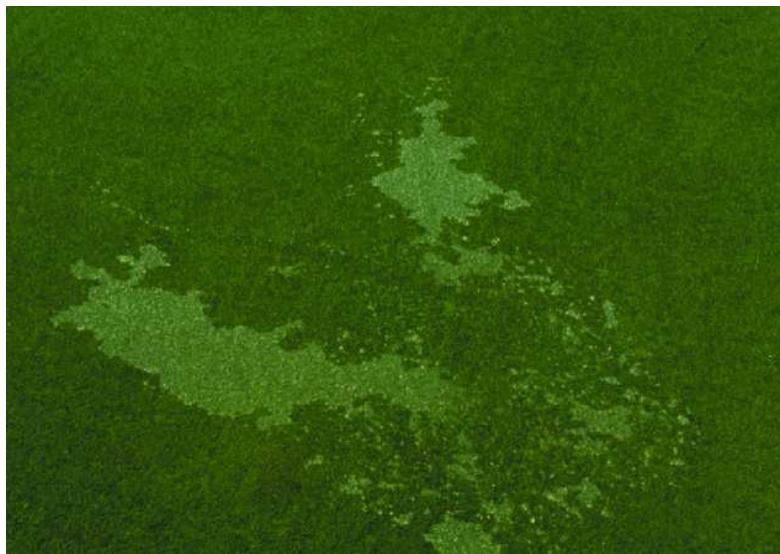


Figure 7-13. Surface organic matter accumulation results in hydrophobic conditions that can lead to increased runoff. The use of wetting agents can mitigate such problems. *Source:* Frank Rossi.

7.4.1 Factors That Increase Organic Matter

Many factors influence the accumulation of organic matter including turfgrass species, fertilization, and soil physical and chemical properties. Some turf species such as the fine leaf fescues produce significant amounts of highly lignified tissue that degrades slowly. Other species such as perennial ryegrass produce very little lignified tissue and therefore do not accumulate much surface organic matter. Grasses with high amounts of stem tissue, like rhizomes and stolons, often accumulate greater amounts of organic matter.



Figure 7-14. Wet surfaces lead to reduction in golf turf performance, such as plugged balls. This also increases the risk of runoff when soil surface is persistently wet. *Source:* Frank Rossi.

7.4.1.1 Grass Type

Creeping bentgrass and annual bluegrass are considered intermediate in their development of organic matter. They accumulate organic matter, but often that matter is not highly lignified tissue and, under warm moist soil conditions, it degrades. Still, these grasses accumulate

organic matter at the surface at a rate greater than microorganisms can degrade and thus the accumulation requires dilution or mechanical removal.

7.4.1.2 Fertilization

Increase in biomass is a normal aspect of plant growth. Supplemental fertilization for functional and aesthetic purposes produces more biomass and more organic matter when compared to an unfertilized turf. The rate of decomposition also increases with supplemental fertilization, up to a point. Therefore applying enough fertilizer to meet the visual and functional requirements of the turf, but not in excess of these requirements, is critical. Excess fertilization increases biomass production that leads to excess surface organic matter production, reduced infiltration, and increased runoff.

Organic matter is a food source for macro- and microorganisms. The soil food web requires an adequate amount of organic matter and microbial activity to function properly. Degradation of organic matter is maximized in a well-aerated, moist soil with temperatures greater than 65°F. For every ten degree Celsius increase in soil temperature, microbial activity increases tenfold; this principle is referred to as the "Q10".

7.4.1.3 Soil Management

Poorly drained soils with high bulk density and predominance of fine particles that restrict soil gas exchange reduce microbial activity. These dense, cool soils also restrict rooting to the surface, which further exacerbates the surface organic matter problem. Maintaining a permeable soil surface sustains adequate microbial activity, good deep root development, and proper infiltration. Taken together, these practices lead to a turf surface less likely to create runoff and more able to retain chemicals applied to turf top prevent leaching.

Understanding soil physical properties and amending the soil to minimize the potential for compaction is the key to proper soil management. Soil modification is best performed at establishment. Additionally, hollow-tine cultivation by removing existing soil and organic matter and adding coarse textured material such as sand or compost can be effective over time. Hollow-tine cultivation that removes 0.5 inch soil cores to a 4 inch depth has been shown to influence less than 5% of the turf surface during normal operation. Equipment modifications can be made to increase that percentage to as much as 20%, however, this is a tedious and long-term process.

Additional forms of cultivation such as solid tine, needle tine, or water injection cultivation that make a hole but do not remove soil can also increase soil infiltration. The benefits of these practices are short-lived and consequently must be repeated routinely to maintain a permeable surface. Due to golf traffic, soils prone to compaction will continue to become compacted and limit infiltration without soil modification.

Figures 7-15 through 7-22 illustrate soil management techniques.



Figure 7-15. Slice holes made from a putting surface spiking operation used to maximize infiltration and gas exchange. Source: Frank Rossi.



Figure 7-16. Core cultivation shown from a distance (top) and up close (bottom) is an ideal method for alleviating compaction, removing organic matter, and amending problem soils, which should increase infiltration and reduce the risk of runoff. *Source: Frank Rossi.*

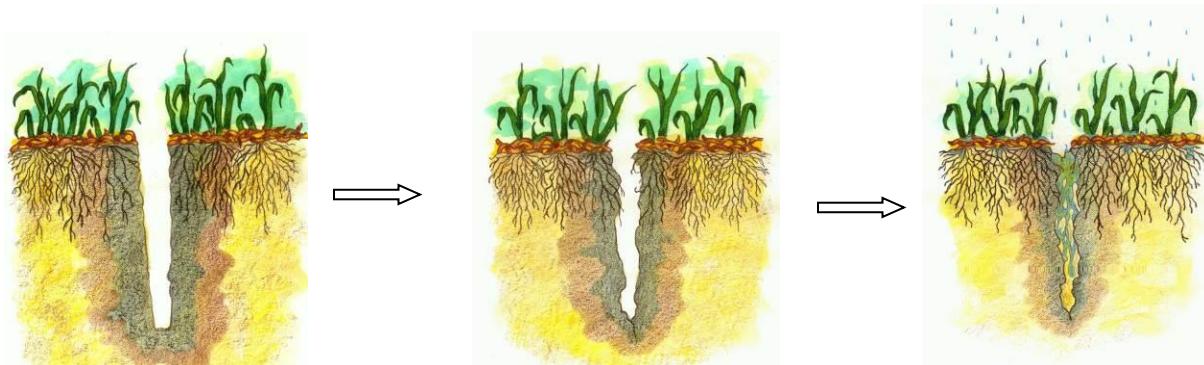


Figure 7-17. Schematic representation of core hole over time. Note hole edges are different colors depicting change in bulk density around the core. Over time the core edges collapse as water and roots begin to infiltrate the core.



Figure 7-18. Deep slicing can aid with remediating large areas of soil in need of increased infiltration and gas exchange. Source: Frank Rossi.



Figure 7-19. Spiking attachments aid with increasing infiltration and can affect significant amounts of surface areas. Source: Frank Rossi.



Figure 7-20. Less invasive cultivation methods such as water injection significantly increases infiltration and gas exchange. *Source: Frank Rossi.*



Figure 7-21. Water injection cultivation is the 'gold standard' for increasing infiltration and improved gas exchange with minimal surface disruption. *Source: Frank Rossi.*



Figure 7-22. Hollow tine cultivation is an ideal method for amending soils. *Source: Frank Rossi.*

7.4.1.4 Soil Modification With Topdressing

Managing surface organic matter is best accomplished by prevention through proper fertilization and soil management. Many common golf turf grasses, however, under routine maintenance and adequate prevention still produce organic matter that requires some level of management. The most effective means of managing surface organic matter is through regular applications of sand or soil via topdressing. A light (0.1 to 0.2 inches) application of material applied and integrated into the surface of the turf dilutes the organic matter and creates a physical matrix that functions as a soil.

Topdressing is often performed in conjunction with some form of cultivation that either removes a core or makes a hole. The cultivation can not only provide minor removal of the surface material but also create space for topdressing to serve the purpose of dilution and creation of a pseudo-soil matrix.

Recent research suggests that under normal golf turf management, creeping bentgrass putting surfaces require between 18 and 22 cubic feet of sand per 1000 square feet per year to properly dilute surface organic matter. This application requires topdressing as frequently as every 5 days without any cultivation, to as many as 14 to 21 days with more routine cultivation. Ultimately, the goal of proper dilution is to ensure the adequate infiltration while preserving sufficient retention of the turf system to prevent leaching. Figures 7-23 through 7-26 illustrate soil modification with topdressing.



Figure 7-23. Although large scale sand topdressing operations can be costly, they aid in reducing runoff from soils with organic matter accumulation and heavy compaction. *Source: Frank Rossi.*



Figure 7-24. Sand topdressing helps provide high performance playing surfaces that also reduce the risk of runoff by increasing infiltration, reducing compaction, and diluting organic matter. *Source: Frank Rossi.*



Figure 7-25. Sand-based greens offer the best options for maximizing performance and minimizing water quality issues. *Source: Frank Rossi.*



Figure 7-26. Proper topdressing material selection and storage are vital for maintaining a permeable turf surface. *Source: Frank Rossi.*

7.5 Summary

BMPs for golf course turf to preserve and protect water quality using cultural practices must be designed to sustain high turf shoot density. A dense turf reduces runoff and the negative effect of off-site movement of water and pollutants. This density maintenance must be a primary concern for golf courses.

A dense turf, however, accumulates surface organic matter that can restrict infiltration and lead to increased runoff. Maintaining the permeability of the turf surface is as important as maintaining turf density. Strategies for preventing excessive organic matter accumulation are important, but the management through dilution and cultivation of the soil is key. This practice can include modification to improve the root zone, balance adequate infiltration as means of reducing runoff, and adequate retention to prevent leaching.

BMP Statements

- Use and manage turfgrass species and varieties adapted to macro and micro climatic conditions of your location.
- Maintain turf with high shoot density to minimize runoff and maximize infiltration.
- Manage the surface accumulation of organic matter to maintain a permeable system that minimizes runoff and maximizes subsurface retention.

8 INTEGRATED PEST MANAGEMENT

Integrated pest management (IPM) concepts were originally developed in the 1960s by entomologists who examined pest management, especially the use of pesticides, as it relates to both economic value and environmental impact in agriculture. Since then, the definition and practice of IPM has grown to include all types of pests (insects, weeds, pathogens and diseases, and vertebrates) and settings beyond agriculture such as parks, golf courses, homes, and office buildings (Bajwa and Kogan 2002; Hoffmann and Gangloff-Kaufmann 2004). The turf industry has embraced IPM and virtually all modern textbooks and courses on turfgrass management include IPM. IPM for turf can be defined as follows:

IPM is a sustainable approach to managing pests by combining biological, cultural, physical, and chemical tools in a way that minimizes economic, health, and environmental risks and maintains turfgrass quality.

The concepts and principles of IPM should continually be reviewed and refocused with the goal of protecting water quality and soil on any property. Key tenets of IPM include pest prevention as a first line of defense and basing pest management decisions on:

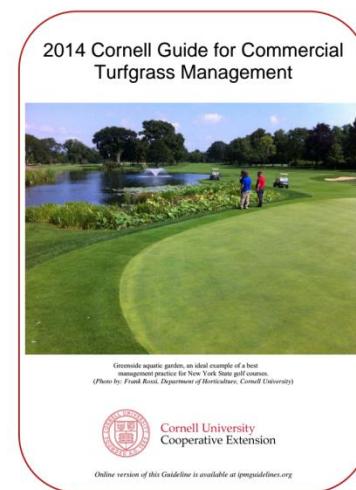
- knowledge of pest biology and life cycle
- action thresholds—derived scientifically and through experience
- monitoring of pests
- monitoring of turfgrass health
- monitoring of weather conditions and forecasts

IPM is a useful framework for addressing course needs, while prioritizing initiatives and tasks. Using IPM requires careful attention to detail, which usually results in improved course quality, often using fewer inputs. By following the latest research, managers can have high quality playing surfaces with minimal impact on the environment.

Research at Bethpage State Park has shown that IPM can result in 33 to 96% less environmental impact without reducing course quality, and does not cost more than conventional management (Rossi and Grant 2009). IPM is flexible and superintendents can usually balance course quality and environmental goals.

For more information:

- New York State's IPM Program:
<http://www.nysipm.cornell.edu/default.asp>
- *Reducing Chemical Use on Golf Course Turf: Redefining IPM*: www.hort.cornell.edu/turf/pubs/manual.html
- *Cornell Guide for Commercial Turfgrass Management*: ipmguidelines.org/turfgrass/
- Bethpage State Park research:
http://www.nysipm.cornell.edu/publications/long_term/files/long_term.pdf



8.1 Seven Steps of IPM

Although IPM permeates all aspects of course management and planning, it can be thought of in seven steps. The steps are sequential, but in practice all are ongoing and overlapping:

- Step 1 – Planning
- Step 2 – Identification and Monitoring
- Step 3 – Course Management
- Step 4 – Evaluation & Analysis
- Step 5 – Intervention
- Step 6 – Record Keeping
- Step 7 - Communication

8.1.1 Planning

Many environmental stresses that result in higher pest incidence and severity can be avoided through careful course design and planning, however, most superintendents are faced with managing an existing course. Pest problems and inputs can still be minimized through course modifications and preventive cultural practices.

Knowledge of past pest occurrence, locations (“hot spots”), and management practices are essential as past problems are likely to recur or continue without intervention. The winter months are a valuable time for reviewing pest issues from the previous season, by asking questions such as:

- Can environmental conditions be modified to reduce pest pressure? For example, can trees be removed around a putting green to increase airflow and reduce disease incidence and severity?
- Can traffic be routed to reduce stress? For example, can cart or walking paths be moved to diffuse walk-off areas on a putting green?
- Were monitoring procedures adequate to detect pests early? For example, should pitfall traps be installed to monitor for early season annual bluegrass weevil migration?
- Can pest-resistant grass cultivars be overseeded on any area of the course? For example, a cultivar such as Memorial, a dollar spot resistant cultivar of bentgrass, can be used to overseed putting greens.
- Are cultural practices adequate for minimizing pest problems? For example, would more frequent topdressing decrease anthracnose pressure?
- Have suppliers of new or hard to find products or equipment been identified in order to be prepared to react quickly to a pest outbreak? For example, where can entomopathogenic nematodes for grub control be obtained if needed and desired?

Part of planning is also being aware of new pests. Educational meetings, trade journals, blogs, listserves, and contact with other superintendents and local cooperative extension personnel are usually the best avenues for being alerted. Once a threat is identified, a superintendent should plan how to prevent, monitor, and manage the new pest.

8.1.2 Identification and Monitoring

Every course should have a plan for formal pest monitoring or “scouting” of all areas. For example, the frequency should be daily on putting greens, at least weekly on tees and fairways and bi-weekly on. Whenever possible, the pest pressure should be quantified with measurements such as:

- number of insects per unit area
- disease patch sizes
- percent area affected

Qualitative descriptors such as “high”, “low”, or “very bad” are subjective and difficult to calibrate and track change over time. Photographs also provide excellent documentation and can be used for identification and training.

Once detected, pests must be properly identified and documented, including mapping on an area map and recording the date of the outbreak. This information can be used to build a database for reference in future seasons. Superintendents and staff should continually hone and improve skills by attending training seminars and field days, obtaining reference materials, and providing peer-peer training on problems occurring on the course. Golf course personnel should also know where to send photos or samples when additional expertise is warranted for identification or confirmation.



Figure 8-1. Pink and gray snow mold.

Source: Jennifer Grant.



Figure 8-2. Soap flushes are a useful monitoring technique. The soap irritates many insects and causes them move out of the thatch and lower plant parts to the tips of grassblades for easier detection and counting. This technique is especially useful for monitor.



Figure 8-3. Soil cores removed with cup cutters can be searched quickly and easily for the presence of white grubs. The grubs can also be identified for species and life stage. Source: Curt Petzoldt.

