Part VII:

Appendices

Cockolds Creek, ACE Basin, South Carolina. Photo by Bill Lea

Appendix A

City of Baltimore Municipal Reservoirs, Incorporating Forest Management Principles and Practices

Robert J. Northrop[1]

Introduction

The city of Baltimore owns and operates the Loch Raven, Prettyboy, and Liberty Reservoirs, located north and northwest of the city, in the northern Piedmont region of Maryland (appendix fig. A.1). They supply water to over 1.5 million people. The reservoirs are surrounded by 17,580 acres of city-owned forest that was acquired between 1880 and 1955 to ensure control of land use in critical areas immediately adjacent to the reservoirs. Forest management on the reservoir land dates back to 1919. Following the clearing for Loch Raven and Prettyboy Reservoirs, a logging and sawmill crew was retained for forestry work, and the first professional forester was hired. This forest management program was undertaken to harvest and sell forest products while protecting the reservoir. Revenues were used for watershed enhancements, and lumber was used by the Department of Public Works in Baltimore.

In recent years, the reservoir land has also been valued as a core area for the conservation of regional biodiversity and for dispersed outdoor recreation. In 1989, concerns about timber harvesting, uncontrolled access, and a rapid increase in recreational use convinced the city to reevaluate its management practices. At the same time, the public agencies responsible for Maryland's Source Water Protection Assessment [Safe Drinking Water Act Amendments of 1996 (Public Law 104–182)] were expressing concern over the eutrophic nature of the three reservoirs and their loss of storage capacity due to sedimentation.

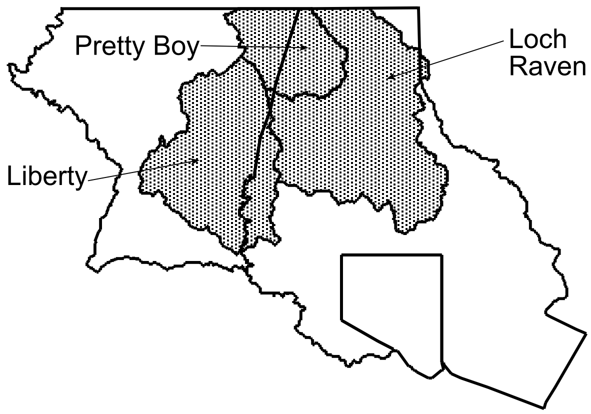
The watersheds, which are the primary sources of water for the reservoirs, are in Baltimore, Harford, and Carroll Counties in Maryland, as well as York County, PA. City-owned land makes up only an average of 7 percent of the total area of the watersheds draining into each reservoir. These source water drainages are part of the urbanizing and expanding Baltimore-Washington metropolitan area, which is the fourth largest in the United States. The Prettyboy and Liberty basins, however, are still rural in character with agricultural use predominant. Preserving the quality of the water that flows into the reservoirs requires careful control of sediment, as well as point- and nonpoint-source pollutants.

Our watershed management strategy is seen as vitally important to the continued efficient and economical provision of safe drinking water for the region's residents by all Federal, State, and local agencies. Since forest management can influence water quantity, as well as quality, by filtering and sequestering various forms of soluble and solid pollutants coming from adjacent land uses, it is recognized as a key component of the management of these watersheds. Private forest landowners are enhancing water quality by applying several forest conservation principles on their land. They are restoring forest wetlands and riparian forests and are using silvicultural practices to maintain forest vigor.

Studies

The Maryland Department of Natural Resources (MD-DNR), Forest Service, has entered into an agreement with the city of Baltimore to develop a comprehensive Forest Resource Conservation Plan for the 17,580 acres of land surrounding the Loch Raven, Prettyboy, and Liberty Reservoirs. Through a cooperative agreement with the U.S. Department of Agriculture, Forest Service, and the use of its NED–1[2] Decision Support Software, a detailed forest stand level analysis incorporating forest patch methodology will be conducted. Additional data will be collected on wildlife habitat composition and structure, and on the quality of water in first- and second-order streams. A separate recreational use survey will be conducted through contract with a regional university.

[1] Regional Watershed Forester, Maryland Department of Natural Resources–Forest Service, North East, MD.
[2] A prescription design system that incorporates management goals for multiple objectives, analyzes current forest conditions, produces ecommendations for management alternatives, and predicts future conditions under different alternatives. This system assists in evaluating silvicultural decisions at a project level using landscape-scale factors.



Appendix figure A.1—Watersheds supplying Baltimore, MD, with water.

Goals for conservation were set through a series of 20 public meetings conducted by the city of Baltimore's Department of Public Works during 1991. These goals included:

1. The protection and enhancement of water quality.
2. The maintenance and restoration of regional biological diversity within the public lands surrounding the reservoirs.
3. The management of woodlands to maximize forest habitat value.
4. Providing recreational opportunities compatible with the above objectives.

Concurrently, the MD-DNR Forest Service has also begun work with the Baltimore Metropolitan Council of Governments and the Gunpowder Watershed Project. They have a U.S. Environmental Protection Agency (EPA) small watershed grant project, where Federal, State, and local staff work to develop cooperative and collaborative strategies to address various environmental issues, including source water protection, in a holistic fashion at the watershed level. Background data and information on the Loch Raven and Prettyboy Reservoir drainage basins are being supplied through the Maryland Department of the Environment's Source Water Assessment Program (Safe Drinking Water Act, sec. 1453). Background data and information on the Liberty Reservoir drainage basin are being supplied through the Department of Natural Resources' Unified Watershed Assessment, as part of the State's Clean Water Action Plan.

Both studies used land-use loading coefficients to estimate the pounds of nutrients and sediment typically produced for a classified land use. Composite storm event samples and baseflow were collected at various sites in the Prettyboy and Loch Raven drainage basins but not the Liberty basin. Preliminary reports from the modeling exercises indicate that there is a statistically significant increasing trend in nitrate concentrations reaching the Loch Raven Reservoir, with highest concentrations in baseflow, indicating historical ground water contamination. These reports are also indicating that nutrient contamination is widespread throughout the Prettyboy and Liberty drainage basins as well, with current levels in the same range as at the Loch Raven basin.

Source water protection strategies being developed by these groups and associated State agencies highlight the need to conserve the existing forest in a healthy and vigorous condition. Forest wetlands and riparian forests need to be restored for their functional ability to filter sediment and other suspended solids, sequester pollutants in woody tissue, and promote denitrification. Forest wetland and riparian forest restoration activities within the three drainage basins will be targeted to specific sites that provide the best opportunity to intercept ground water and overland flows before they reach the receiving streams. Using a Geographic Information System (ArcView) and data layers from various Federal, State, and local agencies, the MD-DNR has developed a method that locates and ranks potential restoration sites. Potential forest wetland restoration sites are located by identifying hydric soils that lack natural vegetative cover. This system also locates potential riparian forest restoration sites by identifying stream segments that lack forest cover and assessing their potential to improve water quality. A weighed ranking is assigned based upon the nutrient loading potential of adjacent land uses, the size of the ownership parcel, and stream order (lower order streams receive higher ranking).

Interest in the management of the city-owned and surrounding forest is keen. Public support is critical to the plan's successful implementation. The Friends of the Watershed, an existing city-sponsored citizen's advisory group, will be invited to review data sets that are being collected, as well as the proposed analysis. They will also be asked to assist in the identification of public meeting sites and the context for stakeholder involvement.

Anticipated Results

Through the analysis of forest resources at multiple scales (unit to ecoregion) and timeframes, city-owned tracts will be evaluated to determine their potential to:

1. Serve as buffers to adjacent land uses.

2. Support an increasing desire on behalf of the growing urban population for outdoor recreation.

3. Assist in the conservation of biological diversity at the regional scale.

The comprehensive forest conservation plan will provide explicit management recommendations, allowing the city to plan and organize its conservation activities in the most efficient and effective manner. The deliberate and comprehensive involvement of interested citizens and community associations will lead to the public consensus the city needs to once again feel comfortable in actively managing its properties for the multiple values consistent with its stated goals.

Finally, the plan will offer forest management guidance to Federal, State, and local agencies concerned with the continued decline in the region's forest land base. This decline has been compounded by the cumulative impacts of pollution, fragmentation, and habitat loss. The plan will support and clarify the functions of forest resources as integral to the long-term sustainability of local watersheds and lead to the incorporation of forest management techniques into watershed strategies concerned with water quality.

Appendix B

Managing the Shift from Water Yield to Water Quality on Boston's Water Supply Watersheds

Thom Kyker-Snowman[1]

Boston's drinking water derives from surface reservoirs within three major watersheds: the Quabbin, Ware River, and Wachusett (appendix fig. B.1). These watersheds total in excess of 225,000 acres [90 000 hectares (ha)]; about 40 percent is under the care and control of the Metropolitan District Commission's Division of Watershed Management (MDC-DWM). This system supplies approximately 250 million gallons [900 million liters (L)] daily to accommodate the drinking water demands of 2.5 million people, about 40 percent of the population of the Commonwealth. The water is currently treated (chlorine and chloramines for disinfection, fluoride to promote healthy teeth, and soda ash and carbon dioxide to prevent corrosion of pipes), but not filtered. The objective to avoid the costs and the many other ramifications of filtration is at the center of current management decision-making for these watersheds. This objective represents a dramatic shift from the focus on water quantity, which has dominated the history of Boston's water supply.