Recommended diagnostic laboratory locations include:

- Cornell Cooperative Extension County office (diagnostic labs available in limited locations), http://www.cce.cornell.edu/learnAbout/Pages/Local_Offices.aspx
- Cornell University Insect Diagnostic Laboratory, <http://entomology.cornell.edu//extension/idl/index.cfm>
- Cornell University Plant Disease Diagnostic Clinic, <http://plantclinic.cornell.edu/>
- Rutgers University Plant Diagnostic Laboratory, <http://njaes.rutgers.edu/plantdiagnosticlab/default.asp>

8.1.3 Course Management

Almost every aspect of golf course management affects the likelihood and severity of pest problems. Although practices required for playability sometimes supersede the optimal IPM choice, manipulating cultural practices should be a key part of an IPM approach. For example, low mowing heights used to obtain high ball roll distances on putting greens can be modified by mowing and rolling greens on alternate days to lessen turf stress while still providing the same ball roll. Similarly, frequent topdressing buries the crown, effectively giving the plant a higher height of cut, while still providing good ball roll. Ultimately stress-reducing practices such as these decrease the incidence of disease and reduce weeds, which in turn reduces reliance on chemical pesticides.

8.1.4 Evaluation and Analysis

IPM is a knowledge-intensive decision-making system, requiring evaluation of incoming information, such as:

- scouting results

- weather forecasts
- golf course calendar events
- previous pest history and course hot spots
- past pest management success (for example, timing and efficacy of cultural practices, biological controls, and pesticides)
- new information from university research and the experience of peers

By constantly integrating these sources of information, the superintendent can best decide if a pest threat exists, and when, whether, and how it can be avoided or controlled. For some pests, action thresholds will trigger an intervention reaction (Step 5) in season. For others, cultural management strategies may be intensified.

8.1.5 Intervention

Intervention is the action taken when pest levels reach the threshold known to cause unacceptable damage or turf loss. In some cases, these thresholds have been determined scientifically, while in other instances these thresholds are based on site-specific experience. To avoid unacceptable damage or loss, the IPM method relies on an integrated approach using multiple cultural, mechanical, and biological management methods. Using the IPM approach, chemical control is reserved as a last option used only when other methods are insufficient for maintaining acceptable turfgrass quality and playability.

When chemical control is warranted, evaluation and analysis (Step 4) often allows for early intervention, which may result in the use of lower toxicity treatments and spot treatment rather than whole area treatments. An IPM practitioner considers all approaches and selects the least disruptive, but effective, option.

8.1.6 Record Keeping

Documentation is key to connecting the elements of an IPM program and increasing its value. In order to be effective, IPM record keeping should exceed legal requirements (see Table 8-1, Figure 8-4).

Table 8-1. IPM Record Keeping

Record-keeping Category	Record Details
Scouting Records	Pest occurrence, location and severity
	Improvements or increases in pest issues in response to management tactics
Cultural Management Logs	Frequency, timing, location
	Equipment settings, rates (e.g. amount of sand used for topdressing)
	Operator
Weather Conditions	Current
	Forecasted

Record-keeping Category	Record Details
Pesticide Application Records	All legal requirements such as date, location, product, area treated, and applicator
	Reason(s) for application
	Results
Water Requirements	Monitor soil moisture

Ways to simplify documentation and integration of IPM methods with other aspects of course management include the following:

- Integrate scouting records with mandatory pesticide application records.
- Encourage all staff to report pest sightings and have a convenient method for tracking and sharing this information.
- Use electronic records rather than hand-written records.
- Encourage staff use of tablets and phones for sending data and photos to a central location.
- Use Cornell's TracGolf software program (http://www.nysipm.cornell.edu/trac/about/about_golf.asp)
- Emphasize scouting records and other IPM information as part of staff training, meetings, and daily communications.



Figure 8-4. Photographs are useful for documenting pest occurrence and damage, and can be compared against past and future photos. Source: Jennifer Grant.

8.1.7 Communication

Good communication within the maintenance team is an essential aspect of IPM. Regardless of who monitors pest issues, all staff should be aware of pest problems and management activities

and should be encouraged to report observed and potential problems. Furthermore, IPM training should be provided to as many staff as possible.

Communication to golfers, members, administrators, and neighbors is also important. Communicating with these stakeholders lessens the chance of surprises and conflicts and increases recognition of the superintendent and staff as trained professionals that care about protecting the environment. Explaining the IPM approach in personal communications, promotional literature, club newsletters, blogs, and websites helps to advance these goals.

8.2 Management Options

An IPM manager uses a mix of preventive and reactive strategies to manage pest problems. Course management decisions and cultural practices are ongoing, while reactive measures are decided and implemented in season. Selecting from a number of management options according to incoming information instead of the calendar is a hallmark of an IPM manager.

8.2.1 Diversification

Diversification of management options is key, using a variety of cultural, biological, physical, and possibly chemical strategies. The case against sole reliance on chemical approaches is obvious because it promotes resistance, and frequent use may subject applicators, golfers and the environment to unnecessary risks. Similarly, reliance on any other single-tactic approaches is also not recommended, because if it fails, damage or turf loss is likely which can also negatively affect water quality. IPM's diversification of tactics allows for multiple layers of protection, and therefore better insurance against pests.

8.2.2 Role of Cultural Management

Turfgrass is a perennial plant system in which cultural practices, especially irrigation, mowing, topdressing, aeration, and venting, greatly affect both short and long term plant health. Healthy plants and soil can better withstand pest pressure. Weak turf can be outcompeted by weeds that take advantage of bare ground or thin turf. Pathogens in particular can take advantage of weak, stressed, or otherwise unhealthy plants and cause disease. Unhealthy plants are also less able to fend off, compensate for, mask, or recover from insect damage. Below are examples of how an IPM approach can be used to for a specific weed, disease, and insect pest issue.

8.2.2.1 Weed Example

One of the most effective prevention strategies in weed management is to use the appropriate turf varieties for the specific site conditions and intended use on the golf course. For example, a recent development in some golf courses is the use of tall fescue/blue blends in the rough because heat and drought in the summers create challenges for turf management (Figure 8-6). Another



Figure 8-5. *Poa annua*. Source: Jennifer Grant.



Figure 8-6. Tall fescue/bluegrass blend in a rough. Source: Bob Mugaas, University of Minnesota.

concept is to use weed suppressive fine fescues in the roughs, such as Intrigue II and Columbra II that produce allelochemicals from their roots. These compounds inhibit the growth of weeds while maintaining a healthy stand of fine fescues. New turf varieties have been developed that provide improved drought tolerance, disease resistance, and have a greater ability to handle foot and cart traffic. In the near future, salt tolerance will be added to the growing list of improved turf varieties as restrictions on high quality water use become an

increasing concern for golf courses. Using these improved turf varieties can effectively minimize weed infestation in greens and fairways with low turf density or bare areas.

Another effective prevention strategy is to use high quality turf seed that is free of weed seeds. Many suppliers provide a guarantee that states the percentage of weed-free content. The same strategy is useful in determining sod installations for the course as most suppliers guarantee a percentage cover of weed-free sod. The general rule is to purchase high quality seed that is greater than 99% weed free and sod that is 100% weed free, including annual bluegrass.

While prevention is a critical component in weed management, post-emergence control is a necessary part of routine turf management. Many chemical methods for post-emergence control provide rapid, inexpensive eradication of grass and broadleaf weeds. The nonchemical control options include use of thermal weeding technologies, such as propane weed torches, steam wands, and infrared heating devices. These thermal devices can remove patches of weeds or sections of turf for a renovation project. A study conducted at the Royal Quebec Golf Course showed control of *Poa annua* in bentgrass fairways treated with flame weeding using a tractor fitted with burners. The bentgrass was able to recuperate, while *P. annua* declined after one month (see GCSA Management article <http://www2.gcsaa.org/gcm/1997/oct97/10poawar.html> for more information). Thermal weeding can give stoloniferous or rhizomatous turfgrasses a competitive edge over weeds that grow as bunchgrasses.



Figure 8-7. Hand weeding is sometimes the most effective and environmentally friendly method of weed management. This photo shows invasive species in the rough. Source: Jennifer Grant.

Dollar spot, caused by the pathogen *Sclerotinia homoeocarpa*, is a common golf course disease in New York State (Figure 8-8). Besides using chemical controls, managers can plan to lessen disease incidence and severity with the following activities:

- Plant resistant cultivars of creeping bentgrass such as Memorial and Declaration.
- Minimize moisture stress and leaf wetness.
- Remove morning dew as early as possible.
- Roll putting greens three or more times per week.
- Apply biological organisms known to suppress dollar spot such as *Bacillus licheniformis*, *Bacillus subtilis*, and *Pseudomonas aureofaciens*.
- Use horticultural oils (Civitas), labeled for the intended use both for treated area and pest, instead of or in conjunction with traditional fungicides.



Figure 8-8. Dollar spot. Source: Jennifer Grant.

8.2.2.2 Insect Example

Annual bluegrass weevils (ABW) are pests of golf courses in many parts of New York (Figure 8-9). The only cultural practice known to successfully minimize their damage is to reduce the amount of annual bluegrass in infested areas. In mixed stands of annual bluegrass and creeping bentgrass, as is commonly found on putting greens, practices that favor bentgrass can be

promoted. In other areas, it may be acceptable to convert the grass to alternate species such as ryegrass or Kentucky bluegrass. It may also be possible to protect areas by creating a barrier strip of an alternate grass species that deters the spring migration of ABW adults traveling from their overwintering sites to playing surfaces.

Vacuuming has been used to monitor ABW adults in turf, but may also work as a physical and mechanical control practice if done frequently, especially during the spring migration (Figure 8-

10). Biological control methods have been largely unsuccessful in scientific research, but the use of entomopathogenic nematodes may still hold promise.

Beyond the techniques listed, IPM for ABW has relied mainly on careful monitoring of the insect as well as phenological indicators and degree days to target insecticide applications. Pitfall traps, soap flushes, and vacuum sampling detect when and where the adults are moving from their overwintering spots. An insecticide targeting adults is typically timed for the peak migration time. Subsequently, these sampling techniques, along with saline floats that monitor larval development, are used to time the application of an insecticide targeted at 3rd to 5th instar larvae.



Figure 8-9. Annual bluegrass weevils. Source: Jennifer Grant.



Figure 8-10. Vacuuming to determine annual bluegrass weevil adult presence, location, and movement. Source: Jennifer Grant.

8.2.3 Use of Softer and Alternative Pesticides

IPM encourages the use of pesticides as a “last resort” when other methods of pest control prove to be inadequate. However, when pesticides are deemed necessary, an effective product least likely to harm human health or the environment should be selected. Other management options include using an alternative product, such as biological controls or reduced risk pesticides.

8.2.3.1 Biological Controls

Biological control uses other living organisms to suppress or eliminate pests. Several organisms are known to have some efficacy against turfgrass pests and have been marketed as pest control products. These biological controls may act to suppress pest populations alone or work synergistically with other natural, cultural, physical, or chemical management methods. Examples of biological controls that are commercially available in New York State are provided in Table 8-2.

Table 8-2. Biological controls

Beneficial Bacteria	Action
<i>Bacillus licheniformis</i>	Labeled for dollar spot management
<i>Bacillus subtilis</i>	Labeled for management of brown patch, dollar spot, powdery mildew, rust and anthracnose
<i>Pseudomonas aureofaciens</i> (strain TX-1)	Labeled for management of anthracnose, dollar spot, pink snow mold and pythium
<i>Bacillus thuringiensis</i>	Labeled for management of caterpillars in turf. A strain that affects white grubs is known, but not currently commercially available.
<i>Paenibacillus popilliae</i> and <i>Paenibacillus lentimorbus</i>	Cause “milky spore disease” and are labeled for management of Japanese beetle grubs in turf. Other strains cause milky spores in other species of grubs, but are not commercially available.
Entomopathogenic Nematodes	Action
<i>Heterorhabditis bacteriophora</i> and <i>Steinernema glaseri</i>	Effective against white grubs
<i>Steinernema carpocapsae</i>	Effective against cutworms and possibly annual bluegrass weevils

8.2.3.2 Reduced Risk Pesticides

The EPA defines conventional “Reduced Risk” pesticides as having one or more of the following advantages over existing products:

- low impact on human health
- low toxicity to non-target organisms (birds, fish, and plants)
- low potential for groundwater contamination
- lower use rates
- compatibility with IPM

A number of reduced risk pesticides can be used on turfgrass in NYS (Table 8-3).

Biological pesticides, which also have many of these desirable characteristics, are classified separately by the EPA.

Table 8-3. Reduced risk pesticides

Category	Reduced Risk Pesticide
Fungicides	Azoxystrobin
	Boscalid
	Fludioxonil
	Trifloxystrobin
Herbicides	Bispyribac-sodium
	Carfentrazone-ethyl
	Mesotrione
	Penoxsulam
Insecticides	Chlorantraniliprole
	Spinosad

8.3 Pesticide Selection Criteria

When chemical control is needed, several important criteria can be used to select the right pesticide:

- must be registered for use in New York State
- must be properly transported, handled, and stored
- should be effective in treating the pest problem
- the frequency of pesticides usage considered with respect to the possibility of chemical resistance
- costs should be considered
- environmental risk and potential for water quality impacts must be evaluated

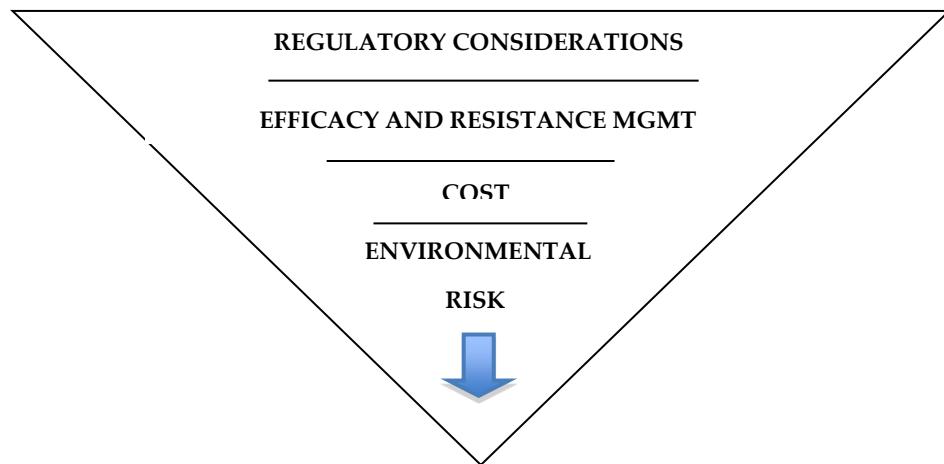


Figure 8-11: Pesticide selection criteria.

8.3.1 Efficacy and Resistance Management

Among the pesticides registered for use in New York, selection should be based on the effectiveness of the product to prevent or treat pest problems. Products that are more effective can often be used at lower rates and fewer applications. The *Cornell Guide for Commercial Turfgrass Management* published annually by Cornell University lists recommendations for the most effective treatments of pest problems. In addition to these guidelines, manufacturers and trade journals often present research reviewing different products tested. The University of Kentucky provides a special service to the industry by reviewing all research on fungicides and grading the effectiveness of fungicides annually.

If chemical control is required, rotating chemical classes of pesticides used is recommended to manage the potential of resistance to any specific mode of action. Avoiding resistance makes each chemical used more effective, reducing rates and frequencies of applications. Every pesticide label should identify its resistance class.

For more information, see:

- *Cornell Guide for Commercial Turfgrass Management*: ipmguidelines.org/turfgrass/
- University of KY fungicides report: www.ca.uky.edu/agc/pubs/ppa/ppa1/ppa1.pdf
- Fungicide Resistance Action Committee: www.frac.info
- Herbicide Resistance Action Committee: www.hracglobal.com/
- Insecticide Resistance Action Committee: www.irac-online.org/
- EPA Pesticide Resistance Labeling: www.epa.gov/PR_Notices/pr2001-5.pdf
- International Survey of Herbicide Resistance Weeds: www.weedscience.com/summary/home.aspx

8.3.2 Costs

Pesticides are marketed in a variety of forms and packaging. Product selection should not be based on the price per container, as application rates and intervals vary and more effective products with a lower environmental risk can cost less per day of treatment. The real costs of products can be compared using simple tools. Table 8-4 shows an example that compares very effective bio-based controls to conventional pesticides for the treatment of dollar spot.