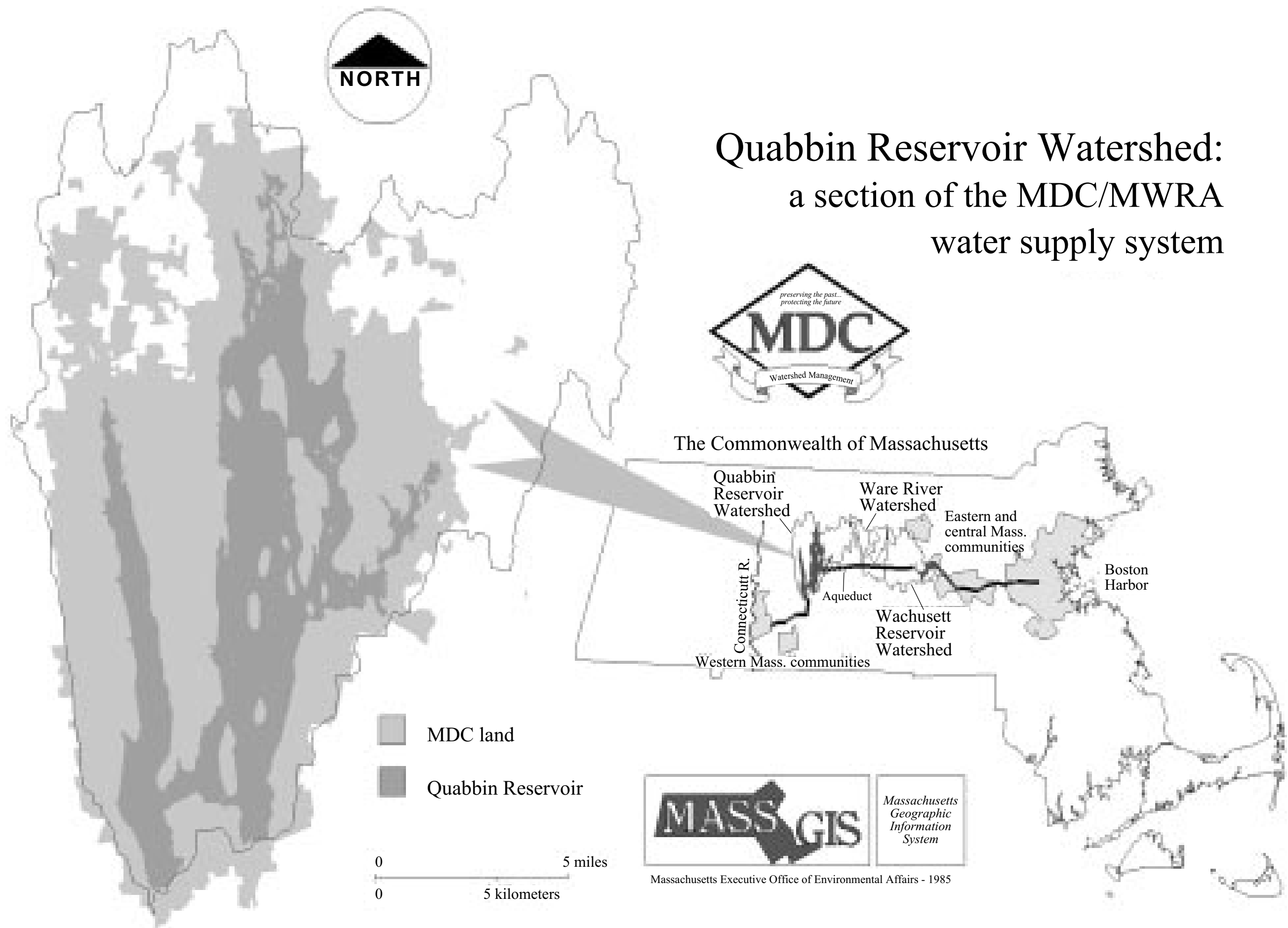
Since the settlement of Boston, its citizens continued to look west to meet the increasing demand for water. In 1795, the Aqueduct Corporation was created to tap Jamaica Pond in Roxbury to supply the 20,000 Boston inhabitants. In 1848, Lake Cochituate was added, and in short order from 1870–80, the Sudbury River and Framingham Reservoirs came on line. By 1895, Boston's population exceeded 500,000 and the metropolitan area exceeded a million. The Wachusett Reservoir, the largest reservoir in the World at the time, was built by 1908 and added a 65 billion gallon (234 billion L) capacity to the system. This was still not enough to keep up with the growing demand. Then Boston tapped the Ware River with an aqueduct to the Wachusett Reservoir, and finally constructed the 412-billion-gallon (1500-billion-L) Quabbin Reservoir within the Swift River Valley.

Despite these efforts, water quantity persisted as a concern. In 1967, just 20 years after the Quabbin Reservoir filled to capacity, a severe drought lowered the reservoir to 45 percent of its capacity and skeptics worried it would ever fill again. Although Quabbin Reservoir filled to capacity again by 1976, water demands were exceeding the safe yield from the system (300 million gallons per day or 1.1 billion L per day) by almost 50 million gallons (180 million L) per day. After lengthy debates about augmenting supplies by diverting the Connecticut or Millers River to the reservoirs, the MDC-DWM was mandated to address the situation by increasing water yield from its lands. The primary approach was to clearcut 2,000 acres (800 ha) of red pine (*Pinus resinosa* Ait.) plantations and to convert them to grass fields, which was estimated to provide an additional 300 million gallons (1.1 billion L) of water annually. After a 1989 drought dropped Quabbin Reservoir to a 17-year low, authorities declared a water emergency. Water conservation efforts (spurred in part by raising water rates), and an aggressive leak detection and repair program have dramatically lowered water consumption. Today, the daily draw on the system is 50 million gallons (180 million L) below its safe yield.

In addition to converting pine plantations to grass, MDC-DWM postponed management of an inflated deer population, because it was thought that deer browsing the understory could increase in water yield. The deer population in the Quabbin watershed had grown to nearly 48 to 80 deer per square mile (19 to 31 deer per square kilometer) (6 to 8 times the statewide average), under the hunting restrictions on MDC-DWM lands. Early forest management plans had acknowledged the impact of this population on the understory. The emphasis on water yield made it easier to choose to avoid the difficult politics associated with starting a deer management program, especially following 50 years of hunting prohibition.

Changes in drinking water laws and regulations have dramatically altered the approach to managing natural resources on the watersheds whose waters are unfiltered surface supplies. The Federal Safe Drinking Water Act (SDWA) became law in 1974, and set national standards for maximum contaminant levels and treatment techniques.

[1] Natural Resources Specialist, Massachusetts Metropolitan District Commission, Division of Watershed Management, Belchertown, MA.



Appendix figure B.1—Location of Quabbin Reservoir and water supply system for Boston, MA.

Amendments to the SDWA in 1986 established a priority for using filtration as a dominant treatment technique. The EPA addressed this priority through the Surface Water Treatment Rule of 1989 (SWTR), which essentially required that all surface water supplies be filtered unless a supply could pass a rigorous test allowing it to qualify for a waiver from filtration. The SWTR established disinfection and monitoring requirements and set new limits for pathogens and turbidity, which indicate the success or failure of either artificial or natural filtration.

It has been estimated that the construction costs alone for a filtration plant for Boston's water supply would exceed $200 million. This alone is a strong incentive to maintain a waiver, but perhaps more important is the threat of losing the mandate for watershed protection, should filtration become a reality. The MDC-DWM currently owns and controls 64 percent of the Quabbin watershed (appendix fig. B.1), and this control is a critical argument in favor of relying on natural filtration. If artificial filtration were installed, it is worth wondering if the budget required to manage MDC-DWM lands and to pay tax substitutes to the local towns would persist. Similarly, recreation is carefully limited on these watershed lands, and it would be increasingly difficult to resist these pressures in the absence of a requirement for natural filtration of Boston's drinking water.

The combination of reduced pressure to increase yields and of the increasing desire to avoid filtration have shifted the management focus in the Quabbin watershed away from water production and sharply toward water-quality protection. From the natural resources perspective, this meant demonstrating that wildlife and forest are being managed to avoid degrading and, if possible, improving the natural filtration process. Two major wildlife issues were met squarely along these lines: water birds (in particular, gulls and geese) and white-tailed deer. Seagulls threaten the maintenance of water-quality standards when they spend their days feeding in landfills and returning to roost by the thousands on open surface water supplies, transporting pathogens that can threaten human health. The MDC-DWM has devised an elaborate gull-harassment program that deals with the problem by moving roosting birds far from the water supply intakes.

The browsing by the high populations of white-tailed deer consumes the forest understory and threatens the regeneration of forest cover if it is lost to natural or human disturbance. The threat of major overstory losses associated with catastrophic hurricanes can recur in New England every 100 to 150 years; the most recent was in 1938. A model to predict hurricane damage was developed by Harvard University on their forest in Petersham, MA, immediately adjacent to the Quabbin Reservation. This model predicted in 1992 that 50 to 75 percent of the conifers and 25 to 75 percent of the hardwoods in the Quabbin watershed would be damaged by such a storm. During the writing of the most recent Quabbin land management plan, it was decided that an even-aged, relatively mature forest with greatly impaired regenerative capacity was incompatible with the desire to maintain predictable long-term natural filtration of the drinking water supply.