Table 8-4. Cost comparisons of alternative chemical control of dollar spot

Control	App Rate (oz or fl oz per 1000 ft ²)	Cost per 1000 ft ²	Acres Treated	Spray Interval	Cost per Day	FRAC Class	EIQ Quotient	Field Use EIQ
Traditional Program								
Daconil	4	\$1.94	3	14	\$18.09	MS	37.42	336
Banner Maxx	2	3.30	3	14	\$30.77	3	31.63	25
Program 4								
Emerald	0.13	\$2.36	3	28	\$11.00	7	26.64	7
Civitas	16	\$3.59	3	28	\$16.77	Bio-based	0.00	0

8.3.3 Environmental Risks

The use of pesticides presents certain risks in terms of toxicity to human or other nontarget organisms including soil microbes, insects, birds, animals, and aquatic species. Pesticides can migrate off the target site through the environmental transport process of runoff, leaching, or drift. Understanding both the site and pesticide characteristics and their relationship is the basis for assessing a pesticide's site-specific vulnerability to environmental transport.

8.3.3.1 Pesticide Toxicity

Pesticides may pose varying degrees of risk to humans denoted by the EPA as acute toxicity levels for oral ingestion, dermal sensitivity, inhalation, and eye irritation. Signal words on labels characterize pesticide into four toxicity-based categories to invoke special attention when handling or applying the pesticide (Table 8-5).

Table 8-5. Signal words by toxicity ratings

Toxicity	Signal Word
Category I	DANGER
Category II	WARNING
Category III	CAUTION
Category IV	None required

Pesticide labels also stipulate proper personal protective equipment (PPE) to be worn when handling or applying pesticides. In addition, instructions on the label specify proper procedures in case of accidents or emergencies to prevent exposure. Not as much is known about chronic toxicity due to prolonged exposure to a pesticide as is known about acute toxicity. Some pesticides are known to accumulate over time, although the risks of such accumulation have not been fully identified.

The Pesticide Action Network has compiled a pesticide database that identifies pesticides with known or suspected toxicity. Appendix C provides human health and aquatic toxicity risk ratings for pesticides registered for use in New York State.

For more information:

- PAN Pesticide Database: <http://www.pesticideinfo.org>
- Pesticide Properties Database (PPDB), pesticide physicochemical, toxicological, ecotoxicological and other related data: <http://agrochemicals.iupac.org>

8.3.3.2 Pesticide Characteristics

The fate of a pesticide applied to turf is determined by the soil characteristics, environmental conditions, and the chemical properties of the pesticide. These factors can be used to help recognize conditions and select pesticides that can help minimize the risk of ground and surface water contamination through leaching, runoff, or drift.

Information for pesticides approved for use in New York State are summarized in Appendix C and includes the following information: rate ranges, Field Use EIQ ranges, Chemical Class, Aquatic Toxicity, Solubility, Soil Adsorption (Koc), half life, GUS values, and WIN PST ratings for sand greens. The tables provide reference tools to select pesticides based on their environmental fate and toxicity. A summary of chemical and physical property threshold values indicating the potential for groundwater contamination is provided in Table 8-6.

Table 8-6. Threshold values indicating potential for groundwater contamination by pesticides.

Chemical or Physical Property	Threshold Value
Water solubility	Greater than 30 ppm
Henry's Law Constant	Less than 10^2 atm to m^{-3} mol
Kd	less than 5, usually less than 1 or 2
Koc	less than 300 to 500
Hydrolysis half-life	more than 25 weeks
Photolysis half-life	more than 1 week
Field dissipation half-life	more than three weeks

8.3.3.3 Soil

Soil texture is based on the proportion of sand, silt, and clay. Soils with larger particle sizes have higher aeration (macropore) porosity and greater risk of leaching. Soil surveys classify soil type and texture into four hydrologic groups according to the rate of water infiltration when the soils are not protected by vegetation, are thoroughly wet, and receive precipitation for a long period. The NRCS Soil Survey defines four hydrologic soil groups that vary with respect to leaching and runoff potential (Table 8-7).

Table 8-7. Leaching and runoff potential by soil group

Soil Group	Description
A	Soils having a high infiltration rate (low runoff potential) when thoroughly wet. These consist mainly of deep, well drained to excessively drained sands or gravelly sands. These soils have a high rate of water transmission.
B	Soils having a moderate infiltration rate when thoroughly wet. These consist chiefly of moderately deep or deep, moderately well drained or well-drained soils that have moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission.
C	Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission.
D	Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a clay pan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.

Leaching Potential
↓

4 Pesticide Persistence

Once applied, pesticides break down in the environment through a number of processes: exposure to light (photodegradation), chemical reactions in the soil, and the action of soil microbes or other organisms (biodegradation). Environmental conditions such as temperature, moisture, and pH also affect the rate of pesticide degradation. The rate of degradation is expressed in terms of half-life, which is the number of days required for half the concentration of a pesticide to breakdown. Persistent pesticides, those with a half-life greater than 21 days, pose a threat to water quality.

8.3.3.5 Solubility

Pesticide chemical properties include a measure of the chemicals cold water solubility, often expressed as grams per liter (g/L), milligrams per liter (mg/L), or parts per million (ppm). A pesticide with a solubility of less than 30 ppm (mg/L) is considered to have a low potential risk to ground and surface water contamination.

8.3.3.6 Soil Adsorption (Koc)

Once in the soil, pesticides vary in how tightly they are adsorbed to soil particles. Chemical mobility in soil is determined by the ratio of the pesticide's solid and aqueous phases, K_D , in the soil. In a solid phase, the pesticide can bind to soil particles and organic matter. In the aqueous phase, the pesticide dissolves in water. The K_D factor varies by soil type. Soil scientists normalize the values, calculating a new coefficient, Koc that accounts for soil organic matter content. The higher the Koc value the greater the bond between the soil and the pesticide. Pesticides with a Koc less than 300-500 are considered a risk to ground water quality, as they tend to dissolve and move with water. The Koc is not well correlated in high clay soils. In these cases, K_D is used to evaluate soil mobility.

8.3.3.7 Groundwater Ubiquity Score

The Groundwater Ubiquity Score (GUS) was developed to model persistence and soil adsorption factors to provide a method to determine the relative risk of leaching. The model was validated by comparing actual leaching data with predicted risks. Pesticides with GUS values greater than 2.8 have high risk of leaching. Pesticides with GUS values below 1.8 are considered to have a low risk of leaching. GUS values for pesticides approved for use in New York have been charted to identify the "leachers" from the "non-leachers" (Tables 8-7, 8-8, and 8-9). These GUS values assess risk based on the chemical properties and do not account for soil conditions. Soils with high infiltration rates or sites with excessive slope may be more prone to leaching and runoff. Nonetheless, GUS values provide a tool to help turf managers select chemicals with the lowest GUS value.

8.3.3.8 Volatility

Some pesticides volatilize readily. Volatility is influenced by environmental conditions, such as temperature, relative humidity, and air movement. High temperatures and low humidity increase evaporation rate. The level of a pesticide's volatility may be indicated on the label.

8.3.4 Pesticide Evaluation Tools

Models have been developed that combine multiple characteristics and give relative weighting or ranking of the potential risk of specific pesticides. These are briefly discussed below. For further information on pesticide evaluation tools, see:

- Cornell EIQ calculator: <http://www.nysipm.cornell.edu/EIQCalc/input.php>
- WIN-PST: <http://go.usa.gov/Kok>

- IRPeQ: <http://www.mddep.gouv.qc.ca/pesticides/indicateur-en.htm>

8.3.4.1 Environmental Impact Quotient

The Environmental Impact Quotient (EIQ) was developed to rate the risk of pesticides to human health and non-target organisms. The EIQ value is derived from mathematically weighting all the risk factors into a quotient. The EIQ is multiplied by the rate of application and percent active ingredient to calculate the Field Use EIQ Rating (FUEIQ):

$$\text{FUEIQ} = \text{EIQ} \times \text{Rate (lbs/acre)} \times \% \text{AI}$$

The FUEIQ provides a measure of the weighted risk or toxicity of a pesticide expressed as a value per acre. Multiplying the FUEIQ by the number of acres treated provides a risk/toxicity rating for the treated area. Summarizing all applications in this manner provides a summation of risks/toxicity for the entire property over a period. Cornell provides an online EIQ calculator to compare FUEIQ results (<http://www.nysipm.cornell.edu/EIQCalc/input.php>). A FUEIQ under 25 is desirable. Any value over 100 poses high risks to applicators and the environment. The *Cornell Guide for Commercial Turfgrass Management* lists the range of FUEIQs for the rate range on each pesticide registered for use in New York. The Cornell publication *Reducing Chemical Use on Golf Course Turf: Redefining IPM* describes the methodology to evaluate pesticide environmental toxicity using EIQ.

8.3.4.2 Windows Pesticide Screening Tool

Windows Pesticides Screening Tool (WIN-PST) is an environmental risk screening tool developed by USDA-NRCS for pesticides. This tool uses site-specific information to evaluate the potential of pesticides to move with water and eroded soil/organic matter and affect non-targeted organisms.

The risk of pesticide contamination of either surface water or groundwater is mostly affected by the properties of the pesticide, the properties of the soil, and the amount of rainfall after application. Unlike the EIQ and GUS, WIN- PST can be tailored to site-specific soil conditions and management practices. The method uses standard soil properties provided by the NRCS data base or can be adjusted to site-specific soil factors that affect the movement of pesticides, such the depth of the root zone and the organic matter content. The environmental risk can also be evaluated based on anticipated weather (rainfall).

The following example illustrates how WIN PST can be used for golf course conditions such as a sand green. For this example, the soil is sand at a typical greens depth of 12 inches and the average organic content for the 12 inch profile is 1%, by weight. The pesticides were applied to the turf foliage under two rainfall conditions: low potential for rainfall and a high potential for rainfall. Appendix G contains the WIN PST risk screening for pesticide leaching for most pesticides registered in NYS for use on golf courses. Under the low rainfall potential scenario, most of the pesticides evaluated had a low or very low risk (four had a high/extrahigh) to humans (long term exposure as a drinking water source) and only one pesticide has a high or

extra high risk to fish, even when applied to this very high leaching-groundwater contamination soil like sand. When applied under a high potential rainfall scenario, however, 15 pesticides had a high/extra high risk to humans, and 20 had high/extra high risk to fish.

Based on these results, one of the BMPs for this example is to only apply pesticides when the potential for rainfall is low. On sites where greens drainage is discharged near streams or near drinking water wells, extreme care needs to be taken if a pesticide application is needed during a period with a high potential for rain. Appendix G can be used to select pesticides that have a low risk even under these conditions.

8.3.4.3 Pesticide Risk Indicator for Quebec

Quebec's Ministry of Sustainable Development, Environment, Wildlife and Parks developed the Pesticide Risk Indicator for Quebec (IRPeQ), a diagnostic and decision-making tool designed for the optimal management of pesticides. This tool has both a health component and an environmental component.

BMP Statements

- Conduct a thorough assessment of pest pressure.
- Establish appropriate pest thresholds for managed turf areas.
- Identify and correct growing environments that exacerbate pest pressure.
- Implement sanitation, exclusion, and cultural practices to minimize pest pressure.
- Determine least toxic pest control programs including preventive approaches.
- Assess control program effectiveness using established monitoring practices.
- Recognize environmental fate of pesticides and select pesticides using a selection strategy that includes an evaluation of pesticide characteristics and potential for nontarget effects.

9 PESTICIDE STORAGE, HANDLING AND APPLICATION

Pesticides are an integral component of progressive IPM programs and are tools used to increase or maintain the economic value of properties being managed. The purchase, storage, handling, and use of pesticides are regulated by a number of state and federal agencies because of concerns these compounds pose for human health and the environment.

Recent survey information collected and published by the Environmental Institute for Golf's Environmental Profile Project indicates the level of safeguards currently enacted in the golf course management industry (Lyman et al. 2012). The survey indicated that 98% of average 18-hole golf facilities stored pesticides on the property, with no significant difference in the percentage of golf facilities storing pesticides based on the number of holes, facility type (private or public), or maintenance budget. The most common characteristics of pesticide storage areas include:

- locked or restricted access (94%)
- signs indicating pesticide storage (85%)
- emergency shower or eyewash station nearby (74%)
- impervious floor (68%)
- spill kits (67%)
- floors capable of containing liquid spills (63%)
- passive venting (58%)
- separate/dedicated building (54%)
- impervious shelving (51%)
- powered venting (50%)
- explosion-proof fixtures (30%)

The study also surveyed pesticide handling facilities. The most common characteristics of pesticide handling stations for average 18-hole golf facilities include:

- spill kit located near mix/load area (60%)
- anti-siphoning device on water line (56%)
- emergency water shut-off valve (45%)
- impervious floor (45%)
- recycling of pesticide containers (36%)
- tank-filling capacity greater than 50 gallons per minute (36%)
- floors capable of containing liquid spills (35%)
- overhead protection from weather (29%)
- pesticide rinsate collection (27%)
- stand-alone pesticide mixing tank (15%)

Golf course monitoring programs conducted in New York and several other states indicate little to no risk of water contamination of pesticides applied to golf turf (Appendix B). The application of pesticides is often made with low concentrations of active ingredients, often

between 1 to 5% solutions. Simple attention to proper application procedures, especially avoiding direct discharges into water bodies or near wellheads, should typically suffice.

The storage and handling of pesticides on golf courses presents the greatest risk to water quality contamination because of the potential for an unintended release of a large volume of pesticides. Therefore the greatest attention to BMPs should be directed at storage and handling. Properly selecting, storing, handling, and applying pesticides minimizes their potential to reach surface water or groundwater through runoff, leaching, or drift.

For more information on the general use and management of pesticides, see:

- Pesticide Safety Education Program (PSEP), Cornell University Pesticide Management Education Program (PMEP): psep.cce.cornell.edu
- Pesticide Product Ingredient Manufacturer System (PIMS): pims.psur.cornell.edu/
- Cornell University, College of Agriculture and Life Sciences, Occupational & Environmental Health Pesticide Program Overview: oeh.cals.cornell.edu/pestmain.html

9.1 Pesticide Use Regulations

The New York State Environmental Conservation Law (ECL), Article 33, Part 325, establishes statutory authority to the New York State Department of Environmental Conservation to regulate pesticides and pesticide use.

9.1.1 Business Registration

All businesses must register for permits to with the NYSDEC to commercially apply pesticides.

9.1.2 Certified Applicators and Technicians

The law requires commercial applicators and technicians applying pesticides to golf course turf to be certified in categories 3A (ornamentals, shade trees, and turf) or 3B (turf only). Commercial applicators must meet requirements in continuing education credits. Special supervisory restrictions apply to technicians and apprentices.

9.1.3 Labels

When chemical controls are to be used, only pesticides labeled for use in New York State are permitted. In addition to a listing by NYSDEC of registered pesticides, Cornell's pesticide Product Ingredient Manufacturer System (PIMS) lists all registered pesticides searchable by EPA registration number, common name, or active ingredient.

9.1.4 Pesticide Reporting Law

Applicators are required to file an annual report by February 1 each year summarizing their pesticide applications from the previous calendar year. These applicator reports are compiled each year in a summary report on sales and use around the state. The DEC is also monitoring

water quality reports to assess pesticide levels in high-risk watersheds, aquifers, and wells across the state.

9.1.5 Neighbor Notification

The ECL was amended to include the Neighbor Notification Law requiring a 48-hour notice to adjoining property owners prior to pesticide application. However, the requirement is only effective for counties that adopt the requirements into local ordinances; golf courses and sod farms are specifically exempted. Registered businesses should check with county officials or regional NYSDEC offices to see if specific local requirements apply.