The first step in reversing this untenable condition was to reduce the impact of deer, primarily through controlled hunting. The MDC-DWM engaged in a lengthy, multiyear public campaign for support of this idea, which overcame opposition including a Federal lawsuit filed by an animal-rights organization. This suit claimed that there was a probability that an unrecovered deer, wounded by a lead slug, would die and be fed upon by a bald eagle, which might in turn ingest lead from the wound and die as a result. At that time, this would have constituted an illegal taking of a Federally protected, endangered species. The plan to reinstitute hunting, in order to protect the drinking water supply, persisted through this debate, and the first hunt in 50 years was conducted in 1991. Hunting has continued since then, and regeneration of both trees and other understory plants has been dramatic as a result. Wildflowers like trillium (*Trillum* spp.) and marsh-marigold (*Caltha* spp.) that were not found before hunting have reappeared after a long absence.

In addition, plans called for diversifying both the age and the species structure of the watershed forest cover. This objective calls for maintaining an understory as the reserve forest; a midstory for its rapid nutrient uptake; and an overstory for its regulation of organic decomposition, its provision of seed, and the water infiltration and retention function of its deep root system. These canopy layers are to be balanced, in an uneven-aged silvicultural approach, throughout the managed forest surrounding MDC-DWM reservoirs. This deliberate restructuring is accomplished through commercial harvesting using primarily group selection and irregular shelterwood approaches. The drinking water supply context mandates state-of-the-art best management practices, including a requirement that all equipment be supplied with a spill kit for potential oil leaks and strict restrictions on ground pressures allowed on sensitive land.

The working hypothesis of this approach is that frequent, endogenous disturbance of the scale of group-selection silviculture will lessen the amplitude of the disturbance wave represented by infrequent, exogenous disturbances, such as catastrophic hurricanes. The MDC-DWM made the commitment that any short-term negative effects of timber harvesting would not exceed the long-term benefits to drinking water derived from this deliberate forest structuring. While the large volume of Quabbin Reservoir dilutes differences in tributary water quality, the no-net-negative policy will require intensive monitoring at the tributary level, especially during storm events and spring runoff. This monitoring effort has recently begun at Quabbin and will hopefully quantify the effects of incorporating large, infrequent disturbances into management planning for unfiltered surface supplies of drinking water.

Appendix C

Cumulative Impacts of Land Use on Water Quality in a Southern Appalachian Watershed[1]

Wayne T. Swank and Paul V. Bolstad[2]

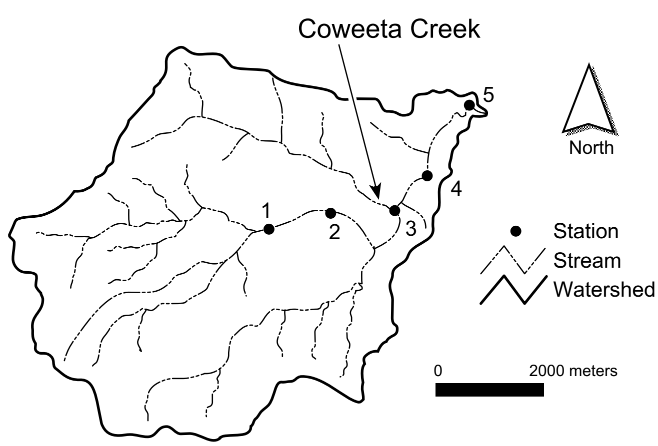
Introduction

Water-quality variables were sampled over 109 weeks along Coweeta Creek, a fifth-order stream located in the Appalachian Mountains of western North Carolina. The purpose of the study was to observe any changes in water quality over a range of flow conditions with concomitant downstream changes in the mix of land uses. Variables sampled include pH, bicarbonate (HCO_3^{-1}), conductivity, nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4^+-N), phosphate phosphorus (PO_4^{3-}–P), chloride (Cl^{-1}), sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), sulfate (SO_4^{-2}), silica (SiO_2), turbidity, temperature, dissolved oxygen, total and fecal coliform, and fecal streptococcus. Landcover and land use or both were interpreted from 1:20,000 aerial photographs and entered in a Geographic Information System, along with information on total and paved road length, building location and density, catchment boundaries, hydrography, and slope. Linear regressions were performed to related basin and near stream landscape variables to water quality.

Five water-quality monitoring stations were located over 5.4 miles (8.7 kilometers) of Coweeta Creek (appendix fig. C.1). Along Coweeta Creek, stream size and permanent landscape alteration increases, e.g., conversion of forest to agriculture and increases in road density, from lower to higher station numbers (appendix table C.1). Sites were selected to encompass incremental additions and a variety of land uses. Most of the area above station 1 was covered with mature, deciduous forest, and paved road density was low, while unpaved road density was relatively high. Downstream stations were selected to encompass additional land-use features such as residences along the stream, grazing and other agricultural practices, plus additional roads. Stations 2 through 4 were characterized by a 6- to 20-foot (2- to 6-meter) wide riparian shrub strip [chiefly alder, (*Alnus* spp.), bramble (*Rubus* spp.), and willow *Salix* spp.)] with a mix of pastures, homesites, and farmland beyond the riparian strip. Station 5 was in a low-density suburban mix, with mown grass to the stream edge.

Streamwater samples were collected during baseflow and stormflow periods. During baseflow, grab samples were collected in 1-liter bottles from the free-flowing section of the stream. Sampling was initiated the first week of June 1991 and was conducted twice weekly through August. Thereafter, baseflow sampling was conducted approximately weekly through the first week of November 1993.

During selected storm events, two different sampling methods were used. Grab samples were taken on the rising limb of the hydrograph, near peak flow, and on the hydrograph recession. Some storm events were also sampled using a time-proportional automated sampler, which was activated near storm onset.



Appendix figure C.1—Watershed boundary and stream sampling locations in the Coweeta Creek Watershed in western North Carolina. Stations 1 through 5 are arranged down the stream gradient on Coweeta Creek. First-order streams are not shown.

[1] This example is excerpted from a paper by Bolstad and Swank (1997).
[2] Retired Project Leader, USDA Forest Service, Southern Research Station, Otto, NC; and Professor of Forestry, University of Minnesota, Minneapolis, MN, respectively.

Appendix table C.1—Summary data for the catchments above five sampling stations along Coweeta Creek in western North Carolina

Characteristics upstream of sample station	Units	Sampling station number: Upstream 1	2	3	4	Downstream 5
Total area	Ha	1605	1798	3099	4163	4456
Forest area	Ha	1600	1782	2986	3904	4113
Agricultural area	Ha	4	13	89	155	192
Urban/suburban area	Ha	1	3	24	104	151
Total road length	Km	39.8	45.2	80.8	106.8	122.6
Unpaved road length	Km	38.6	43.9	73.4	96.4	106.5
Total road density	Km/km^2	2.49	2.51	2.61	2.60	2.75
Unpaved road density	Km/km^2	2.41	2.44	2.37	2.33	2.39
Structures/area	No./100 ha	.37	3.06	5.36	6.01	9.23

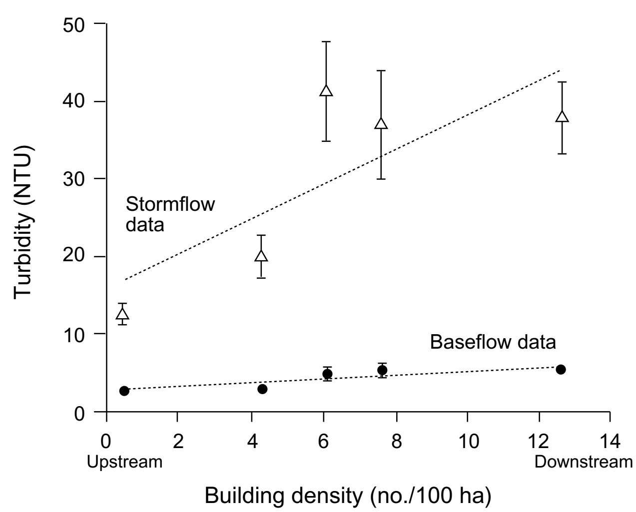
Baseflow Water Quality

Water quality was good during baseflow conditions over the 3-year study period. Concentrations of most solutes averaged < 1 milligram per liter, typical of stream chemistry for lightly disturbed forest watersheds in the Southern Appalachians. NO_3-N, NH_4^+-N, and PO_4^{3-}—P were very low, indicating the absence of point sources of inorganic solutes into the stream. Turbidity during baseflow was generally low, typical for the Southern Appalachians (appendix fig. C.2), averaging < 6 nephalometric turbidity units for all stations. Mean counts of total fecal coliform and fecal streptococci at station 1 were typical of mean values reported for other streams draining relatively undisturbed forested watersheds in western North Carolina. Several variables showed distinct downstream increases. Cation concentrations, SiO_2, HCO_3^{-1}, SO_4^{-2}, Cl^{-1}, conductivity, turbidity, and temperature generally increased downstream from station 1 to 5.

Mean baseflow levels for total coliform, fecal coliform, and streptococci counts increased from threefold to eightfold downstream (appendix table C.2). Thus, there is a cumulative increase in bacteria populations, indicating additive sources downstream. The transport of these bacteria is probably primarily through the soil or direct input by warm-blooded vertebrates, e.g., raccoons, livestock, since base-flow samples represent periods when there is little or no overland flow input from adjacent lands.