9.1.6 Pesticide Storage

The pesticide label is the law and all pesticides should be stored according to instructions on their labels. In addition to the label, Part 326.11 of the New York Codes, Rules and Regulations (NYCRR)(<http://www.dec.ny.gov/regs/4423.html>) states “No person shall store any restricted pesticide or empty containers thereof in such a manner as may be injurious to human, plant or animal life or to property or which unreasonably interferes with the comfortable enjoyment of life and property throughout such areas of the State as shall be affected thereby.” Pesticide storage areas should be designed and managed in a manner that prevents or minimizes the risk of injury, harm to the environment or any impact on the use or value of property. The following suggestions are offered for consideration:

- Storage facilities should be structurally separate from “residential, office and general work areas; livestock quarters, food, feed or seed storage and water supply sources”. Storage should be in separate buildings and situated to be at least 50 ft away from residential or farm property. Fencing is currently not stipulated but could be considered as an added precaution.
- To the extent practical, pesticides should be stored more than 500 feet from wetlands and waterbodies.
- Storage areas should have a raised berm on all sides and an impervious surface for containment.
- Facilities should be equipped with “spill containment material” and fire extinguishers. Suggested spill containment material includes absorbent spill containment pads, sweeping compound, brushes or brooms, a dust pan, shovel and a disposal container or bag.
- Protective equipment should be available near but not within the storage area.
- The storage facility should be locked and properly posted with warnings.
- Annual updates should be provided to the local fire department and include a “Fire and Spill Response Plan”. Additional precautions might include provisions of the National Fire Protection Association (NFPA) codes.
- Chemicals should be segregated by function (fungicide, insecticide, and herbicide) and hazard level. All flammable and “incompatible” materials should be stored separately.
- Mixing areas should be similarly bermed with impervious surfaces.
- Indoor mixing areas should be properly vented.

- Bulk containers, construed to be equal to or greater than 55 gallons, should be locked and drains should be used to collect any spills into a containment area. The spill containment system should have a capacity equal to or greater than 25% of the volume of pesticides stored.
- A water supply and wash station are required at or adjacent to the facility for emergencies.
- A suitable first aid kit for pesticide poisoning should be nearby.
- Forced air vent systems capable of exchanging the air volume 3 to 4 times per hour should be considered along with temperature control for keeping temperatures under 95°F and above freezing.
- Local fire departments should be made aware of the pesticides and fertilizers stored to prepare in event of a fire at the storage facility.

Very old or inadequate storage areas may or may not be out of compliance, but consider planning for improvements to implement these recommendations over time. For more information, see also NYSDEC guidelines for pesticide storage at <http://www.dec.ny.gov/regs/4423.htm>.

9.1.7 Pesticide Transport

Off-property transport of pesticides must comply with New York State Department of Transportation (NYSDOT) regulations. Regulations require that the driver be trained for hazardous material transport. Drivers are required to carry the pesticide label and SDS sheet, have sufficient knowledge to handle any spills, and communicate with emergency responders in case of spills. Pesticides transported off the property or stored in a sprayer tank must be labeled with basic pesticide information as required under the Environmental Conservation Law.

9.1.8 Mixing and Loading

Mixing, loading, and washing areas should be well ventilated and should take place in contained areas that are bermed, have impervious surfaces, and roofed to prevent rainfall spreading pesticide residue. Precautions should be in place to effectively respond to emergencies, such as the availability of proper PPE, spill response kits, and emergency wash stations.

NYSDEC regulations require the use of Backflow Prevention Devices (BPD) when public water is used with pesticide application equipment. Use caution and read the labels carefully to ensure that pesticides mixed together are compatible. Water used for mixing should be tested for pH to ensure that tank mixes do not expire prematurely due to alkaline hydrolysis.

The State of Michigan currently has some of the most comprehensive regulations addressing the construction of mixing and loading areas. This information is also part of the MI Environmental Stewardship Program that includes a useful module developed by Michigan State University

designed to help golf courses determine need, size and capacity of mixing/loading areas (see www.mitesp.org/assets/Modules/05PestMixLoad2009.pdf).

9.1.9 Pesticide Waste and Rinse Water Disposal

Pesticide containers must be cleaned and disposed of or recycled properly. Procedures typically include triple rinsing nonflammable containers and either returning cleaned empty containers to the vendor or properly sealing and disposing of them in a sanitary landfill. Rinsate may be re-applied to turfgrass consistent with instructions on the label. Unused pesticides must be disposed of in accordance with state regulations, such as by returning to the supplier or disposing at an approved hazardous waste facility.

9.1.10 Aquatic Pesticide Applications

The application of any pesticide to water, such as an aquatic herbicide used to control vegetation in golf course ponds, or mosquito or other insect control applied to water, must be covered under a SPDES General Pesticide Permit.

For more information on pesticide usage, see:

- NY Pesticide Business Registration: www.dec.ny.gov/permits/209.html
- Pesticides Registered in NY: www.dec.ny.gov/chemical/27354.html
- NY State Pesticide PIMS: pims.psur.cornell.edu/
- NY Pesticide Reporting Law: www.dec.ny.gov/chemical/27506.html
- NYSDEC Pesticide Storage Guidelines: <http://www.dec.ny.gov/regulations/8871.html>
- NYSDEC Policies on Backflow Prevention Devices: www.dec.ny.gov/regulations/23471.html
- NYSDEC Waste Transporter Permit Program: www.dec.ny.gov/chemical/8483.html
- Regulated Hazardous Wastes in NY: <http://www.dec.ny.gov/chemical/8486.html>
- New York State Solid Waste Management <http://www.dec.ny.gov/chemical/8498.html>
- Michigan State University mixing and loading pad module, including checklists: www.mitesp.org/assets/Modules/05PestMixLoad2009.pdf
- SPDES General Pesticide Permits: <http://www.dec.ny.gov/chemical/70489.html>.
- Clean Sweep NY: www.cleansweepny.org

9.2 Pesticide Application Strategies

In addition to selecting an appropriate pesticide based on the strategies discussed in Chapter 8, a number of factors should be considered when applying pesticides to avoid water quality impacts (Table 9-1). For example, a number of site-specific considerations for the use of pesticides should be evaluated using the results from the site analysis to identify areas where the risks of pesticides reaching surface or groundwater are greater (such as steep slopes, shallow water tables, and areas with frequently wet soils). In addition, pesticides should be applied accurately and with care to avoid conditions that can increase the chances of runoff, leaching, or drift (Figure 9-1).

Table 9-1. Factors contributing to greater risk for groundwater and surface water contamination.
Source: USGA 1995

Chemical	Soil	Site	Management
High solubility	Porous soil (sand)	Shallow water table	Incomplete planning
Low soil adsorption	Low organic matter	Sloping land	Misapplication
Long half-life (persistent)		Near surface water	Poor timing
Low volatility		Frequently wet soils	Over-irrigation



Figure 9-1. Typical fairway pesticide application using foam and dye for accuracy.
Source: Robert Alonzi.

9.2.1 Preventing Runoff and Leaching

Pesticides can be transported into water by several means:

- surface runoff following precipitation events or irrigation
- leaching through the soil horizon to reach groundwater

- adsorption on eroded soil that reaches surface water
- flowing directly to groundwater through sinkholes and permeable rock

The use of vegetated buffers may be the single most important strategy mitigating the impact of runoff as these buffers can “capture” pesticides and prevent them from reaching waterways. In addition, the timing and location of applications should be thoroughly evaluated. Preventing runoff and leaching of pesticides is heavily influenced by weather and irrigation scheduling. Pesticide applications followed by heavy rain or irrigation can cause the pesticides to leach into groundwater. This leaching can occur even for nonpersistent pesticides (those with a short half-life). Pesticide applications on saturated soils following heavy rain or irrigation can also lead to surface runoff. In addition, avoid applying pesticides in sensitive areas.

9.2.2 Preventing Drift

Drift can potentially cause water quality impacts, damage to susceptible nontarget crops, and a lower than intended rate to the turfgrass, thus reducing the effectiveness of the pesticide. Two types of drift occur: airborne (spray) drift and vapor drift. Spray drift is influenced by many interrelated factors including droplet size, nozzle type and size, sprayer design, weather conditions, and the operator. The amount of vapor drift depends upon a pesticide’s volatility and atmospheric conditions such as humidity and temperature. Volatile turfgrass pesticides should be avoided. In some cases, the pesticide label may indicate low volatility. Low volatility, however, does not mean that a chemical will not volatilize under conducive conditions, such as high temperatures or low relative humidity. For more information, see Appendix H, Preventing Drift.

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- Ensure full compliance with existing pesticide regulations, including applicator and technician certification and following all label directions.
- Adapt or implement as many NYSDEC pesticide storage guidelines as possible.
- Assess site and weather conditions thoroughly before applying pesticides.

10 MAINTENANCE FACILITIES

Every golf course has a central area for the maintenance and storage of equipment and supplies. These areas can potentially become point sources of pollution because of unintended releases of chemicals such as pesticides, fertilizers, or fuel during storage or handling of these materials. Maintenance and storage facilities are high priority areas to address in protecting water quality. Containment measures in these areas can easily prevent chemicals from becoming point sources of pollution.

10.1 Regulatory Considerations

While federal and state regulations or guidelines may apply to maintenance facilities, these areas are more likely to be subject to a number of local requirements, which may vary by county or town. Local building inspectors should be consulted during planning for new facilities to outline the permitting process and local requirements. Also, consider meeting with a representative from a NYSDEC regional office and the local fire marshal. The NYSDEC requests a State Environmental Quality Review (SEQR) for new construction, which is administered by local governments. NYSDEC comments on SEQR as well as other interested and involved agencies.

10.1.1 Pesticide and Fertilizer Storage

Pesticides are labeled with legal requirements for proper storage and disposal requirements. New York State (NYS) has published guidelines for the storage of pesticides as discussed in Chapter 9. These guidelines are also relevant for fertilizer storage, as the potential water quality impacts from spills of fertilizer are the same, particularly for large containers (greater than 55 gallons) of liquid fertilizers. Fertigation often has large tanks for the liquid fertilizer and the storage/containment structure can be large (often part of the irrigation pump house).

10.1.2 Fuel and Fuel Oil Storage

NYS has regulations for above and below ground storage of fuel and fuel oil in Part 613 of the ECL. Every facility manager should review this regulation carefully. The regulations require daily inspection logs be kept and annual inspections. Counties and towns may also have their own fuel storage regulations.

10.1.3 Other Materials Storage

Use caution when storing other hazardous material including lubricants, cleaners, flammable paints, and other volatile organic compounds (VOCs). Incompatible and flammable materials should be stored separately in approved storage cabinets.

10.1.4 Mixing and Loading

NYS guidelines recommend mixing and loading areas to be contained and bermed, with impervious surfaces. These areas should also be well ventilated. Precautions should be in place to effectively respond to emergencies such as the availability of proper PPE, spill response kits, and emergency wash stations. New York State also requires the use of backflow prevention

devices (BPDs) to protect potable water supplies, unless an air gap is maintained between water sources and container.

10.1.5 Washing

Currently no federal, state, or county regulations exist for the design and operation of wash stations. However, NYS guidelines recommend wash areas to be contained and bermed, with impervious surfaces.

Wastewater or rinse water can be reapplied to turf areas by certified pesticide applicators. Discharge of wastewater from wash stations with low concentrations of pesticides and fertilizers onto the ground does not require any special permits. However, USEPA and the NYSDEC do not permit wastewater to be discharged into a stormwater runoff system or any groundwater recharge area without special permits.

10.1.6 Stormwater

The concentration of activities in and around the facility may increase the levels of chemical residues that would be susceptible to runoff from heavy precipitation. Stormwater collection areas may need to be established to capture runoff in accordance with NYSDEC specifications. Discharges may require a SPDES general permit and compliance testing. In addition to chemical contamination limits (CCLs) for nitrites, nitrates, and pesticides, the NYSDEC also has a limit for phosphorus levels in stormwater of 0.1 mg P per liter.

10.1.7 Waste Management

Golf courses may generate a number of different types of wastes. Examples of wastes that may be generated at a golf facility include, but are not limited to, the following:

- parts wash solvents
- waste gasoline
- cleaning materials
- paints
- waste oil
- lead-acid batteries
- aerosol cans
- spent fluorescent bulbs
- unusable pesticides and inner bag liners
- unusable herbicides and inner bag liners
- antifreeze

A waste is a hazardous waste if it exhibits a specific characteristic (ignitability, corrosivity, reactivity, toxicity) or if it is included in any of the four specifically listed categories of hazardous waste. Many waste fluorescent lamps are hazardous wastes due to their mercury content. Other examples of lamps that, when spent, are commonly classified as hazardous waste include: high-intensity discharge (HID), neon, mercury vapor, high pressure sodium, and

metal halide lamps. In New York State, the hazardous waste regulations are found in 6 NYCRR Parts 370 through 374-3 and 376.

USEPA issued the Universal Waste Rule in 1995 to streamline compliance with hazardous waste regulations. This rule is designed to reduce the amount of hazardous waste in the municipal solid waste stream, to encourage the recycling and proper disposal of some common hazardous wastes and to reduce the regulatory burden on generators. Universal wastes include such items as hazardous batteries, hazardous mercury-containing thermostats, certain pesticides, and hazardous lamps. Although handlers of universal wastes must meet less stringent standards for storing, transporting, and collecting wastes, the wastes must comply with full hazardous waste requirements for final recycling, treatment, or disposal. Therefore, every golf club is responsible (and liable) for the safe handling of the product and proper waste disposal by a reputable waste removal service. These services should be certified and bonded for transporting your waste to similarly accredited processing centers.

For more information, see:

- NYSDEC State Environmental Quality Review: <http://www.dec.ny.gov/permits/357.html>
- NYSDEC regulations on handling and storing petroleum: <http://www.dec.ny.gov/regs/4433.html>
- NY policies on backflow prevention devices: www.dec.ny.gov/regulations/23471.html
- NY Stormwater Design Manual: <http://www.dec.ny.gov/chemical/29072.html>
- Regulated Hazardous Wastes in New York: <http://www.dec.ny.gov/chemical/8486>
- New York State Solid Waste Management: <http://www.dec.ny.gov/chemical/8498.html>
- NYSDEC: Hazardous Waste Management: www.dec.ny.gov/chemical/8486.html
- Lead Acid Batteries: www.dec.ny.gov/chemical/86024.html
- NYSDEC Waste Transporter Permit Program: www.dec.ny.gov/chemical/8483.html

10.2 Maintenance Facilities Design and Operation

A site analysis can identify and assess risk for ground or surface water contamination. The first step is to determine the environmentally sensitive areas, potential release points, and containment strategies currently employed. This analysis should address aspects of storage and handling of chemicals.

10.2.1 Storage

The goal of an ideal storage facility is the safe siting and storage of potential contaminants that ensures a high level of water quality protection (Figure 10-1). NYSDOH does not allow chemical storage or mixing and loading facilities within 100 feet of a potable well. Other requirements include local zoning for the siting of maintenance facility and operations, which vary by town and county. Requirements often include a minimum distance (set-back) from wetlands, surface wells and property lines. The Freshwater Wetlands Act (<http://www.dec.ny.gov/lands/4937.html>) requires a 100 ft buffer around wetlands. Some townships have even broader requirements.



Figure 10-1. Chemical storage building organization. Source: Robert Alonzi.

Modular or independent containment units can be installed in many sizes. The units are typically self-contained, fireproof and secure and can be temperature controlled with ventilation. Options include fire suppression, eye washes, and safety showers.



Figure 10-2. Modular containment units can be installed in many sizes. Source: Robert Alonzi.

Floor drains should include a sump and a chemical pump to move the chemicals discharged to a waste tank as in Figure 10-1. The material can be reclaimed, diluted to label concentrations, and applied to turf areas or collected for disposal using certified hazmat haulers.

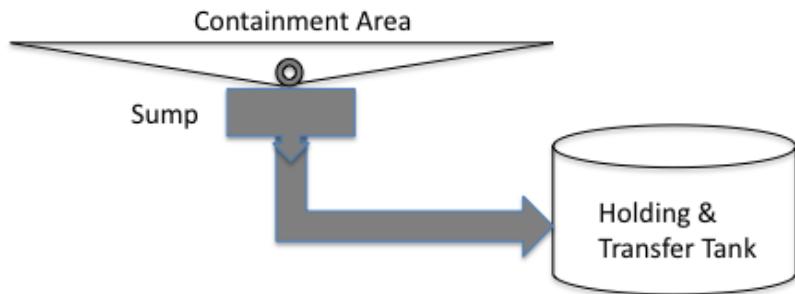


Figure 10-3. Containment area with sump and transfer to holding tank.