Stormflow Water Quality

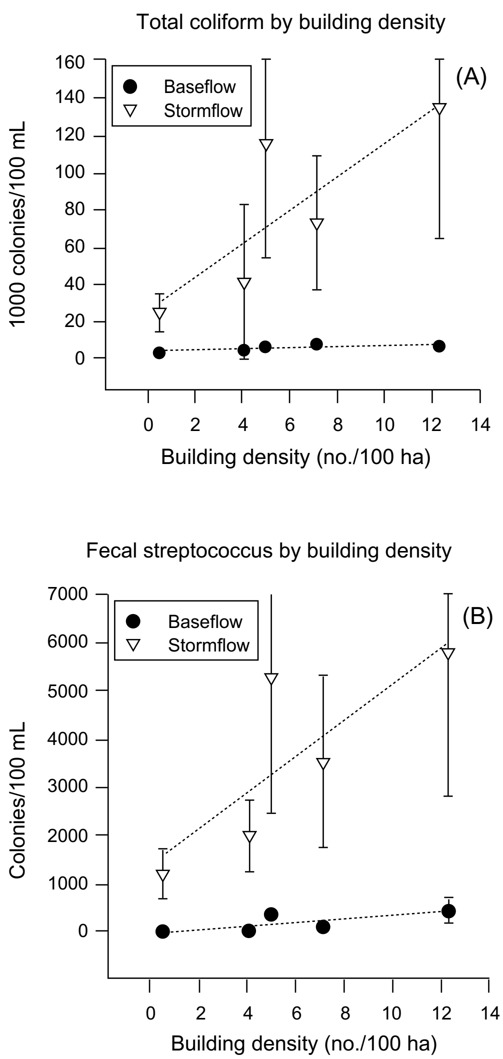
Conductivity, NO_3-N, HCO_3^-, Cl-, K^+, Na^+, Ca^{2+}, Mg^{2+}, SiO_2, turbidity, temperature, and total coliform often showed cumulative increases downstream. Two patterns were obvious in comparing stormflow and baseflow data. First, mean values for most variables at most stations were higher during stormflow. These increases range from slight and nonsignificant to quite large (turbidity, appendix fig. C.2).



Appendix figure C.2—Mean and standard error (bars) for turbidity, plotted against building density for each sampling condition (baseflow and stormflow).

Appendix table C.2—Summary water-quality data from baseflow grab samples (means) at each of the five sampling stations along Coweeta Creek in western North Carolina

	Station number				
Variable	1	2	3	4	5
	Per 100 milliliters				
Total coliform	9,470	13,660	40,040	30,740	52,140
Fecal coliform	200	340	460	1,130	840
Fecal streptococcus	710	1,310	2,180	1,590	1,840



Appendix figure C.3—Mean and standard error (bars) for (A) total coliform and (B) fecal streptococcus, plotted against building density for each sampling condition (baseflow and stormflow). (Building density increases downstream).

Appendix table C.3—Summary water-quality data from stormflow samples (means) at each of the five sampling stations along Coweeta Creek in western North Carolina

	Station number				
Variable	1	2	3	4	5
	Per 100 milliliters				
Total coliform	18,790	34,640	NA	77,160	98,390
Fecal coliform	880	130	NA	970	1,260
Fecal streptococcus	450	8,710	NA	3,260	4,190

NA = Not available.

Bacteria levels were among the most responsive water-quality variables during storm events, although patterns were highly variable among storms and among seasons. Total coliform, fecal coliform, and fecal streptococci typically increased twofold to threefold during storm events compared to baseflow populations. The source of these large downstream increases in bacteria may be attributed to observed overland flow from adjacent lands directly into streams, disturbance of bottom sediments, and streambank flushing (appendix table C.3, appendix fig. C.3).

Conclusions

In summary, this work identifies consistent, cumulative downstream changes in Coweeta Creek concomitant with downstream changes in land use. Furthermore, this work indicates consistently higher downstream changes during stormflow when compared to baseflow conditions, suggesting cumulative impacts due to landscape alteration, as tested here, are much greater during stormflow events.

Literature Cited

Bolstad, P.V.; Swank, W.T. 1997. Cumulative impacts of landuse on water quality in a Southern Appalachian watershed. Journal of the American Water Resources Association: 519–533. Vol. 33, no. 3.

Appendix D

Protozoan Pathogens *Giardia* and *Cryptosporidium*

David Stern[1]

Introduction

Two pathogens carried by wildlife, *Giardia* spp. and *Cryptosporidium* spp., are of great interest in drinking water. *Giardia* cysts and *Cryptosporidium* oocysts are parasitic protozoans. They are active and reproduce within their hosts and encyst to survive in the environment during transmission between hosts. Many species of wildlife have been found to be hosts for these parasites (appendix table D.1). These organisms are significant sources of gastrointestinal illness (Jokipii and others 1983, Kenney 1994, Moore and others 1994). The risk posed by these parasites is believed to be significant. As little as one cyst may be able to cause infection (Medema and others 1995, Rose and Gerba 1991, Rose and others 1991). What is more, these organisms are resistant to disinfection (Campbell and others 1982, Clark and Regli 1993, Craun 1981, Haas and Heller 1990, Hoff and Rubin 1987, Jarroll and others 1981, Kong and others 1988, Quinn and Betts 1993, Rice 1981, Rubin and others 1989). Although there are medications that are effective in treating giardiasis, currently there are no drugs available to treat infections caused by *Cryptosporidium.*

Federal Regulation

In 1986, the U.S. Congress recognized the threat posed by these protozoan parasites and revised the Safe Drinking Water Act to begin to address this concern. The Surface Water Treatment Rule for the Safe Drinking Water Act (SDWA), promulgated in 1991 (U.S. Environmental Protection Agency 1996), requires all surface water supplies to be filtered prior to distribution to the public, unless it can be demonstrated that a certain level of purity exists and can be maintained. The Surface Water Treatment Rule emphasizes water supply filtration because disinfecting by chlorination does not eliminate the threat posed by *Giardia* and *Cryptosporidium* (Campbell and others 1982, Clark and others 1989). Accordingly, prevention or filtration is recommended as the response to this threat. In its continuance of concern for the threat posed by *Giardia* and *Cryptosporidium*, the Federal Government enacted 1996 amendments to the SDWA to fund additional watershed research on these organisms.

Giardia

To survive in the environment, *Giardia* encysts itself into a resistant form. *Giardia* cysts are 5 to 15 microns in size and oblong in shape. Early research on this parasitic protozoan identified it on the basis of median body morphology and the host it was found in. Accordingly, *Giardia* species are *G. muris, G. agilis,* and *G. duodenalis* and are usually found in rodents, frogs, and warm-blooded vertebrates, respectively. This early nomenclature was due to the assumption that *Giardia* was highly host-specific. More recent research has shown that *Giardia* can cross-infect different species of hosts (Meyer and Jarroll 1980).

Identification of *Giardia* as a waterborne parasite for humans was first reported in the 1940's during a study of a disease outbreak in an apartment building in Tokyo, Japan (Davis 1948). *Giardia* has more recently been reported as the most frequently identified parasite responsible for disease outbreaks in surface water supplies in North America (Craun 1984). A significant portion of the literature has reported on the occurrence, disinfection, and treatment of *Giardia* cysts.

The life cycle for *Giardia* has been described by Meyer and Jarroll (1980). *Giardia* is monoxenous, which means that all of its life stages occur in one host. These stages include an inactive cyst form that is capable of resisting environmental stresses and a free-living form known as a trophozoite. The trophozoite has a ventral sucker disk that attaches to the intestinal wall to obtain subsidence. The life cycle consists of: (1) a host ingesting the cyst, (2) excystation (emergence of the trophozoite out of the cyst) occurring in the small intestine after the cyst has been subjected to the digestive environment, (3) the released trophozoite attaching to the intestinal wall where it feeds and reproduces by binary fission, and (4) some of the reproduced trophozoites encyst within the intestine and the resultant cyst is excreted in the infected animal's feces to be transmitted to other hosts.

Cryptosporidium

Cryptosporidium was first identified by Tyzzer (1910) over 90 years ago as a parasite of the common mouse. Its

[1] Pathogen Program Supervisor, New York City, Department of Environmental Protection, Valhalla, NY.