Updating chemical storage areas does not necessarily require a new building. Many changes can be easily attained:

- impervious flooring
- flooring sloped to a drain
- curbing to contain at least 25% of the volume of liquid chemicals and fertilizers stored
- ventilation to exhaust any fumes in the event of a spill
- PPE for workers and emergency wash stations

10.2.2 Mixing and Loading

As with the storage areas, the handling area (mixing and loading) of pesticides and fertilizers should be contained to minimize release of concentrated or diluted pesticides and fertilizers. These compounds should be mixed and loaded on a covered impervious surface properly sized and sloped to capture the maximum potential spill. Backflow preventers should be installed on fresh water supplies used for filling. The station could also be upgraded to pre-mix pesticide/fertilizer loads in a controlled environment then transferred to the sprayer. See Figures 10-4 through 10-6 for proper mixing and loading practices.



Figure 10-4. Loading fill spray tank from premix. *Source: Robert Alonzi.*



Figure 10-5. Recovery lines and trans pump in the equipment mixing and loading area.
Source: Robert Alonzi.



Figure 10-6. Mixing and loading recovery tanks. Source: Robert Alonzi.

10.2.3 Wastewater Handling

The release of organic waste associated with equipment cleaning needs the same level of protection afforded liquid and granular nutrients and pesticides. When debris is removed from equipment, it should not be released into open surface waters or in a location near well heads or shallow groundwater. Figure 10-7 shows a well designed wash area.



Figure 10-7. Equipment wash area. Source: Old Oaks County Club.

Often effective equipment cleaning areas can be maintained as mixing and loading areas with impervious flooring and drains that allow for some separation of organic solids and liquids (Figure 10-7). When using the simple wash-pad and collection area be sure to direct any uncontained liquid to be dispersed along the land, preferably along a designed bio-filtration system. Closed system cleaning stations are available that separate clippings/solids and treat the wash water. The recycled water is reused as wash water. The EPA suggests the stages of treatment, as shown in Figure 10-8. Another approach to wastewater treatment uses microbes to break down chemical compounds (Figure 10-9). Both types of systems may require additional purification steps to remove odors and harmful bacteria. These systems must be carefully sized to process the peak water volume anticipated for contaminant levels expected. The equipment varies in costs but increases with structural requirements and permits.

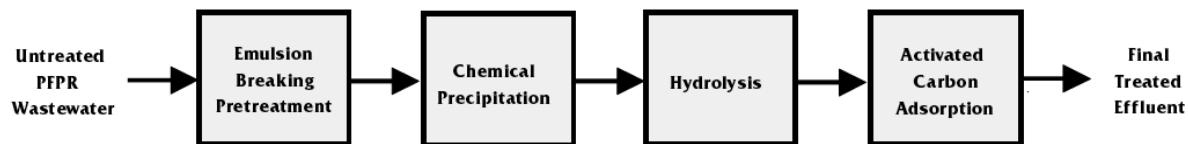


Figure 10-8. Stages of treating wastewater, as shown for an activated carbon adsorption system (EPA, P2 Guide).



Figure 10-9. Microbial system for treating wastewater. Source: Robert Alonzi.

10.2.4 Integrated Chemical Management

New construction designs should consider integrating storage, mixing, and washing operations in an integrated chemical management system. Buildings and infrastructure are designed to account for the traffic and usage. The resulting design should provide a much better envelope of the operations compared to separately constructed areas. Integrated designs often include fuel storage and filling stations within the same containment areas.

10.2.5 Organic Matter Management

Nutrient BMPs recommend that clipping be widely redistributed to turf. Research has shown that nitrate levels in leachate increased to as much as 30 mg/L in areas that received four times the normal clippings return. Some clubs elect to collect clippings from fairways and then dump these clippings as yard waste. The accumulation of clippings and other yard wastes such as leaves, tree limbs, and other plant debris can be a substantial source of contamination to surface water and groundwater if placed close to water courses.

Clippings should be screened and collected when cleaning equipment in the maintenance area (Figure 10-13). They should not be allowed into the stream of wastewater. The inherent concentration of organic nitrogen and phosphorus, along with any pesticide residues, can contaminate the wastewater or reduce the effectiveness of wastewater treatment equipment. Ideally, clippings should be blown off using compressed air and then collected

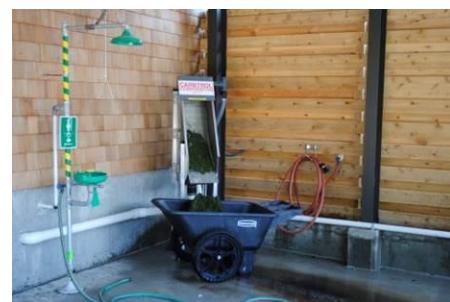


Figure 10-10. Clippings removal unit. Source: John J. Genovesi, CGCS, Maidstone Club.

(Figure 10-11). If water is being used, sumps should screen and convey clippings and other solids prior to wastewater disposal or treatment.



Figure 10-11. Prior to washing equipment, removing clippings while over grass (top) or a pad (bottom) with an air hose or prewash reduces the amount of organic debris in the wash water. *Source: Robert Alonzi.*



Figure 10-12. Typical equipment wash area with drain. *Source: Robert Alonzi.*



Figure 10-13. A Retrofitted RGF system separates solids in the wash water. *Source:* Robert Alonzi.



Figure 10-14. A retrofitted RGF system solid separation pad. Source: Robert Alonzi.

Many clubs have contracted with local composting companies to haul their organic waste. Material is generally accumulated in dumpsters and then frequently removed.

10.2.6 Lubricants, Greases, Paints, and Solvents

Lubricants, greases, paints and solvents should be stored appropriately, typically in fireproof enclosures, separately from pesticides and fertilizers. Special cleaning stations are commercially available that contain and recycle solvents and degreasers.

In addition to any handling precautions specified on the product label or MSDS sheet, added steps should be taken to prevent and contain any spills. Spills should be cleaned up using approved dry absorbants. Contaminated material should be stored in containers specially marked as hazardous waste and disposed of using licensed waste haulers and hazmat processors.

10.3 Emergency Planning

Planning and preparations should be made for potential emergencies. Local emergency personnel such as local fire departments should be consulted and notified of the locations of pesticides and fertilizers storage as well as regularly updated lists of chemicals stored. Storage areas should be properly placarded. Training and orientation should also be conducted with employees to review those plans and preparations.

New York State responds to reports of petroleum and other hazardous material releases through the Spill Response Program maintained by the NYSDEC. Spill response staff throughout the State investigate such spill reports and take action based on the type of material spilled, the potential environmental damage, and safety risks to the public. Releases to the environment should be reported to the NYSDEC Spills Management Hotline at 1-800-457-

7362. See <http://www.dec.ny.gov/chemical/8428.html> for more information on reporting of spills.

10.3.1 Safety Data Sheets (SDS)

The Hazard Communication Standard (HCS) (29 CFR 1910.1200(g)), revised in 2012, requires that the chemical manufacturer, distributor, or importer provide Safety Data Sheets (SDSs) (formerly MSDSs or Material Safety Data Sheets) for each hazardous chemical to downstream users to communicate information on these hazards. The information contained in the SDS is largely the same as the MSDS, except now the SDSs are required to be presented in a consistent user-friendly, 16-section format. More information on SDS can be found at: <https://www.osha.gov/Publications/OSHA3514.html>.

10.3.2 First Aid

Adequate provisions should be provided to immediately treat any person exposed to chemical exposure including eye wash stations and showers. First aid kits should be maintained to treat skin contact, ingestion, or inhalation.

Cornell's Occupational and Environmental Health Department (OEHD) at the Cornell College of Agricultural Sciences have guidelines that can be used a template for spill management:

- Evacuate personnel from the immediate area of the spill.
- Control the spill. Do not endanger yourself. To the extent possible, shut off the source and block the flow.
- Call 911 if:
 - anyone is injured
 - the spill is too large for a local clean up
 - the spill migrates off-site
 - the spill threatens the health and safety of anyone
- Identify the spilled material(s).
- Barricade the area and notify others in surrounding areas not to enter the spill area.
- Wait for help to arrive.

Spill kits (Appendix I) can be used for incidental releases and the following procedures followed:

- Consult the appropriate SDS and label (for pesticides).
- Wear the appropriate PPE.
- Contain the spill. Prevent spread or escape from the area by using sorbents.
- Clean up the spill. Never hose down an area until the cleanup is completed.

To clean up pesticides:

- Recover as much product as possible in a reusable form. Store and use as intended. Recover the rest of the product as a waste product by using an adsorbent or sweeping compound.

- When all recoverable material is secured, clean contaminated surface residues using triple-rinse technique; for instance, a spill of liquid on the floor requires that the area be damp-mopped three times.

To clean up all other chemicals:

- Small liquid spills can be cleaned up with a commercially available absorbent. Avoid using paper towels; they increase the surface area and the rate of evaporation, increasing the fire hazard.
- For acid or base spills, use a sorbent that will neutralize the liquids (trisodium phosphate, sodium bicarbonate, or other commercially available products).
- Use a dustpan and brush to sweep up the absorbed spill. Wash the contaminated area with soap and water.

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- Assess potential point source pollution risk.
- Manage organic and inorganic waste to minimize potential point source pollution.
- Ensure compliance with regulatory requirements designed to prevent point source pollution.

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APPENDICES

Appendix A: Glossary

Aquifer – An underground source of water made up of porous rock, like sand, shell or limestone.

Available Water – The difference between soil moisture content at field capacity and the point at which plants wilt due to lack of moisture little water remains available to the plant.

Biological control – The use of living organisms to reduce populations of other living organisms- namely pests.

Environmental Impact Quotient (EIQ) – A method for quantifying the effect of pesticides on the environment, people, water and wildlife.

Eutrophication – The enrichment of bodies of fresh water by inorganic plant nutrients (e.g. nitrate, phosphate). It may occur naturally but can also be the result of human activity (cultural eutrophication from fertilizer runoff and sewage discharge) and is particularly evident in slow-moving rivers, shallow lakes, and impoundments.

Evaporation – The process by which water changes from a liquid into a gas.

Evapotranspiration - The sum of evaporation and plant transpiration from the Earth's land surface to atmosphere.

Flow – The movement of water from one place to another.

Groundwater Recharge – The hydrologic process by which water enters into groundwater.

Hypoxia - Very low levels of dissolved oxygen in the water column

Infiltration – The process by which water is absorbed into the ground.

Leaching - The downward movement of a chemical or nutrient (e.g. pesticide or nitrogen from fertilizer) through the soil and potentially into groundwater.

Nonpoint Source – Nonpoint source pollution is caused by water moving over and through the ground picking up and carrying away natural and human-made pollutants and finally depositing them into lakes, rivers, wetlands, coastal waters and ground waters.

Nutrients – Elements as nitrogen and phosphorus compounds necessary for plant growth and survival. Elevated levels can cause unwanted growth of algae, and can result in the lowering of the amount of oxygen in the water when the algae die and decay.

Runoff – the movement of water across the turf and soil surface, typically following a storm event or heavy irrigation

Sedimentation – The deposition of loose particles of sand, clay, silt, and other substances that settle at the bottom of a body of water. Sediment can come from the erosion of soil or from the decomposition of plants and animals.

Pesticide Drift – The U.S. Environmental Protection Agency defines spray or dust drift as “the physical movement of pesticide droplets or particles through the air at the time of pesticide application or soon thereafter from the target site to any non- or off-target site”.

Pesticide Resistance – The decreased susceptibility of a pest population to a pesticide that was previously effective at controlling the pest.

Pesticide Volatilization – the chemical process whereby pesticide surface residues change from a solid or liquid to a gas or vapor after application. Once airborne, volatile pesticides may drift off site. Pesticide volatility varies, and not all pesticides volatilize.

Point Source- A point source is a source of pollution from originating from a single identifiable source. However, this does not legally include agricultural storm water discharges and return flows from irrigated agriculture, including turf.

Stormwater - Water that originates in some form of precipitation as either rainfall or snowmelt.

Transpiration – Loss of water through the leaves of plants.

Watershed – An area of land that drains into a body of water (e.g. river, lake, reservoir, etc.) and includes the network of rivers, streams and lakes that convey the water, as well as the land surfaces from which water runs off.

Water Table – Marks the very top of the ground water layer, and is the border between the unsaturated and saturated zone.

Appendix B: Groundwater quality of eastern long island, ny, golf courses

In New York, groundwater quality has been tested on 27 golf courses in Suffolk County by the Suffolk County government. From 1999 to 2010, up to 42 wells were sampled for a total of 366 sampling events. The samples were tested for a wide range of compounds from nutrients like nitrate and ammonia; metals like arsenic, cooper and cadmium; and 54 organic compounds, including pesticides and metabolites. These sample tests resulted in over 20,000 individual results. These test results are provided on the next page and as a download from the NY BMP web site.

Nitrate was found to be a common contaminant of groundwater in some areas, although 57% did not have a detectable level of nitrate. Twenty nine percent had nitrate concentrations of less than 5 mg/L, 10 % had concentration from 5 to 10 mg/l and only 4 % were greater than 10 mg/L, the drinking water standard. The Nitrogen Challenge with Suffolk County golf courses and the Peconic Estuary Program has set a target goal of groundwater of no greater than 2 mg nitrate/L. Sixty eight percent of the samples tested were below this goal level.

The most commonly detected golf course pesticide was metalaxyl. Fourteen percent of the samples tested had detectable levels of metalaxyl, with concentration ranging from 0.1 to 2.74 ppb (ug/L). An old no longer used herbicide dacthal (the acid metabolite) was detected in 9% of the samples, at concentration as high as 272 ppb. Imidacloprid was detected in 6% of the samples in concentrations no greater than 10 ppb. Several other pesticides (PCNB, propiconazole and iprodione) were occasionally detected at very low concentrations (<1 ppb).

The results of this testing would suggest than golf courses are having at most a minor impact on the groundwater quality of eastern Long Island.

Appendix D: Conversion Tables

Hectare =	107,639.10	sq ft
Acre =	43,560.00	sq ft
Hectare =	2.47	acres
kilogram =	2.20	lbs
inch =	2.54	cm
cm =	0.39	in
gallon H ₂ O =	8.35	lbs
gallon H ₂ O =	3.79	kg
gallon =	0.13	cu ft
gallon =	3.79	L
cu ft =	7.48	gal
cu ft =	1,728.00	cu in

Appendix E: Guidelines for Using Recycled Wastewater for Golf Course Irrigation in the Northeast

Joann Gruttadauro and A. Martin Petrovic, Cornell University

Introduction

The availability of fresh water for irrigation in many parts of the United States is becoming critically limited. This is especially true for irrigation of non-food and fiber production sites including parks, commercial and residential lawns, athletic fields, golf courses, cemeteries, sod farms and other landscape plantings. This is true even for the northeastern US where many people perceive an abundance of fresh water. In order to meet demand, major metropolitan water suppliers in the northeastern US are required to double the supply capacity of their systems for the three summer months that are dominated by landscape irrigation demands.

As urban and suburban sprawl continues, the demand for freshwater resources also increases. Water conservation and/or the use of alternative water sources, such as waste water for landscape irrigation can help address the growing demand for fresh water. Most large-scale waste water irrigation comes from sewage treatment plant effluent. The southwestern US has successfully used treated sewage effluent and gray water for irrigation for many years.

The benefits of using waste water as an irrigation source include: conservation of freshwater that would be used for irrigation, supply of small amount of nutrients to enhance plant growth every time the site is watered, and a reduction of pollutant (phosphorus and nitrogen) discharge into surface water.

The potential hazards from waste water irrigation involve salt injury to plants, long term effects on soil health (reducing in drainage and increase in runoff/erosion), other soluble compounds in the water and human pathogens in the waste water. Proper water treatment has all but eliminated the human pathogen issue. Long-term use of waste water irrigation of turfgrass sites in the desert southwest, a low rainfall area, has shown to increase salts levels in the soil which could harm plant growth and impede drainage by destroying the structure of soils with clay. However, in areas with 30 to 60 inches of rainfall per year, will waste water irrigation harm plant growth and soil health?

In the Northeast, waste water use for irrigation has been very limited. For example, in New York State only two golf course complexes out of 850 golf courses use waste water for irrigation. One golf course (45 holes) in Lake Placid, NY, gets all its irrigation water from the Village of Lake Placid and the Village of Lake Placid has reduced its phosphorus loading into Lake Champlain by 25 percent. At the Turning Stone Casino Resort, four of the five courses use recycled waste water, which is generated by on-site use, exclusively for irrigation. To date, neither the Lake Placid golf courses nor the Turning Stone Casino golf courses have reported any observable turf damage from the use of recycled waste water.

Water as an Essential Resource

Potable water reserves comprise only 2-5% of the total global water supply. Ground water makes up only 1.7% of that total. Ground water supplies only 30% of the water resources used for human and industrial purposes, the remaining 70% comes from surface water sources.

The demand for fresh water for human consumption and uses continues to increase. Interest in conserving fresh water and finding alternative water sources to be used for agriculture and landscape management has become important societal concerns/issues.

What is Waste Water?

Waste water is water that has been reclaimed from municipal waste water or sewage treatment plants. Waste water is also referred to as recycled water, reclaimed water, effluent water and gray water. Recycled water can beneficially be used for agricultural or landscape purposes and for recharging ground water supplies.

Before being recycled or discharged into streams or lakes, the waste water goes through a primary, secondary or tertiary treatment process. The primary treatment process removes the sediments and is not recommended for use. The secondary treatment uses a process of biological oxidation and disinfection. The resulting effluent can be used to irrigate non-food crops, and possibly for industrial cooling processes, wetland and wildlife habitat, stream augmentation and ground water recharge of aquifers not supplying potable water. Tertiary treatment involves chemical coagulation, filtration and disinfection. This water can be used for golf course and landscape irrigation, food crop irrigation and other uses.

Using recycled waste water for golf course irrigation can decrease the diversion of freshwater from sensitive ecosystems, decrease the discharge of waste water to sensitive water bodies, may be used to enhance wetlands and riparian habitats and prevent or reduce pollution.

Why golf courses?

Golf courses serve important environmental, recreational and economical roles in our communities as sites for recreation, wildlife sanctuaries and comprise land that can help to filter recycled water.

The typical Northeast 18-hole golf course uses between 15-30 million gallons of water per year. The Northeast is currently fortunate to have access to water to meet this demand under most non-drought conditions. Other parts of the country with low rainfall have had to switch to alternative water sources for irrigation so enough freshwater would be available for human consumption.

Use of Recycled Waste Water for Golf Course Irrigation

Golf course managers in the Northeast are largely unfamiliar about using recycled waste water for irrigation. Many questions have slowed the adoption of this practice including:

1. Will the waste water be harmful to the turf?
2. Will I have a consistent water supply when I need it for irrigation?
3. Would extra equipment or retrofitting the current irrigation system be necessary?
4. How would the public or clients react to the use of this water on the golf course?
5. Is it necessary and easy to get approval to use waste water for irrigation?
6. How must management be changed when using waste water?
7. What are the costs or savings associated with using waste water?

Potential benefits of irrigating with waste water include the opportunity to conserve a precious natural resource, to provide a site that would serve as a biofilter (thus reducing the amount of effluent water reaching streams and lakes), to use a water source that contains some nutrients (which would reduce the need for some additional fertilization) and to find a less expensive water source than potable water.

New York Golf Course Experiences with Recycled Waste Water for Irrigation

We are using the experiences of three New York golf courses to provide insight on using waste water for irrigation: Lake Placid Resort Golf Course, Turning Stone Casino and Resort, and Indian Island Golf Course.

Lake Placid Resort Golf Course

The Lake Placid Resort Golf Course is a rather large operation with 45 holes of resort golf turf. For the last 7 years, 12 - 20 million gallons of recycled waste water have supplied all their irrigation needs. The Lake Placid Resort Golf Course had the opportunity to be part of a New York State Energy Research Development grant associated with the Lake Champlain Basin program with the objective of helping to reduce the amount of phosphorus reaching the lake. The grant funded the testing of the river water and ground water as well as some startup costs at the treatment plant and the golf course.

The close supply of recycled water, within a mile of the golf course, aided a quick start up. The water was tested weekly and a close working relationship with treatment plant manager was established. Joe De Forest, assistant golf course superintendent, stated that access to this waste water allowed the golf course to irrigate the fairways which previously were not irrigated. He found that the turf was healthier and better able to handle periods of stress. The regular

fertilizer program could be reduced slightly and there was a dramatic increase in the turf quality which led to increased revenue from more play.

With the ability to irrigate areas not previously irrigated, such as the fairways and by keeping the turf growing during the summer period, there was a slight increase in disease, insect and weed pressure and expense to manage these changes. More labor was needed to handle the extra mowing and pest management which was an expected outcome when increasing the amount of irrigated land.

When irrigating with waste water, Deforest suggests:

- 1) Developing a good relationship with the treatment plant personnel so they can keep you informed of plant operations that might affect your water supply.
- 2) Having the water tested on a routine basis, monthly as a minimum and weekly if the water has a high salt content.
- 3) Keeping or developing an alternate water supply in case there is an interruption of water supply from the treatment plant.

The overall environmental impact to the community included a 25% reduction of phosphorus loading into the Lake Champlain Basin from the Village of Lake Placid Sewage Treatment Plant. On average the golf course used 20 million gallons of waste water per year and served as a bio-filter thus reducing the amount of waste water directly discharged into the Chubb River.

Turning Stone Casino and Resort

Turning Stone Casino and Resort had the unique opportunity to build their golf courses knowing that waste water would be the main source for irrigation. This is a very large complex with three 18-hole and two 9-hole golf courses. Four of the five courses use waste water exclusively for irrigation. The golf course managers anticipated certain benefits of using waste water including the ability to conserve a natural resource by using recycled waste water, have a constant reliable supply of water that contained some needed nutrients and have a relatively inexpensive source of water. However the managers had some concerns which focused on water quality issues for growing turf including: 1) the pH of the waste water, 2) whether there would be a slight odor, any pathogens or trace organics, and 3) the heavy metal and salinity content.

The Oneida County Waste Water Treatment Facility is a two stage aerobic processes in which the water passes through a series of filters and screens, then a chlorine contact, next through a tertiary filter, chlorinated and finally discharged. Water is tested four times a day for non-turf related water quality parameters before it leaves the plant.

Turning Stone has two of their 18-hole courses and one 9-hole par three course certified in the Audubon International Sanctuary Program. This certification program requires water quality analysis be made twice a year for total phosphorus, pH, total calcium carbonate (CaCO₃), total metals, total kjeldhal nitrogen as nitrogen, chloride, nitrate nitrogen, sulfate, alkalinity as CaCO₃ and total dissolved salts. The results indicated the water was suitable for irrigation with minor modification.

Daily 1.1 million gallons of waste water is pumped to the golf course regardless of demand and held in a holding pond. The unused water or extra water moves through an overflow system which drains into a stream that has many opportunities for the water to be filtered before it exits the golf course and finally reaches Oneida Lake.

The golf course director, Andy Knappenburger and the course manager Frank Albino have been quite pleased with the quality of the turf and playability. They advise regular water testing so informed management decisions can be made throughout the growing season.

Indian Island Golf Course on Riverhead, Long Island

In this situation, the Waste Water Treatment Plant in Riverhead discussed with the Suffolk County Parks Committee the possibility of using effluent water from the plant to irrigate the golf course which was right next to the plant. The goal was to conserve their fresh water supply and hopefully reduce the effluent discharged into the Peconic Estuary. The golf course agreed to consider using the waste water for irrigation if the Health Department verified a lack of public safety concerns and if trial applications demonstrated the recycled water was suitable for growing turf.

The golf course built a practice green, tee and fairway as a test model to see how the use of this recycled water would affect the turf. They replicated the grasses and management regime used elsewhere on the golf course and began testing the soil and water. The results from the demonstration site showed no impact from using recycled waste water.

However, in order to meet the daily quality and quantity requirement of 350,000 gallons of high quality water for the golf course, the existing water treatment system at the plant would need to be upgraded. The original cost of the system upgrade was estimated in 2004 to be almost two million dollars. Current estimates now come close to three million dollars so the project is on hold until supplemental funding is procured to launch this project.

When considering recycled water for irrigation, plan ahead and use the following steps:

- Determine what town, county and state permits and approvals are necessary when considering using recycled waste water for irrigation.
- The ideal situation would be to have the recycled water source fairly close to the golf course. If this is not possible the costs to set up a delivery system can be extremely costly.

- Visit the water treatment plant, learn about their water treatment process, ask for an analysis of the water and begin to develop a relationship with the plant manager.
- Your course may need some additional equipment to be able to utilize the new water source efficiently. A booster pump and electricity may be needed for the additional pump capacity.
- Where will the extra recycled water be stored? Are there lakes or ponds on the golf course that could serve as holding areas? These ponds may have an odor problem.
- Be prepared to devote more time to management. More time will be necessary to monitor soil nutrient levels and water quality. With the increase in acreage irrigated there will be more mowing and possibly more pest pressure to deal with. Depending on water quality more time will be necessary to monitor drainage.
- If weeds and algae build up in the irrigation pond a herbicide treatment may be necessary to reduce aquatic weed growth. Be sure the herbicide treatment will not harm golf course grasses or have any restrictions for use as an irrigation source.
- Be sure your membership is aware that recycled water is being used.
- Take steps to be sure the irrigation water does not reach adjacent properties or potable water sources by runoff off or overspray into wetlands or water courses.
- Make sure it will not be used for drinking.

Evaluating Recycled Waste Water for Growing Turf

Begin with a water sample

Be sure to use a certified water testing laboratory. Each water testing laboratory has specific guidelines for sampling water and submitting samples for testing so be sure to follow their instructions. Generally, the water should be sampled from the irrigation head after it has run for a few minutes so that stagnant water can be flushed from the line. Do not sample directly from the pond or well. Laboratories usually require about 12-16 oz for a sample. If the laboratory does not supply a sampling bottle, place the sample in a clean plastic bottle after it has been rinsed with the same water to be tested. Avoid using bottles containing carbonated beverages, sports drinks or food. Be sure to label the sample and keep notes regarding the location of where the sample was taken. See appendix for a list of a few labs that test waste water for irrigation.

Which parameters should you test?

When assessing irrigation water quality the following components should be evaluated: the salt content, which is expressed as electric conductivity (ECw) or total dissolved salts (TDS), the sodium (Na) hazard expressed as the sodium adsorption ratio (SARw), the levels of carbonate,

bicarbonate, residual sodium carbonate (RSC), calcium, magnesium, boron, chlorine, and pH. Table A lists the common units used to report water test results.

Table B. Water Components and Units

Quality Factor	Preferred Units
Water – degree of acidity/alkalinity	Ph
Total Salinity – impact on plant growth from higher total salts	
Electrical conductivity (EC)	dS/m, mmhos/cm
Total dissolved salts (TDS)	mg L ⁻¹
Carbonates and Bicarbonates	mg L ⁻¹ , ppm, meq L ⁻¹
Sodium Permeability Hazard – impact on soil structure	
Sodium adsorption ratio (SAR)	meq L ⁻¹
Adjusted SAR (adj SAR)	meq L ⁻¹
Residual sodium carbonate (RSC)	meq L ⁻¹
Ion Toxicity – impact on root and foliar contact	
Na – sodium	meq L ⁻¹ , mg L ⁻¹
Cl – chloride	mg/L
B – boron	mg/L
Nutrients	mg L ⁻¹ , meq L ⁻¹

Note: 1 milligram per liter (mg L⁻¹) equals 1 part per million (ppm). Another unit is miliequivalent per liter (meq L⁻¹).

Additional water quality factors impacting irrigation water include the presence of solid particles which can be organic (organic matter) or inorganic in nature (sand, silt, clay). These particles can clog irrigation heads and nozzles, cause wear and tear on equipment and plug soil pores causing a reduction in drainage. A filtering system should be added to the golf course irrigation system to prevent this. Weed seeds, algae and chemical materials can also be found in recycled water.

Water testing labs may use different units when reporting results. Table B provides conversion factors to convert mg L⁻¹ to meq L⁻¹. For a more comprehensive listing of conversion factors, see Table K at the end of this document.

Table C. Conversion Factors

Component	To convert mg L ⁻¹ to meq L ⁻¹ , multiply by	To convert meq L ⁻¹ to mg L ⁻¹ , multiply by
Sodium (Na ⁺)	0.043	23
Calcium (Ca ⁺⁺)	0.050	20
Magnesium (Mg ⁺⁺)	0.083	12
Bicarbonate (HCO ₃ ⁻)	0.016	61
Carbonate (CO ₃ ²⁻)	0.033	30
Chloride (Cl ⁻)	0.029	35

For example, if your water test report states the calcium level was 1.6 meq L⁻¹ and you wanted to know the level in mg L⁻¹, take $1.6 \times 20 = 32$ mg L⁻¹ of calcium.

Soluble Salts

Salts found in the soil originate from mineral weathering to form soil, from fertilizers or irrigation water. All irrigation water will contain some soluble salts and traces of other materials. Soluble salts include sodium chloride, calcium chloride or magnesium sulfate and at high concentrations can inhibit growth. Insoluble salts, which do not inhibit growth but can clog soil pores, include limestone, calcium carbonate and gypsum (magnesium sulfate).

Some salts are nutrients and are beneficial to turf but many can be toxic at high concentrations. Salt is the most common problem with recycled water.

Caution must be used if the waste water being used to establish turf or renovate turf is high in soluble salts and if rainfall is limited. Young plants are more sensitive to salt injury than well established mature plants.

High levels of salt in the soil inhibit water uptake by the roots causing reduced growth, discoloration, wilting, leaf curling and eventually desiccation or leaf firing. High salt levels

in the soil influence water infiltration into and percolation through the soil resulting in poor drainage.

The salt content of the waste water will depend on the water source. High levels of salt can accumulate if the irrigation water is high in salts, if there is limited rainfall and if capillary rise of water brings salts to the soil surface due to evapotranspiration. Soils with high levels of salt are called saline soils.

The salinity of the water is reported in several ways, as electric conductivity (ECw) and stated as milimhos per centimeter (mmhos cm^{-1}), micromhos per centimeter (umhos cm^{-1}), decisiemens per meter (dSm^{-1}) or siemens per meter (Sm^{-1}) or as total dissolved salts (TDS) in units of milligrams per liter (mg L^{-1}) or parts per million (ppm). Most sewage effluent contains 200-3000 mg L^{-1} TDS or 0.30 – 4.7 dSm^{-1} . (Feigin et al. 1991). Table C lists the total salinity hazard based on electric conductivity (ECw) and total dissolved salts (TDS).

Table D. Total Salinity Hazard Classification Guidelines for Variable Quality Irrigation Water based on Electric Conductivity (ECw) and Total Dissolved Salts (TDS) (Adapted from Carrow and Duncan, 1998)

Salinity	ECw	TDS	<u>Management Requirements</u>
Hazard Class	(dSm^{-1})	(mg L^{-1})	
Low	<0.75	<500	no detrimental effects expected
Medium	0.75 – 1.50	500 - 1,000	moderate leaching* to prevent salt accumulation
High	1.5 – 3.00	1,000 – 2,000	turf species/cultivar selection, good irrigation, leaching*, drainage
Very High	>3.00	>2,000	most salt-tolerant cultivars, excellent drainage, frequent leaching*, intensive management

* It has not been determined that leaching is required in higher rainfall areas like the Northeastern US.

Turfgrasses tolerance to salt

Turfgrasses differ in the tolerance to salt (see Table D). Cultivars within a species can also vary in their salt tolerance. Acceptable levels for turf irrigation water ranges from 200-800 mg L^{-1} . Soluble salt levels greater than 2000 mg L^{-1} may injure turf.