Appendix table D.1—Species reported as hosts to protozoans *Giardia* and *Cryptosporidium*

Species	Common name	Parasites hosted
Pisces		
Cyprinus carpio	Carp	*Cryptosporidium*
Sciaenops ocellatus	Red drum	*Cryptosporidium*
Plecostomus spp.	Catfish	*Cryptosporidium*
Salmo trutta	Brown trout	*Cryptosporidium*
Oncorhynchus mykiss	Rainbow trout	*Cryptosporidium*
Amphibia		
Ceratophrys ornata	Bell's horned frog	*Cryptosporidium*
Bufo americanus	American toad	*Cryptosporidium*
B. regularis	Common toad	*Giardia*
Rana pipiens	Leopard frog	*Giardia*
R. clamitans	Green frog	*Giardia*
Reptilia		
Chelonia mydas	Green turtle	*Cryptosporidium*
Geochelone elegans	Star tortoise	*Cryptosporidium*
G. carbonaria	Red-footed tortoise	*Cryptosporidium*
Squamata Lacertilia (lizards)		
Agama aculeata	Kalahari spiny agama	*Cryptosporidium*
A. planiceps	Damara rock agama	*Cryptosporidium*
Chameleo c. senegalensis	Chamelon	*Cryptosporidium*
Chamaeleo pardalis	Panther chamelon	*Cryptosporidium*
Chlamydosaurus kingi	Frilled lizard	*Cryptosporidium*
Lacerta lepida	Ocellated lacerta	*Cryptosporidium*
Chondrodactylus angulifer	Sand gecko	*Cryptosporidium*
Serpentes (snakes)		
Crotalus durissus culminatus	Rattlesnake	*Cryptosporidium*
Sistrurus miliarius	Pygmy rattlesnake	*Cryptosporidium*
Lampropeltis getulus holbrooki	Say's kingsnake	*Giardia*
Elaphe subocularis	Trans-Pecos rat snake	*Cryptosporidium*
E. o. obsoleta	Black rat snake	*Cryptosporidium*
E. o. quadrivittata	Yellow rat snake	*Cryptosporidium*
E. o. lindheimeri	Texas rat snake	*Cryptosporidium*
E. guttata	Corn snake	*Cryptosporidium*
E. v. vulpina	Western fox snake	*Cryptosporidium*
Gonysoma oxycephala	Red-tailed green rat snake	*Cryptosporidium*
Pituophis melanoleucus	Black pine snake	*Cryptosporidium*
P. melanoleucus catenifer	Gopher snake	*Cryptosporidium*
Drymarchon corais couperi	Eastern indigo snake	*Cryptosporidium*
Lampropeltis zonata pulchura	San Diego mountain snake	*Cryptosporidium*
L. triangulum	Various subspecies	*Cryptosporidium*
Nerodia h. harteri	Brazos water snake	*Cryptosporidium*
N. r. rhombifera	Diamondback water snake	*Cryptosporidium*
Boiga dendrophila	Mangrove snake	*Cryptosporidium*
C. horridus	Timber rattlesnake	*Cryptosporidium*
C. atrioca udatus	Canebrake rattlesnake	*Cryptosporidium*
C. l. lepidus	Rock rattlesnake	*Cryptosporidium*

continued

Appendix table D.1—Species reported as hosts to protozoans *Giardia* and *Cryptosporidium* (continued)

Species	Common name	Parasites hosted
Aves		
Anseriformes		
Branta canadensis	Canada goose	*Cryptosporidium, Giardia*
Anser anser	Domestic goose	*Cryptosporidium*
Cygnus spp.	Tundra swan	*Cryptosporidium*
C. olor	Mute swan	*Cryptosporidium*
Aix sponsa	Wood duck	*Cryptosporidium*
Anas platyrrhynchos	Mallard duck	*Cryptosporidium*
Mergus merganser	Common merganser	*Cryptosporidium*
Columbiformes		
Columba livia	Pigeon	*Cryptosporidium*
Galliformes		
Gallus gallus	Chicken	*Cryptosporidium*
Meleagris gallopavo	Turkey	*Cryptosporidium*
Coturnix coturnix	Common quail	*Cryptosporidium*
Colinus virginianus	Bobwhite quail	*Cryptosporidium*
Phasianus colchicus	Ring-necked pheasant	*Cryptosporidium*
Pavo cristatus	Peafowl	*Cryptosporidium*
Perdix perdix	Grey partridge	*Cryptosporidium*
Alectoris graeca	Chuckar partridge	*Cryptosporidium*
Numida meleagris	Guinea fowl	*Cryptosporidium*
Charadriiformes		
Larus ridibundus	Black-headed gull	*Cryptosporidium*
L. argentatus	Herring gull	*Cryptosporidium*
L. delawarensis	Ring-billed gull	*Cryptosporidium*
Recurvirostra avosetta	Avocet	*Giardia*
Threskiornis spinicollis	Straw-necked ibis	*Giardia*
Passeriformes		
Poephila cincta	Black-throated finch	*Cryptosporidium*
Lonchura cucullata	Bronze mannikin finch, red cheek finch	*Cryptosporidium*
Passer domesticus	House sparrow	*Giardia*
Zonotrichia georgiana	Swamp sparrow	*Giardia*
Sturnella neglecta	Western meadowlark	*Giardia*
Lanius collurio	Red-backed shrike	*Giardia*
Ciconiiformes		
Ardea herodias	Great blue heron	*Giardia*
A. cinerea	Gray heron	*Giardia*
A. cocoi	Cocoi heron	*Giardia*
Egretta alba	Great egret	*Giardia*
E. caerulea	Little blue heron	*Giardia*
Nycticorax nyctocorax	Black-crowned night-heron	*Giardia*
N. naevius	Night-heron	*Giardia*
Butorides virescens	Green-backed heron	*Giardia*
Egretta intermedia	Intermediate egret	*Giardia*
Bubulcus ibis	Cattle egret	*Giardia*
Botaurus lentiginosus	American bittern	*Giardia*
Ixobrychus minutus	Little bittern	*Giardia*
Plegadis falcinellus	Glossy ibis	*Giardia*

continued

Appendix table D.1—Species reported as hosts to protozoans *Giardia* and *Cryptosporidium* (continued)

Species	Common name	Parasites hosted
Aves (continued)		
Falconiformes		
Cathartes aura	Turkey vulture	*Giardia*
Elanus caeruleus	Black-winged kite	*Giardia*
Mammalia		
Marsupialia		
Didelphis virginiana	Virginia opossum	*Cryptosporidium, Giardia*
Pseudocheirus peregrinus	Possum	*Giardia*
Insectivora		
Sorex spp.	Shrew	*Giardia*
Blarina brevicauda	Short-tailed shrew	*Cryptosporidium*, *Giardia*
S. cinereus	Masked shrew	*Cryptosporidium*
Parascalops breweri	Hairy-tailed mole	*Cryptosporidium*
Myotis lucifugus	Little brown bat	*Cryptosporidium*
Eptesicus fuscus	Big brown bat	*Cryptosporidium*, *Giardia*
Lagomorpha		
Sylvilagus floridanus	Eastern cottontail	*Cryptosporidium*, *Giardia*
Rodentia		
Ondatra zibethica	Common muskrat	*Cryptosporidium*, *Giardia*
Microtus agrestis	Field vole	*Cryptosporidium*
M. chrotorrhinus	Rock vole	*Giardia*
M. pennsylvanicus	Meadow vole	*Cryptosporidium*, *Giardia*
M. pinetorum	Pine vole	*Giardia*
M. longicaudus	Long-tailed vole	*Giardia*
M. ochrogaster	Prairie vole	*Giardia*
M. californicus	Meadow vole	*Giardia*
M. richardsoni	Water vole	*Giardia*
Clethrionomys glareolus	Bank vole	*Cryptosporidium*
C. glareolus skomerensis	Skomer bank vole	*Cryptosporidium*
Apodemus sylvaticus	Wood mouse	*Cryptosporidium*
Rattus rattus	Roof rat or ship rat	*Cryptosporidium, Giardia*
Sigmodon hispidus	Cotton rat	*Cryptosporidium*
Erithizon dorsatum	Porcupine	*Cryptosporidium*, *Giardia*
Mus musculus	House mouse	*Cryptosporidium*, *Giardia*
Zapus hudsonicus	Meadow jumping mouse	*Giardia*
Napaeozapus insignis	Woodland jumping mouse	*Giardia*
Peromyscus leucopus	White-footed mouse	*Cryptosporidium*, *Giardia*
P. maniculatus	Deer mouse	*Cryptosporidium*, *Giardia*
C. gapperi	Red-backed vole	*Cryptosporidium*, *Giardia*
Pitymys savii	Savi's woodland vole	*Giardia*
R. norvegicus	Norway rat	*Cryptosporidium*, *Giardia*
Neotoma cinerea	Wood rat	*Giardia*
Dipodomys heermanni	Kangaroo rat	*Giardia*
Tamia striatus	Eastern chipmunk	*Cryptosporidium*, *Giardia*
Sciurus carolinensis	Eastern gray squirrel	*Cryptosporidium*, *Giardia*
Tamiasciurus hudsonicus	Red squirrel	*Cryptosporidium*, *Giardia*
Glaucomys volans	Southern flying squirrel	*Giardia*

continued

Appendix table D.1—Species reported as hosts to protozoans *Giardia* and *Cryptosporidium* (continued)

Species	Common name	Parasites hosted
Mammelia (continued)		
Rodentia (continued)		
Spermophilus beecheyi	Ground squirrel	*Giardia*
S. richardsoni	Richardson's ground squirrel	*Giardia*
S. tridecemlineatus	13-lined ground squirrel	*Giardia*
Marmota monax	Woodchuck	*Cryptosporidium*, *Giardia*
Coendu villosus	Tree porcupine	*Giardia*
Carnivora		
Ursus americanus	Black bear	*Cryptosporidium*
Mustela erminea	Short-tailed weasel	*Cryptosporidium*
M. putorius furo	Ferret	*Cryptosporidium*
Canis latrans	Coyote	*Cryptosporidium*, *Giardia*
Vulpes vulpes	Red fox	*Giardia*
Urocyon cineroargenteus	Gray fox	*Cryptosporidium*, *Giardia*
Procyon lotor	Raccoon	*Cryptosporidium*, *Giardia*
Paradoxurus h. hermaphroditus	Palm civet	*Giardia*
Mephitis mephitis	Striped skunk	*Cryptosporidium*, *Giardia*
Mustela vision	Mink	*Cryptosporidium*, *Giardia*
M. nigripes	Black-footed ferret	*Giardia*
Meles meles	Badger	*Giardia*
Lynx rufus	Bobcat	*Cryptosporidium*, *Giardia*
Sirenia		
Dugong dugong	Manatee	*Cryptosporidium*
Ruminants		
Cervus canadensis	Elk, wapiti	*Giardia*
Odocoileus virginiana	White-tailed deer	*Cryptosporidium*, *Giardia*
Antilocapra americana	Pronghorn	*Giardia*
Ovis canadensis x. O. musimon	Bighorn x mouflon sheep	*Giardia*
Llama glama	Llama	*Cryptosporidium, Giardia*
Odocoileus hemionus	Mule deer	*Cryptosporidium*

Source: Adapted from Wade and others, in press.

significance began to be recognized in the 1970's when a number of reports identified *Cryptosporidium* as the cause of diarrhea in calves (O'Donoghue 1995). Human infections began to be reported in the mid-1970's and by the 1990's, *Cryptosporidium* was recognized as a significant threat to individuals that are immunocompromised (Current and Garcia 1991, Ungar 1990).