Table E. Turfgrasses Tolerance to Total Salinity (Adapted from Harivandi and Beard, 1998)

Sensitive	Moderately Tolerant	Tolerant	Very Tolerant
0-3 dSm ⁻¹	3.1-6 dSm ⁻¹	6.1-10 dSm ⁻¹	>10 dSm ⁻¹
Annual bluegrass	Annual ryegrass	Perennial ryegrass	Bermudagrass
Colonial bentgrass	Creeping bentgrass	Tall fescue	Seashore Paspalum
Kentucky bluegrass	Fine-leaf fescues		
Rough bluegrass			
Most zoysia spp.			

In the Northeast, the annual rainfall ranges between 30" and 60". We do not expect the accumulation of high levels of salt with this amount of rainfall. However, under serious periods of drought and when the irrigation water has high soluble salts, management strategies may be employed to reduce the salt concentration.

In situations where the salt concentration is medium (500-1000 mg L⁻¹), leaching with fresh water may be necessary to prevent salt accumulation. The volume of water applied should be increased by 12.5% for each 640 mg L⁻¹ rise in TDS in the irrigation water. Additional management strategies must be used when trying to manage sites with very high concentrations of salt, >2000 mg L⁻¹. Along with frequent leaching with good quality water, salt tolerant species should be used, and a routine aeration program should be established, comprised of frequent shallow core aeration and deep tine cultivation (8-12" once or twice a year) to help maintain excellent drainage (Duncan, Carrow and Huck 2000). Leaching could lead to ground water quality problems, so do it as little as possible!

Sodium Permeability Hazard

The sodium (Na) concentration and the quantity of other salts in the irrigation water can affect soil permeability, which is the ability of water to infiltrate into the soil and move through the profile. When irrigation water has sodium levels > 200 mg L⁻¹ sodium (Na) may build up over time and will affect permeability. Calcium which is important to soil structure stability is displaced by sodium which causes the soil structure to break down resulting in reduced water and oxygen infiltration and percolation. This problem can become a more serious problem on fine-texture clayey soils, than sand-based systems. (See Table E).

To assess the potential of the problem you need to know the following:

1) **sodium adsorption ratio** (SARw) which incorporates the influence of sodium, calcium and magnesium concentrations. SAR values >6 meq L⁻¹ contain sodium (Na) high enough to cause structural deterioration of some soils.

2) **bicarbonate and carbonate levels.** The bicarbonate ion can combine with calcium and/or magnesium and precipitate out as calcium carbonate and magnesium carbonate. This increases the Sodium Adsorption Ratio because it lowers the amount of dissolved calcium concentration.

Also, high levels of bicarbonate in the water can raise the pH to undesirable level.

3) **type of clay in the soil.** Expanding clays like montmorillonite and illite are more susceptible to structural breakdown than other clays that do not crack when drying.

Table F. Sodium Permeability Hazard (Adapted from Harivandi and Beard, 1998; Carrow and Duncan, 1998)

<u>Irrigation Water Components</u>	<u>Degree of Problem</u>		
<u>SARw or adj SARw</u>	<u>Low</u>	<u>Moderate</u>	<u>High</u>
(sodium adsorption ratio by clay type (mg L ⁻¹)			
Clay type unknown	<10	10 – 18	>18
Clays that shrink and swell*	<6*-8** 6*-16**	>9*->16**	
Clays do not crack on drying *** <16 or swell on wetting	<16	16 – 24	>24
Sands with ECw >1.5 dSm ⁻¹	<10	10 – 18	>18
Sands with ECw <1.5 dSm ⁻¹	<6	6 - 9	>9
RSC (residual sodium carbonate)	<1.25	1.25 – 2.50	>2.50

* Montmorillonite clays (2:1); ** Illite clays (2:1); *** Kaolinite (1:1). Other 1:1 types are Fe/Al oxides and allophones.

Another fact to keep in mind is that sodium (Na) is absorbed by plant roots and transported to the leaves, where it can accumulate and can cause plant injury.

The Residual Sodium Carbonate (RSC) is also used to assess the sodium permeability hazard and includes the influence of bicarbonates and carbonates as compared to the calcium and magnesium concentration. To determine the residual sodium carbonate (RSC) the levels of bicarbonate and carbonate are added and the combined calcium and magnesium levels are subtracted and reported as meq L⁻¹. RSC = (CO₃ + HCO₃) – (Ca + Mg), in meq L⁻¹. If the RSC is >1.25 meq L⁻¹ and the SARw is >6 meq L⁻¹, water acidification may be necessary.

The total salt content of the water (EC_w) and the sodium adsorption ratio (SAR_w) must be considered together when determining the sodium permeability hazard. The high soluble salt concentration inhibits or counteracts the dispersing influence sodium. The electric conductivity and the sodium adsorption ratio of the waste water can be used to assess the potential for irrigation problems (Table F).

Table G. Assessing Soil Permeability* and Potential Irrigation Problem using Electric Conductivity (EC_w) and Sodium Adsorption Ratio (SAR) together (Adapted from Harivandi 1998)

<u>Soil water infiltration</u>	<u>Degree of Restriction on Use</u>		
	<u>None</u>	<u>Moderate</u>	<u>Severe</u>
if SAR _w = 0-3 & EC _w =	>.7	0.7 – 0.2	<0.2
if SAR _w = 3-6 & EC _w =	>1.2	1.2 – 0.3	<0.3
if SAR _w = 6-12 & EC _w =	>1.9	1.9 – 0.5	<0.5
if SAR _w =12-20 & EC _w =	>2.9	2.9 – 1.3	<1.3
if SAR _w =20-40 & EC _w =	>5.0	5 – 2.9	<2.9

* Soil permeability is the ability of water to infiltrate into the soil and percolate/drain. Gas exchange is also reduced by low soil permeability.

Ion Toxicities

Ions that can cause some toxicity problems include sodium (Na⁺), chloride (Cl⁻), boron (B⁺), bicarbonate (HCO₃⁻), and pH (H⁺ or OH⁻). (See Table G). Germinating seeds and young seedlings are especially sensitive to high levels of these ions. Use Table G to assess the risk factor in terms of toxicity to roots or leaves.

Table H. Specific Toxic Ion Reference Points (Adapted from Harivandi and Beard, 1998; Carrow and Duncan, 1998)

Specific Toxic Ions	Risk			
	Low	Moderate	High	
Sodium Content				
toxicity to roots	SARw	<3	3 - 9	>9
	mg L ⁻¹	<70	70 – 210	>210
toxicity to leaves	meq L ⁻¹	<3	>3	
	mg L ⁻¹	<70	>70	
Chloride Content				
toxicity to roots	meq L ⁻¹	<2	2 – 10	>10
	mg L ⁻¹	<70	70 – 355	>355
toxicity to leaves	meq L ⁻¹	<3	>3	
	mg L ⁻¹	<100	>100	
Residual Chlorine (Cl₂) mg L⁻¹				
		<1	1 – 5	>5
Boron				
toxicity on roots	mg L ⁻¹	<0.7	0.7 – 3.0	>3
Bicarbonate				
	meq L ⁻¹	<1.5	1.5 – 8.5	>8.5
	mg L ⁻¹	<90	90 – 500	>500

Nutrient Levels

Recycled water contains a number of different nutrients that can have an impact on the golf course fertility program and can have an environmental effect. Routine testing is necessary so in season adjustments can be made to reduce supplemental fertilization when sufficient nutrients are supplied by the recycled waste water. Table H offers some general guidelines for interpreting the nutrient content of the recycled waste water.

Table I. Nutrient Guidelines in Irrigation Water (mg L⁻¹) (Adapted from Duncan, Carrow and Huck, 2000)

<u>Nutrient</u>	<u>Low</u>	<u>Normal</u>	<u>High</u>	<u>Very High</u>
mg L ⁻¹				
P	<0.01	0.1 – 0.4	0.4 – 0.8	>0.8
PO ₄ ⁻	<0.3	0.3 – 1.21	1.21 – 2.42	>2.42
P ₂ O ₅	<0.23	0.23 – 0.92	0.92 – 1.83	>1.83
K	<5	5 – 20	20 – 30	>30
K ₂ O	<6	6 – 24	24 – 36	>36
Ca	<20	20 – 60	60 – 80	>80
Mg	<10	10 -25	25 -35	>35
N	<1.1	1.1 – 11.3	11.3 – 22.6	>22.6
NO ₃ ⁻	<5	5 – 50	50 – 100	>100
S	<10	10 – 30	30 – 60	>60
SO ₄ ⁻	<30	30 – 90	90 -180	>180

By calculating the ratios of specific nutrients you may be able to detect a possible nutrient deficiency. Concerns should be verified by a plant tissue analysis before making major fertilizer program changes.

Table J. Nutrient Ratios in Irrigation Water and Potential Deficiencies* (Adapted from Duncan, Carrow and Huck, 2000)

Ca: Mg	<3:1	Ca deficiency
	>8.1	Mg deficiency
Ca:K	<10:1	Ca deficiency
	>30:1	K deficiency
Mg:K	<2:1	Mg deficiency

>10.1	K deficiency
-------	--------------

* Irrigation water with nutrient concentrations outside these ranges can be used; the fertility program may be adjusted to avoid deficiencies

Example Waste Water Report

The reference tables provided can be used to assess the suitability of the waste water for turf irrigation. The following is a sample water test report.

CAYUGA LABORATORIES			
Green Valley Golf Club		File Number:	736548
Pleasantville, NJ		Date Received:	
<hr/>			
Sample Location:			
Sample Description:			
<hr/>			
pH	8.43		
Hardness	304.36	mg L ⁻¹	
Hardness	17.80	grains/gal	
Conductivity	1.61	dSm ⁻¹	
<hr/>			
Sodium Adsorption Ratio	5.23		
Adjusted SAR	9.62		
pHc	7.56		
Residual Sodium Carbonate	-2.10		
<hr/>			
	mg L ⁻¹	meq/L	lbs/ac in
<hr/>			
Calcium	(Ca)	57.95	2.89
Magnesium	(Mg)	38.66	3.18
			13.14
			8.77

Potassium	(K)	16.05	0.41	3.64
Sodium	(Na)	209.66	9.12	47.55
Iron	(Fe)	< 0.30		
Total Alkalinity	CaCO ₃)	198.36		44.99
Carbonate	(CO ₃)	21.90	0.73	4.97
Bicarbonate	(HCO ₃)	197.53	3.24	44.80
Hydroxide	(OH)	0.00		
Chloride	(Cl)	319.99	9.02	72.57
Sulfur as	(SO ₄)	76.52	1.59	17.36
Salt Concentration	(TDS)	1033.60		234.42
Boron	(B)	0.18		0.04

Use the following steps to determine the suitability of the water represented in the above water sample report (Modified from Carrow).

1. Check **Electric Conductivity (ECw)** and **total dissolved salts (TDS)** for their impact on turfgrass.
 Check the values listed in the sample report for conductivity 1.61 mmhos/cm* and the TDS level of 1033.60 mg L⁻¹ with Table C. Both values are considered high.

* 1 mmhos cm⁻¹ = 1dSm⁻¹

High total salinity values in conjunction with low sodium Na⁺ and bicarbonate HCO₃⁻ levels would indicate the potential to create a saline soil condition. Do not use this water if possible or other management practices may be needed such as aeration and leaching.
2. Check sodium (Na) level.
 Use Table G to evaluate the sodium (Na) level which is 209.66 mg L⁻¹. Although this is a moderate level, Na levels >200 mg L⁻¹ can build up over time.

3. It may be worthwhile to note the Sodium Adsorption Ratio (SARw) at this time especially if the soils are more fine-textured. These soils are more susceptible to structure deterioration when the salt concentration is high.

According to Table G. the SARw level of 5.23 meq L⁻¹ is under the level of concern for plant roots.

4. The permeability hazard can be determined by evaluating the electric conductivity (ECw) in conjunction with the sodium adsorption ratio (SAR) levels. Knowledge of the clay type will be useful. These values will determine the level of aerification, amendments and leaching that may be needed.

Use Table F to see that with ECw at 1.61 (mmhos/cm which = dSm⁻¹) and a SARw of 5.23 there would be no restriction in permeability with this water.

5. Now check for bicarbonates and carbonates in the water. If concentrations are greater than 120 mg L⁻¹ and 15 mg L⁻¹, respectively, you will have to take an additional step.

**The report states the bicarbonate and carbonate levels at 197.53 + 21.90 = 219.43 mg L⁻¹
Both levels are higher than the cautionary levels.**

6. Check the Adjusted Sodium Adsorption Ration (adj SAR) and the Residual Sodium Content (RSC) to verify the degree of impact that these ions will have on Ca and Mg activity. A SARw level >6 meq L⁻¹ and a RSC level >1.25 mg L⁻¹ may indicate that acid treatment plus lime or gypsum applications are needed.

The SARw level of 5.23 meq L⁻¹ and the RSC level of -2.10 are under the level for concern as shown in Table D.

7. Use Table H to check sulfur (S) and or sulfate (SO₄²⁻) levels in the water. If S >60 mg L⁻¹ or SO₄ > 180 mg L⁻¹, you may need to use lime as an amendment. The high sulfates (sulfur) in the water will combine with lime to form gypsum. Removing the excess sulfur and sulfates will help minimize anaerobic problems and black layer formation when regular aeration and leaching are used in management protocols.

Sulfur reported as sulfate is 76.52 mg L⁻¹. Table H indicates this level is in the normal range and below the level of concern which is 180 mg L⁻¹.

8. Check actual Chloride (Cl) and Boron (B) levels for their specific ion toxicity potential. These ions normally will affect susceptible turf cultivars but continued accumulation can eventually

influence even tolerant species. Plants tolerant to high total salinity also are generally tolerant to high levels of these specific ions.

The value for Cl it is 319.99 mg L⁻¹ and for B it is 0.18 mg L⁻¹. Both levels are considered moderate according to Table G.

9. Check levels of actual nutrients and make appropriate adjustments in your fertility program to account for nutrient additions or any induced deficiencies. Check the report levels for the following nutrients and compare with Table H. Calcium at 57.95 ppm is in the normal range, magnesium at 38.66 ppm is considered very high and potassium 16.05 ppm is in the normal range.
10. Calculate Ca:Mg, Ca:K and Mg:K ratios and adjust the fertility program accordingly.

The ratio of Ca: Mg is 1.5:1, for Ca:K it is 3.5:1 and for Mg:K 2.4:1. According to Table I, these ratios indicate there could be calcium and magnesium deficiencies. At this point, you could look for symptoms of calcium and magnesium deficiencies and have a tissue test done to confirm this possibility.

In summary, this water poses some concerns if used because of its high electric conductivity, moderate sodium level and high bicarbonates and possible calcium and magnesium deficiencies.

How much nutrients are supplied by waste water irrigation?

Another useful management step is to determine the amount of nutrients supplied with the irrigation water so that the total amount of supplemental fertilization can be reduced accordingly. Table J lists the amount of nutrients supplied per inch of irrigation water per 1000 sq. ft.

Table K. Nutrients Supplied by Waste Water Irrigation per 1000 sq ft per Inch of Irrigation at a concentration of 1 mg L⁻¹

Nutrient or Element	Concentration mg L ⁻¹	Lb of nutrients/ 1000 sq ft/ Inch of irrigation
N	1	.005
NO ₃ ⁻	1	.001
P	1	.012
PO ₄ ³⁻	1	.004
P ₂ O ₅	1	.005
K	1	.006

K ₂ O	1	.005
Ca ⁺⁺	1	.005
Mg ⁺⁺	1	.005
S	1	.005
SO ₄ ²⁻	1	.002

The below sample water test results will be used to demonstrate how to calculate the nutrients provided given the analysis of this particular irrigation water.

Sample

Waste Water Results from Sun Mountain Golf Course

Parameter		
Ammonium	NH ₄	12.07 mg L ⁻¹
Nitrate Nitrogen	NO ₃	3.17 mg L ⁻¹
Phosphorus	P	.32 mg L ⁻¹
Potassium	K	8.62 mg L ⁻¹
Calcium	Ca	85.69 mg L ⁻¹
Magnesium	Mg	15.17 mg L ⁻¹
Sulfur	S	.33 mg L ⁻¹
Sodium*	Na	21.36 mg L ⁻¹
Chloride*	Cl	230.85 mg/kg
Electric Conductivity *	EC	.82 dS/m

During the 2005 growing season, Sun Mountain Golf Course irrigated with 20" of the above waste water. The manager wanted to determine if an adjustment in their fertilizer program would be necessary after applying 20" of this particular water.