Cryptosporidium oocysts are spherical and 4 to 6 microns in diameter (Barer and Wright 1990, Casemore 1991, Casemore and others 1985, Current 1987, Current and others 1986, Fayer and Ungar 1986, Issac-Renton and others 1987, O'Donoghue 1995, Smith and Rose 1990, Ungar 1994). Most oocysts contain up to four sporozoites (free-living form). A number of species have been identified among various hosts. Many of these species can cross-infect different species of hosts. Several *Cryptosporidium* species are found more often in association with certain host species, especially when the host species are vertebrates. Thus, *C. muris* is common in mammals, *C. meleagridis* in birds, *C. crotalia* in reptiles, and *C. nasorum* in fish (Levine 1984, O'Donoghue 1995).

O'Donoghue (1995) and Current and Bick (1989) described the life cycle for *Cryptosporidium*. Like *Giardia*, *Cryptosporidium* encysts to survive outside its host, and its life stages occur in the infected animal. Its life cycle is more complex due to the addition of a sexual stage of reproduction within the host. The oocyst of *Crypto-sporidium* undergoes excystation (release of sporozoites) after it has been ingested by a host and has been subjected to conditions usually found in a digestive system. These conditions have been identified as including temperature, low pH, and digestive enzymes (Fayer and Leek 1984, Reduker and Speer 1985). The released sporozoites attach to epithelial cells of the small intestine, where they are identified as trophozoites (*Cryptosporidium* attached to intestine). The trophozoites mature into meronts that produce merozoites through asexual reproduction. The merozoites, in turn, develop into either other meronts or produce the sexual form of *Cryptosporidium*, microgametes (male form) and macrogametes (female form). The mobile microgametes fertilize the macrogametes in sexual reproduction to form a zygote (the sexually reproduced form of *Cryptosporidium*). Most of the zygotes form thick-walled oocysts that are released from the host to infect other hosts and complete the life cycle.

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Appendix E

Water Treatment Technologies Tables

Gary Logsdon[1]

Most raw water is not suitable for human consumption without treatment. Some water only needs to be filtered and disinfected before consumption (Committee on Small Water Supply Systems, National Research Council 1997). Other water must be treated with additional processes to remove specific chemical contaminants or nuisance chemicals like iron and manganese. Appendix tables E.1 to E.4 present information on water treatment techniques that can be used for controlling common contaminants. The tables provide guidance on selecting the appropriate treatment processes. However, a water treatment specialist must select the best process on a site-specific basis. Additional information can be found in recent volumes of Water Quality and Treatment (Letterman 1999) and Safe Water from Every Tap (Committee on Small Water Supply Systems, National Research Council 1997).

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[1] Director, Black and Veatch, Water Process Research, Cincinnati, OH.

Appendix table E.1—Water treatment technologies by disinfectants, oxidants, and aeration[a]

General water quality-constituent	Free chlorine	Chloramine	Chlorine dioxide	Ozone	Potassium permanganate	Ultraviolet radiation	Aeration
General water qualities							
Turbidity, sediment							
Color	x		x	x	x		
Disinfection by-product precursors							
Taste and odor			x	x	x	x	x
Biological contaminants							
Algae							
Protozoa	x		x	x		x	
Bacteria	x	x	x	x		x	
Viruses	x	x	x	x		x	
Organic chemicals							
Volatile organics							x
Semi-volatile compounds							
Pesticides and herbicides							
Biodegradable organic matter							
Inorganic chemicals							
Hardness							
Iron[b]	x		x	x	x		x
Manganese[b]	x		x	x	x		
Arsenic							
Selenium							
Thallium							
Fluoride							
Radon							x
Radium							
Uranium							
Cations							
Anions							
Total dissolved solids							
Nitrate							
Ammonia							

[a] The columns and rows lacking x's are where process is not appropriate or recommended for the constituent.
[b] When oxidant is followed by filtration.
Source: Table adapted from Committee on Small Water Supply Systems, National Research Council 1997.

Appendix table E.2—Water treatment technologies by type of adsorption and ion exchange system[a]

General water quality-constituent	Powdered activated carbon	Granulated activated carbon	Ion exchange	Activated alumina
General water qualities				
Turbidity, sediment				
Color	x	x		
Disinfection by-product precursors	x	x		
Taste and odor	x	x		
Biological contaminants				
Algae		x		
Protozoa		x		
Bacteria		x		
Viruses		x		
Organic chemicals				
Volatile organics	x	x		
Semi-volatile compounds	x	x		
Pesticides and herbicides	x	x		
Biodegradable organic matter	x	x		
Inorganic chemicals				
Hardness			x	
Iron				
Manganese				
Arsenic				x
Selenium				x
Thallium				x
Fluoride			x	x
Radon				
Radium			x	
Uranium			x	
Cations			x	
Anions			x	
Total dissolved solids				
Nitrate			x	
Ammonia				

[a] The columns and rows lacking x's are where process is not appropriate or recommended for the constituent.
Source: Table adapted from Committee on Small Water Supply Systems, National Research Council 1997.

Appendix table E.3—Water treatment technologies by type of membrane treatment system[a]

General water quality-constituent	Microfiltration	Ultrafiltration	Nanofiltration	Reverse osmosis	Electrodialysis/ ED reversal
General water qualities					
Turbidity, sediment	x	x	x		
Color		x	x	x	
Disinfection by-product precursors		x	x	x	
Taste and odor					
Biological contaminants					
Algae	x	x	x		
Protozoa	x	x	x	x	
Bacteria		x	x	x	
Viruses			x	x	
Organic chemicals					
Volatile organics					
Semi-volatile compounds				x	
Pesticides and herbicides			x	x	
Biodegradable organic matter					
Inorganic chemicals					
Hardness			x	x	x
Iron					x
Manganese					x
Arsenic				x	x
Selenium				x	x
Thallium				x	x
Fluoride				x	x
Radon					
Radium				x	x
Uranium				x	x
Cations				x	x
Anions				x	x
Total dissolved solids				x	x
Nitrate				x	x
Ammonia					

ED = electrodialysis.
[a] The columns and rows lacking x's are where process is not appropriate or recommended for the constituent.
Source: Table adapted from Committee on Small Water Supply Systems, National Research Council 1997.

Appendix table E.4—Water treatment technologies by type of filtration system[a]

General water quality-constituent	Direct filtration	Conventional filtration	Dissolved air flotation	Precoat filtration	Slow sand filtration	Bag/cartridge filters	Lime softening
General water qualities							
Turbidity, sediment	x	x	x	x	x		x
Color	x	x	x				
Disinfection by-product precursors	x	x	x				
Taste and odor					x		
Biological contaminants							
Algae		x	x	x			
Protozoa	x	x	x	x	x	x	x
Bacteria	x	x	x	x	x		x
Viruses	x	x	x	x	x		x
Organic chemicals							
Volatile organics							
Semi-volatile compounds							
Pesticides and herbicides							
Biodegradable organic matter	x*	x*	x*		x		
Inorganic chemicals							
Hardness							x
Iron	x	x	x	x			x
Manganese	x	x	x	x			x
Arsenic		x	x				x
Selenium							x
Thallium							
Fluoride							
Radon							
Radium							x
Uranium							
Cations							x
Anions							
Total dissolved solids							
Nitrate							
Ammonia	x*	x*	x*		x		

X* = when the filter is operated in a biologically active mode.

[a] The columns and rows lacking x's are where process is not appropriate or recommended for the constituent.

Source: Table adapted from National Research Council 1997.

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Glossary of Abbreviations and Acronyms

ai: active ingredient

aum: animal unit month

BAER: Burn Area Emergency Rehabilitation

BLM: Bureau of Land Management

BMP: best management practice

BOD: biological oxygen demand

Bt: *Bacillus thuringiensis*

BTEX: benzene, toluene, ethylbenzene, xylene

C: carbon

Ca: calcium

Ca^{2+}: calcium ion

$Ca(HCO_3)_2$: calcium bicarbonate

Cd: cadmium

CDC: Centers for Disease Control and Prevention

CERLA: Comprehensive Environmental Response, Compensation and Liability Act

CH_4: methane

Cl: chlorine

Cl^{-1}: chloride ion

cm: centimeter

CO_2: carbon dioxide

COD: chemical oxygen demand

Cu: copper

CWD: coarse woody debris

DEP: City of New York Department of Environmental Protection

DO: dissolved oxygen

DOD: Department of Defense

EPA: U.S. Environmental Protection Agency

ET: evapotranspiration

F: fluorine

FC: fecal coliform

FDA: U.S. Food and Drug Administration

Fe^{+2}: ferrous iron ion

Fe^{+3}: ferric iron ion

Fe_3S_4: greigite

FeS: pyrite

FeS_2: marcasite

FIFRA: Federal Insecticide, Fungicide, and Rodenticide Act

FS: fecal streptococcus

GIS: Geographic Information System

H^+: hydrogen ion

H_2S: hydrogen sulfide

ha: hectare

HA or HAL: health advisory level

HCN: hydrogen cyanide

HCO_3^{-1}: bicarbonate ion

HTH: chlorine

JTU: Jackson turbidity unit

K: potassium

K^+: potassium ion

km: kilometer

LOAEL: lowest observed adverse effect level

m: meter

MCL: maximum contaminant level

MCLG: maximum contaminant level goal

MD-DNR: Maryland Department of Natural Resources

MDC-DWM: Metropolitan District Commission's Division of Watershed Management (Massachusetts)

Mg: magnesium

Mg^{2+}: magnesium ion

mg: milligram

Mg: metric tonne or megagram

µg: microgram

µm: micron or 1 millionth of a meter

$Mg(HCO_3)_2$: magnesium bicarbonate

$MgSO_4$: magnesium sulfate

MITC: methyl isothiocyanate

Mn: manganese

MTBE: methyl tertiary butyl ester

N: nitrogen

N_2: nitrogen gas

N_2O: nitrous oxide

Na: sodium

Na^+: sodium ion

NAWQA: National Water-Quality Assessment Program

NEPA: National Environmental Policy Act

NFS: National Forest System

NH_4^{+1}: ammonium ion

NH_4+-N: ammonium-nitrogen

NO_2^{-1}: nitrite ion

NO_3^{-1}: nitrate ion

NO_3-N: nitrate-nitrogen

NOAEL: no observed adverse effect level

NOEL: no observed effect level

NTU: nephalometric turbidity unit

O: oxygen

O_2: oxygen gas

OPS: Office of Pipeline Safety

OSM: Office of Surface Mining Reclamation and Enforcement

P: phosphorus

PAH: polycyclic aromatic hydrocarbon

Pb: lead

PFC: Proper Functioning Condition

pH: the negative logarithm (base 10) of the hydrogen ion concentration

PO_4^{-3}: phosphate ion

PO_4^{3-}—P: phosphate phosphorus

ppb: parts per billion

ppm: parts per million

RCRA: Resource Conservation and Recovery Act

RfD: reference dose

S: sulfur

SDWA: Safe Drinking Water Act Amendments of 1996

Si: silicon

SiO_2: silica

SMRCA: Surface Mining and Control Reclamation Act

SO_4^{-2}: sulfate ion

SWA: source water assessment

SWAP: source water assessment program

SWTR: Surface Water Treatment Rule of 1989

TDS: total dissolved solids

TFM: 3-trifluoromethyl-4-nitrophenol

THM: trihalomethane

TT: treatment technique

USGS: U.S. Geological Survey

UST: underground storage tanks

VOC: volatile organic compound

WATSED: Region 1 water and sediment model

WEPP: Water Erosion Prediction Project

WPP: Watershed Protection Program

Zn: zinc

Glossary of Terms

action level: the level of contamination which, if exceeded, triggers treatment or other requirements that a water system must follow.

acute health effect: an immediate, i.e., within hours or days, effect that may result from exposure to certain drinking water contaminants.

allelopathy: a chemical defense mechanism in certain plants to keep other plants from growing under or around their canopy.

anions: negatively charged ions. The most common in natural waters are bicarbonate, nitrate, sulfate, chloride, and different forms of phosphorus.

anoxic: lacking oxygen.

aquifer: a saturated, permeable geologic unit that can transmit significant quantities of water under ordinary conditions.

aquitard: a geologic unit that cannot transmit significant quantities of water under ordinary conditions.

artesian well: a deep well in which water rises under pressure from a permeable strata.

bed load: bed load is sediment too heavy to be continuously suspended in flowing water. This material is rolled or bounded along the stream bottom. The size of particles making up the bed load varies with streamflow, velocity, particle density and shape, and many other factors.

biological oxygen demand (BOD): dissolved oxygen required to decompose biodegradable organic material in parts per million (ppm) or milligrams per liter (mg/L).

capillary fringe: the zone between the water table and the vadose zone where water is held within pores by capillary forces.

cations: positively charged ions. The most common in natural waters are calcium, sodium, potassium, and ammonium.

centralized wastewater treatment system: water treatment system that collects wastewater and transports wastewater via sewers to a central treatment facility.

chemical oxygen demand (COD): dissolved oxygen required to decompose biodegradable and nondegradable organic material in parts per million (ppm) or milligrams per liter (mg/L).

closed well: a well that has been permanently disconnected and capped or filled so that contamination cannot move from the surface into the aquifer.

coliform: a group of related bacteria whose presence in drinking water may indicate contamination by disease-causing microorganisms.

coliphages: viruses (bacteriophage) that infect and replicate in the bacterium *E. coli* and appear to be present wherever *E. coli* are found. Some strains are more resistant to chlorine disinfection than total coliforms.

commercial use: includes water for motels, hotels, restaurants, office buildings, golf courses, civilian and military institutions, and in some areas fish hatcheries. The consumptive use of water for commercial purposes in the United States in 1995 was estimated at 14 percent of withdrawals and deliveries.

community water system: a water system with 15 or more service connections and which supplies drinking water to 25 or more of the same people year-round in their residences.

compliance: the act of meeting all Federal and State drinking water regulations.

confined aquifer: an aquifer that is between two impermeable geologic units.

consumptive use: the part of water withdrawn that is evaporated, transpired, or incorporated into products or crops. In many instances, the consumptive use is the difference between the amount delivered and the amount released.

contaminant: any substance found in water (including microorganisms, minerals, chemicals, radionuclides, etc.) which may be harmful to human health.

conveyance loss: the quantity of water that is lost in transit from its source to point of use or point of return.

***Cryptosporidium* spp.:** a microorganism commonly found in lakes and rivers which is highly resistant to disinfection. *Cryptosporidium* has caused several large outbreaks of gastrointestinal illness, with symptoms that include diarrhea, nausea, and/or stomach cramps.

cutslope: excavated slope uphill from a road located on the side of a steep hill.

decentralized water treatment system: onsite water treatment facility.

disinfectant: a chemical (commonly chlorine, chloramine, or ozone) or physical process, e.g., ultraviolet light, that kills microoganisms such as bacteria, viruses, and protozoa.

distribution system: a network of pipes leading from a treatment plant to customer's plumbing system.

domestic use: includes water used for normal household purposes, such as drinking, food preparation, bathing, washing clothes and dishes, flushing toilets, and watering lawns and gardens. The consumptive use of water for domestic purposes in the United States in 1995 was estimated at 26 percent of withdrawals and deliveries.

drywell: a well used for disposal of liquid wastes, other than an improved sinkhole or subsurface fluid distribution system, completed above the water table so that its bottom and sides are typically dry except when receiving fluids.

enteric viruses: viruses which infect the gastrointestinal tract of humans and are excreted with the feces of the infected individual. These viruses are excreted in relatively large numbers from infected individuals and include polioviruses, coxsackieviruses, echoviruses, other enteroviruses, adenoviruses, rotaviruses, hepatitis A virus, Norwalk viruses, astrovirus, and caliciviruses.

equivalents per liter: a chemical term indicating the number of moles of solute multiplied by the valence of the solute species in 1 liter of solution.

eutrophication: enrichment of surface waters with nutrients, especially phosphorus and nitrogen that leads to enhanced plant growth, algal blooms and depleted oxygen levels as this plant material decays.

exotic: with reference to vegetation, refers to nonnative plant species introduced either accidentally, or to meet some management goal.

fillslope: the downhill embankment on a road constructed on the side of a steep hill.

finished water: drinking water that has been treated and is ready to be delivered to customers.

fire intensity: in a wildfire or prescribed burn, a qualitative term describing the rate of heat release, related to flame length.

fire severity: in a wildfire or prescribed burn, a qualitative term describing the extent of fire effects on ecosystem components, such as vegetation or soils.

gaining stream: a stream that receives flow from ground water discharge.