To calculate the amount of nutrients supplied by waste water irrigation follow the steps below.

1. Add the ammonium (NH₄) and nitrate nitrogen (NO₃) amount to come up with total nitrogen.

$$12.07 + 3.17 = 15.24 \text{ mg L}^{-1} \text{ total nitrogen.}$$

From Table J note that each mg L⁻¹ of nitrogen contributes .005 lb of nutrients with each inch of irrigation. Multiply 15.24 by .005 which = .077 mg L⁻¹ of nitrogen per inch of water. Multiply this by 20 (the amount of total irrigation) to come up with **1.5 lb of nitrogen** which was supplied per 1000 sq ft last year with the waste water irrigation.

2. Phosphorus (P) fertilizer recommendations are reported in the oxide form P₂O₅.

To calculate the P₂O₅ when you have the P value multiply the P value by 2.29.

Take the P value of 0.32 multiple it by 2.29 to come up with 0.73 mg L⁻¹ of P₂O₅. Then multiply this by .005 (the pounds of nutrients supplied with each inch of irrigation) which totals .004 mg L⁻¹ and then multiply by 20 (the total inches of irrigation) to see that **0.07lb of P₂O₅** was supplied per 1000 sq ft last year with the waste water irrigation.

3. Potassium (K) fertilizer is reported as K₂O so you will have to make this calculation first.

To calculate the K₂O when you have the K value multiply K by 1.2.

8.62 mg L⁻¹ of potassium multiplied by 1.2 equals 10.3 mg L⁻¹ of K₂O. Multiply this by .005 (the pounds of nutrients supplied with each inch of irrigation) to get .05 mg L⁻¹ then multiply this by 20 (the total inches of irrigation) to see that **1.0 lb of K₂O** was supplied per 1000 sq ft last year with the waste water irrigation.

* Other reported parameters:

According to Table G, the sodium level of 21.36 mg L⁻¹ is very low and is not of concern, but the chloride level of 230.85 mg/kg is in the moderate risk category. Table C indicates salinity as reported as electric conductivity is in the medium range.

With 20" of irrigation water applied in 2005 the turf was receiving a total of 1.5 lb of nitrogen, 0.07 lb of P₂O₅ and 1.0 lb of K₂O. The golf turf manager should take this nutrient contribution into consideration and adjust the fertilization program accordingly.

Summary

This initial survey of the potential for using waste water to irrigate golf course shows great promise. Managers found that the benefits of using the recycled waste water out weighed the costs. Especially when the waste water source was close to the golf courses, waste water offered less expensive water for irrigation.

It was acknowledged that extra management would be necessary to monitor the water and soil nutrient content through routine testing so timely adjustments could be made throughout the growing season. Managers found that having access to waste water would increase the areas irrigated and offered more play. Extra mowing and pest management may be necessary.

The community would reap environmental benefits by having more water from the treatment plants diverted to the golf course where the soil would serve as a bio-filter and reduce the amount of phosphorus and nitrogen reaching streams and lakes.

These guidelines provide the necessary information on what testing should be done on waste water and how to interpret the results to use waste water safely.

Golf course managers and community members are encouraged to learn all they can about their local water sources. The references listed at the end of this publication contain in-depth information which should be thoroughly reviewed by all interested parties.

References

1. Carrow, R.N. and R.R. Duncan. 1998. Salt affected turfgrass sites: Assessment and Management. Ann Arbor Press, Chelsea, MI. 185p.
2. Duncan, R.R. and R.N. Carrow and M. Huck. Understanding Water Quality and Guidelines to Management. USGA Green Section Record. Sep/Oct 2000.
3. Feigin, A.L. and J. Shalhev. 1991. Irrigation with treated sewage effluent. Management for environmental protection. Springer-Verlag, Berlin
4. Harivandi, M. A. Interpreting Turfgrass Irrigation Water Test Results. University of California. Publication 8009. 1999.
5. Harivandi, M.A. Evaluating Recycled Waters for Golf Course Irrigation. USGA Green Section Record. November/December 2004.
6. Harivandi, M.A., and J. B. Beard. 1998. How to Interpret a Water Test Report. Golf Course Mgmt. 66(6):49-55
7. Huck, M., R.N. Carrow and R.R. Duncan. Effluent Water: Nightmare or Dream Come True? USGA Green Section Record. March/April 2000.

8. Stowell, L. 1999. Pointers on reclaimed water contract negotiations – Pace Pointers (June). Web page (www.pace.ptricom)

Examples of Water Testing Labs that do complete waste water analysis:

Brookside Farms Laboratories, Inc., 308 South Main St., New Knoxville, OH 45871
419-753-2448. www.blinc.com

CLC Labs, 325 Venture Dr., Westerville, OH 43081. 614-888-1663

A & L Great Lakes Lab, Inc. , 3505 Conestoga Drive 209, Fort Wayne, IN 46808
260-483-4759. www.algreatlakes.com

MDS Harris -Agronomic Services, 624 Peach St., Lincoln, NE 68502
402-476-2811. <http://ag.mdsharris.com>

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Will Maxwell, superintendent, Indian Point Golf Course.

Table L. Conversion factors

To convert mg L ⁻¹ to meq/L, multiply by:	To convert meq/L to mg L ⁻¹ , multiply by
Sodium Na ⁺	0.043
Calcium Ca ⁺⁺	0.050
Magnesium Mg ⁺⁺	0.083
Chloride Cl ⁻	0.029
Potassium K ⁺	0.026
Sulfate SO ₄ ²⁻	0.021
Carbonate HCO ₃ ⁻	0.016
Note: 1 mg L⁻¹ = 1 ppm	
For example, to convert 220 mg L ⁻¹ Na ⁺ to meq L ⁻¹ : (220 mg L ⁻¹) x (0.043) = 9.46 meq L ⁻¹ Na ⁺	
<u>Convert ECw</u> <u>Multiply by:</u>	
Electrical Conductivity of Water	
mSm ⁻¹ to dSm ⁻¹	
dSm ⁻¹ to mSm ⁻¹	
0.01	
100	

mScm ⁻¹ to mSm ⁻¹	100
mSm ⁻¹ to ppm	6.4
dSm ⁻¹ to ppm	640
mScm ⁻¹ to ppm	640
ppm to dSm ⁻¹	0.0016

Other Conversion Factors:

1 mmhos cm⁻¹ = 1 dSm⁻¹ = 1,000 umhos cm⁻¹ = 0.1 Sm⁻¹

1 umhos cm⁻¹ = 0.001 dSm⁻¹ = 0.001 mmhos cm⁻¹

1 ppm = 1 mg L⁻¹ (solution) = 1 mg kg⁻¹ (soil)

1% concentration = 10,000 ppm

1 mmolc⁻¹ = 1 meq L⁻¹

1 ECw (dSm⁻¹) = 640 ppm (TDS = Total Dissolved Salts)

TDS (ppm) = ECw x 640; TDS (lb./ac.ft.) \approx TDS (ppm x 2.72)

ppm = grains per gallon x 17.2

(grains/gallon is still used by domestic effluent water purveyors to report hardness)

Sum of cations and anions (meq L⁻¹) \approx EC (dSm⁻¹) x 10

Appendix F: Conversion Factors And Example For Calculating Pounds Nutrient Per Acre-Foot Of Irrigation Water

(Duncan, R. R., Carrow, R. N., & Huck, M. T. (2009). *Turfgrass and landscape irrigation water quality: Assessment and management*. Boca Raton: CRC Press.)

11.3 ppm N = 0.71 lb. N per 1,000 sq. ft.
 50 ppm NO₃⁻ = 0.71 lb. N per 1,000 sq. ft.
 0.4 ppm P = 0.057 lb. P₂O₅ per 1,000 sq. ft.
 1.21 ppm P₂O₅ = 0.057 lb. P₂O₅ per 1,000 sq. ft.
 0.92 ppm K₂O = 0.057 lb. K₂O per 1,000 sq. ft.
 20 ppm K = 1.5 lb. K₂O per 1,000 sq. ft.
 24 ppm K₂O = 1.5 lb. K₂O per 1,000 sq. ft.
 60 ppm Ca = 3.75 lb. Ca per 1,000 sq. ft.
 25 ppm Mg = 1.56 lb. Mg per 1,000 sq. ft.
 30 ppm S = 1.87 lb. S per 1,000 sq. ft.
 90 ppm SO₄⁻ = 1.87 lb. S per 1,000 sq. ft.

1 acre = 43,560 sq. ft.

Example: Irrigation water has 15 mg/L NO₃⁻

$$\begin{aligned}
 15 \text{ mg/L} &= (15)(0.226 \text{ mg/L N}) \\
 &= 3.39 \text{ mg/L as N} \\
 \text{lb N per acre-foot of water} &= (\text{mg/L of N})(2.72) \\
 &= (3.39 \text{ mg/L of N})(2.72) \\
 &= 9.22 \text{ lb N per acre-foot water}
 \end{aligned}$$

Or, 9.22/43.56 = 0.21 lb N per 1000 sq. ft. per 12 in. irrigation water

Appendix G: WIN PST Example

WIN PST can be used for golf course conditions such as a sand green. In this example, the soil is sand at a typical greens depth of 12 inches and the average organic content for the 12 inch profile is 1%, by weight. The pesticides were applied to the turf foliage under two rainfall conditions: low potential for rainfall and a high potential for rainfall. Appendix G contains the WIN PST risk screening for pesticide leaching for most pesticides registered in NYS for use on golf courses. Under the low rainfall potential scenario, most of the pesticides evaluated had a low or very low risk (four had a high/extra high) to humans (long term exposure as a drinking water source) and only one pesticide has a high or extra high risk to fish, even when applied to this very high leaching-groundwater contamination soil like sand. When applied under a high potential rainfall scenario, however, 15 pesticides had a high/extra high risk to humans, and 20 had high/extra high risk to fish.

Based on these result, one of the BMPs for this example is to only apply pesticides when the potential for rainfall is low. On sites where greens drainage is discharged near streams or near drinking water wells, extreme care needs to be taken if a pesticide application is needed during a period with a high potential for rain. Appendix G can be used to select pesticides that have a low risk even under these conditions.

Appendix H: Preventing Drift

Drift can potentially cause not only water quality impacts, but also damage to susceptible off-target crops, and a lower than intended rate to the turfgrass, thus reducing the effectiveness of the pesticide. There are two types of drift, airborne (spray) drift and vapor drift.

Spray Drift

Spray Drift is influenced by many inter-related factors including droplet size, nozzle type and size, sprayer design, weather conditions and the operator.

Droplet Size

Lower spray volumes can result in smaller droplets that enhance leaf coverage although there is a limit to droplet size due to drift. Droplets under 150 microns generally pose the greatest hazard; droplets less than 50 microns have insufficient momentum for impaction as they remain suspended in the air indefinitely or until they evaporate. Research in England concluded that a 100 micron droplet takes 11 seconds approximately to fall ten feet in still air; when a similar size droplet is released into a 5mph wind drifts about 75 feet before hitting the ground. The higher the operating pressure, the smaller the droplet. Conversely, low pressure produces large droplets that may bounce off the target. Certain spray surfactants can change the droplet spectrum, reducing the number of driftable droplets.

Nozzle Type and Size

Correct nozzle selection is one of the most important, yet inexpensive, aspects of pesticide application. A nozzle's droplet size spectrum determines deposition and drift. Conventional flat fan nozzles fitted to a turfgrass sprayer produces droplets in the range of 10 – 450 microns. (Note: 25,000 microns = 1 inch.) Drift is a concern with droplets less than 100 microns. Increasing the Volume Median Diameter (VMD) reduces drift, but droplets that are too large bounce off the leaves to the ground.

Sprayer Design

Shields are better at targeting the spray into the grass, reducing drift and increasing deposition. They vary from the simple to the complex. Shielded sprayers allow managers to apply pesticides in variable weather conditions.

Weather Conditions

Wind speed and direction, relative humidity, temperature and atmospheric stability affects drift. Applying the correct product to the correct target at the correct time with the correct equipment is the key to good spraying.

Operator

Correct sprayer calibration ensures that all the nozzles are discharging the correct amount of liquid at the correct distance and angle to the target and at the correct forward speed.

Vapor Drift

The amount of vapor drift depends upon a pesticide's volatility and atmospheric conditions such as humidity, temperature. Turfgrass pesticides with known volatility should be avoided. In some cases, the pesticide label may indicate low volatility. However, low volatility does not mean that a chemical will not volatilize under conducive conditions, such as high temperatures or low relative humidity.

Best Practices for Spraying

Before spraying:

1. Train the operator to use the sprayer correctly.
2. Plan the spraying operation; consider the use of spray instruction cards as a good management tool.
3. Read and follow the pesticide label.
4. Select the correct nozzle for the target. Adjust the size and position of the nozzles to achieve correct distribution within the grass canopy,
5. Consider the use of sprayer nozzles which direct the spray to the target.
6. Consider spray additives to reduce drift.
7. Improve spraying logistics to ensure adequate time to spray within 'ideal' conditions.
8. Only spray when weather conditions are ideal; avoid spraying on days when conditions are favorable for atmospheric inversion or wind drift.
9. Calibrate the sprayer with water to ensure that everything is working correctly.

During spraying:

1. Stay alert: ensure the spray is not allowed to drift on to non-target areas and watch for changes in wind speed and direction.
2. Keep spray pressure as low as possible and ensure an accurate gauge is used.
3. Maintain a constant speed and pressure. If an automatic regulator is fitted, remember, small increases in speed result in large increases in pressure.
4. Avoid spraying near sensitive crops or watercourses; use a buffer zone.

Appendix I: Spill kits

Spill kits should contain:

- Gloves (nitrile, at least; foil barrier laminate better)
- Tyvek® coverall
- Goggles
- Temporary storage container for spill
- Sorbent pads and/or socks
- Loose absorbent (SlikWik®, vermiculite)
- Sweeping compound
- Warning sign or caution tape
- Chalk (for marking spill area on floor)
- Dust pan or small shovel (plastic preferable)
- Small broom
- Permanent marker (for marking spill container after clean-up)
- Recommended materials and suppliers are provided by Cornell's Occupation & Environmental Health Department at http://oeh.cals.cornell.edu/Spill_Kit_Contents.html

Forms of Sorbents

- Booms: cylindrical shape; vary in length and width; used to control and contain spills
- Socks or mini booms: cylindrical shape; vary in length and width; used in facility spill response or maintenance; contain spills or leaks (placed around equipment)
- Pillows: rectangular in shape; used for medium size spills; can be used for leaks and drips
- Pad and rolls: flat sorbent sheets of various lengths can be used to line shelves, catch leaks under machinery and clean up spills
- Loose sorbents: sorbent media that is not contained in any type of pillow or mesh; typically used on small spills

Sorbent Categories

- Universal sorbents: designed to absorb any liquid; they will absorb aggressive liquids such as acids and bases as well as non-aggressive liquids and solvents, such as cleaners, water-based fluids, gasoline and alcohol; made of polypropylene or expanded silicate materials.
- Petroleum sorbents ("oil-only sorbents"): designed for absorption of oil and/or petroleum-based liquids; these sorbents are hydrophobic (will not absorb water or water-based liquids); can be used in maintenance applications for hydraulic and engine oil cleanup; made of polypropylene or treated cellulose.
- Maintenance sorbents: absorb non-aggressive liquids commonly found in manufacturing and maintenance operations (coolants, lubricants, oils, cutting fluids);

will pick up water-based as well as oil-based fluids; made of recycled materials, such as cotton, wool, cellulose or corn cob; can also be made of polypropylene or any combination of the materials listed.

Sorbent capacity: the amount of weight the sorbent will absorb in relation to itself (e.g., absorbs 12 times its weight) or the liquid capacity of the sorbent (e.g., absorbs 8 gallons). Because all liquids don't weigh the same per gallon, the weight capacity of the sorbent actually varies from liquid to liquid. A more accurate way to assess the sorbent capacity is by its liquid capacity.