***Giardia* spp.:** a microorganism frequently found in rivers and lakes, which, if not treated properly, may cause diarrhea, fatigue, and cramps after ingestion.

ground water: the water that drinking water systems pump and treat from aquifers.

industrial use: includes water use for processing, washing, and cooling in facilities that manufacture products like steel, chemicals, paper, and petroleum refining. The consumptive use of water for industrial purposes in the United States in 1995 was estimated at 15 percent of total withdrawals and deliveries.

in holdings: land parcels contained within public lands that are not owned by the agency managing public lands.

inorganic contaminants: mineral-based compounds, such as metals, nitrates, and asbestos. These contaminants are naturally occurring in some water, but can also get into water through farming, chemical manufacturing, and other human activities.

instream use: water use that takes place without the water body being diverted or withdrawn from surface or ground water sources. Examples include hydroelectric power generation, navigation, freshwater dilution of saline estuaries, maintenance of minimum streamflows to support fish and wildlife habitat, and wastewater assimilation.

irrigation use: includes all water artificially applied to farm and horticultural crops and in some cases golf courses. Of the water withdrawn for irrigation in the United States in 1995, 19 percent was lost in conveyance, 61 percent was consumptive use, and 20 percent was returned to surface of ground water supplies.

karst: geologic formation in limestone strata containing numerous dissolved, undergound channels resulting in high hydraulic conductivity and high risk of ground water pollution.

leachate: a liquid, often containing extremely high concentrations of organic and inorganic pollutants, formed from the decomposition of municipal solid waste.

livestock use: includes offstream use of water for livestock, feed lots, dairies, fish farms, and other on-farm needs. The consumptive use of water for livestock in the United States in 1995 was estimated at 26 percent of withdrawals and deliveries.

losing stream: a stream that loses water to the ground water. Streams that help recharge ground water.

mass concentration: the mass of a solute dissolved in a specific unit volume of solution, usually expressed in milligrams per liter.

mass failure: the collapse of a steep embankment when the gravitational forces within the embankment exceed the strength of the soil to maintain the current slope.

maximum contaminant level (MCL): the highest level of a contaminant that U.S. Environmental Protection Agency allows in drinking water to ensure that drinking water does not pose either a short-term or long-term health risk.

maximum contaminant level goal (MCLG): the level of a contaminant at which there would be no risk to human health. This goal is not always economically or technologically feasible, and the goal is not legally enforceable.

microorganisms: tiny living organisms that can be seen only with the aid of a microscope. Some microorganisms can cause acute health problems when consumed in drinking water. Also known as microbes.

mining use: offstream water uses for the extraction and milling of naturally occurring minerals including coals and ores, petroleum, and natural gases. The consumptive use of water for mining purposes in the United States in 1995 was estimated at 27 percent of withdrawals and deliveries.

molality: the number of moles of solute in a 1 kilogram mass of solvent.

molarity: the number of moles of solute in a liter of solution.

monitoring: testing that water systems must perform to detect and measure contaminants. A public water system that does not follow U.S. Environmental Protection Agency's monitoring methodology or schedule is in violation, and may be subject to legal action.

municipal solid waste landfill: a discrete area of land or an excavation that receives household wastes.

nonpoint-source pollution: contaminants that come from diffuse sources and pollute surface and ground water sources.

nontransient, noncommunity water system: a system which supplies drinking water to 25 or more of the same people at least 6 months per year in places other than their residences. Some examples are schools, factories, office buildings, and hospitals that have their own water systems.

offstream use: water that is diverted or withdrawn from surface or ground water sources and conveyed to the place of use.

organic contaminants: carbon-based chemicals, such as solvents and pesticides, which can get into water through runoff from cropland or discharge from factories. U.S. Environmental Protection Agency has set legal limits on 50 organic contaminants.

oxygenates: organic compounds added to gasoline to increase oxygen content of gasoline and reduce certain emissions.

pathogen: a disease-causing organism.

perched water table: a zone of saturation that is bound below by impermeable material elevated above a vadose zone above the water table.

pH: a common measure of acidity and alkalinity defined as the negative logarithm (base 10) of the hydrogen ion concentration. A pH of 7 represents neutral conditions, a pH value <5 indicates moderately acidic conditions, while a pH value >9 indicates moderately alkaline conditions.

plugging: the act or process of stopping the flow of water, oil, or gas into or out of a formation through a borehole or well penetrating that formation.

point-source pollution: contaminants that can be traced to specific points of discharge and pollute surface and ground water sources.

polycyclic aromatic hydrocarbons (PAH): multiple-ringed carbon compounds that are potentially carcinogenic.

potentimetric surface: the water surface level of the saturated zone in a confined aquifer.

public supply: water withdrawn by public and private suppliers and delivered to multiple users for domestic, commercial, industrial, and thermoelectric power uses. The difference between the amount of water withdrawn and delivered to users typically represents losses in the distribution system and use for water treatment plant filter cleaning, water for fire fighting, street cleaning, and occasionally municipal buildings.

public water system: any water system which provides water to at least 25 people for at least 60 days.

radionuclides: any man-made or natural element that emits radiation and that may cause cancer after many years of exposure through drinking water.

raw water: water in its natural state, prior to any treatment for drinking.

redox potential: a measure of the oxidizing or reducing capacity of a solution where positive values indicate oxidizing tendencies and negative values indicate reducing tendencies. Chemically, it is defined as the energy gained in the transfer of 1 mole of electrons from an oxidant to hydrogen.

return flow: the quantity of water that is discharged to a surface or ground water after release from the point of use and, thus, becomes available for further uses.

road prism: the road and surrounding area directly influenced by the road, including any cutslopes, ditches, fullslopes, and the roadway.

roadway: the surface of a road on which vehicles travel.

rock buttress: a thick layer of rock placed on top of a steep sideslope to reduce the risk of a mass failure.

saturated zone: a soil or geologic zone in which all pores are filled with water.

secondary drinking water standards: nonenforceable Federal guidelines regarding cosmetic effects (e.g., tooth or skin discoloration) or aesthetic effects (e.g., taste, odor, or color) of drinking water.

slumping: a mass failure generally due to an increase in water content within the soil profile on steep slopes.

sole-source aquifer: an aquifer that supplies 50 percent or more of the drinking water of an area.

spring: places on the land surface where the water table or an aquifer intersects the land surface, discharging ground water.

surface water: the water in sources open to the atmosphere, such as rivers, lakes, and reservoirs.

suspended sediment: suspended sediment is material light enough to be carried in suspension in streamflow. The sediment carried in suspension may be either organic or inorganic material. Unless specified, both types are included in suspended sediment estimates. Suspended sediment is often reported as the concentration in water using parts per million or milligrams per liter interchangeably to express the instantaneous concentration at a given point. Sediment not transported in suspension is called bed load.

thermoelectric power: includes offstream uses for the generation of electric power with fossil fuels, nuclear, or geothermal power. In the United States in 1995, surface water supplied more than 99 percent of the thermoelectric withdrawals. Consumptive use was about 2 percent of withdrawals.

total dissolved soils (TDS): determined by weighting the solid residue obtained by evaporating a measured volume of filtered water. Reported in mass per-unit volume, typically in milligrams per liter.

total sediment yield: total sediment yield includes both suspended sediment yield and bed load yield at a point along a stream.

transient, noncommunity water system: a water system which provides water in a place such as a gas station or campground where people do not remain for long periods of time. These systems do not have to test or treat their water for contaminants that pose long-term health risks because fewer than 25 people drink the water over a long period. They still must test their water for microbes and several chemicals that pose short-term risks.

turbidity: turbidity of water is the degree to which light penetration is impeded by suspended material. Turbidity is expressed either in Jackson turbidity units (JTU) or nephelometric turbidity units (NTU).

turbidity unit (tu): one tu is the interference in the passage of light caused by a suspension of 1 milligram per liter of silica. Turbidity ≤ 5 tu is generally not noticeable to the average person.

unconfined aquifer: or water table aquifer. An aquifer in which the water table forms the upper boundary.

vadose zone: this is a geologic or soil zone, which is not saturated. It is a zone of aeration, and water in this zone follows the laws of soil physics. Water in this zone does not flow to a well.

volatile organic compounds (VOC): organic compounds that volatilize at room temperatures.

vulnerability assessment: an evaluation of drinking water source quality and its vulnerability to contamination by pathogens and toxic chemicals.

wastewater release: includes the disposal of water conveyed through a sewer system. In the United States in 1995, approximately 2 percent of these releases were reclaimed for beneficial uses, such as irrigation of golf courses and public parks.

water bar: a ditch excavated across a road to route water from the road surface or uphill ditch to a downhill ditch or hillside, to reduce surface erosion by concentrated flow, and distribute surface runoff along a hillside.

water birds: water birds refer to all waterfowl including swans, geese, and ducks (whistling ducks, marsh ducks, diving ducks, stiff-tailed ducks, and mergansers) or duck-like swimming birds including gulls, cormorants, grebes, loons, coots, and wading birds, such as herons and egrets.

water delivery: the quantity of water delivered to a specific point of use.

water release: the quantity of water released to surface water or ground water after a specific use.

water table: the level at which water stands in a well and is the point where fluid pressure in the pores is exactly atmospheric. Also called phreatic surface.

watershed: the land area from which water drains into a stream, river, lake, or reservoir.

well: a bored, drilled or driven shaft, or a dug hole, whose depth is greater than its largest surface dimension.

wellhead protection area: the area surrounding a drinking water well or well field, which is protected to prevent contamination of the well(s).

withdrawal: the quantity of water diverted or withdrawn from a surface or ground water source.

Subject Index

Dissmeyer, George E., ed. 2000. Drinking water from forests and grasslands: a synthesis of the scientific literature. Gen. Tech. Rep. SRS–39. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 246 p.

This report reviews the scientific literature about the potential of common forest and grassland management to introduce contaminants of concern to human health into public drinking water sources. Effects of managing water, urbanization, recreation, roads, timber, fire, pesticides, grazing, wildlife and fish habitat, and mineral, oil, and gas resources on public drinking water source quality are reviewed. Gaps in knowledge and research needs are indicated. Managers of national forests and grasslands and similar lands in other ownerships, environmental regulators, and citizens interested in drinking water may use this report for assessing contamination risks associated with land uses.

Keywords: Economics, nutrients, pathogens, sediments, source water assessments, toxic chemicals.