CHAPTER 1. INTRODUCTION

The Fairfax County Water Authority (FCWA) provides potable drinking water to approximately 1.2 million people in the northern Virginia suburbs of the U.S. national capital, Washington, D.C., half of which are served from its Occoquan Reservoir raw water source. The Occoquan Reservoir was formed in 1957 by the construction of a concrete high dam near the fall line of the Occoquan River where it enters an embayment of the Potomac River. The tributary watershed drained 570 square miles (sq. mi), and the reservoir was originally thought to impound 9.8 billion gallons (BG). Figure 1-1 shows the map of the entire watershed including the monitoring stations. By the early 1960s, development in the watershed, and the attendant nutrient loads from nonpoint sources and wastewater discharges had caused the reservoir to begin displaying classical symptoms of cultural eutrophication. Excessive nutrient fertilization caused problems with blooms of nuisance algae, which resulted in a range of water quality problems, including clogging of water treatment plant filters; fish kills resulting from oxygen depletion; and taste and odor problems from algal metabolites and other organic compounds (Occoquan Watershed Monitoring Laboratory, 1998).

In response to the deterioration of reservoir water quality, the Virginia State Water Control Board (VSWCB) retained the consulting firm of Metcalf and Eddy to study the Occoquan system, and to make recommendations on management strategies. In 1971, after considering the Metcalf and Eddy report, the VSWCB adopted *A Policy for Wastewater Treatment and Water Quality Management in the Occoquan Watershed* (VSWCB, 1971). The so-called *Occoquan Policy* mandated the construction of high-performance wastewater treatment plants in the watershed to employ state-of-the-art treatment technology to remove nutrients and other contaminants from wastewater entering the surface waters of the basin. The *Policy* also required the establishment of an independent watershed monitoring program to evaluate the success of water quality management programs for both point and nonpoint sources. In 1978, the first regional wastewater reclamation facility was placed into service by the Upper Occoquan Sewage Authority (UOSA). The UOSA plant eliminated 11 existing point source discharges, and began producing an effluent quality that was consistent for indirect reuse in supplementing public water supply (OWML, 1998).

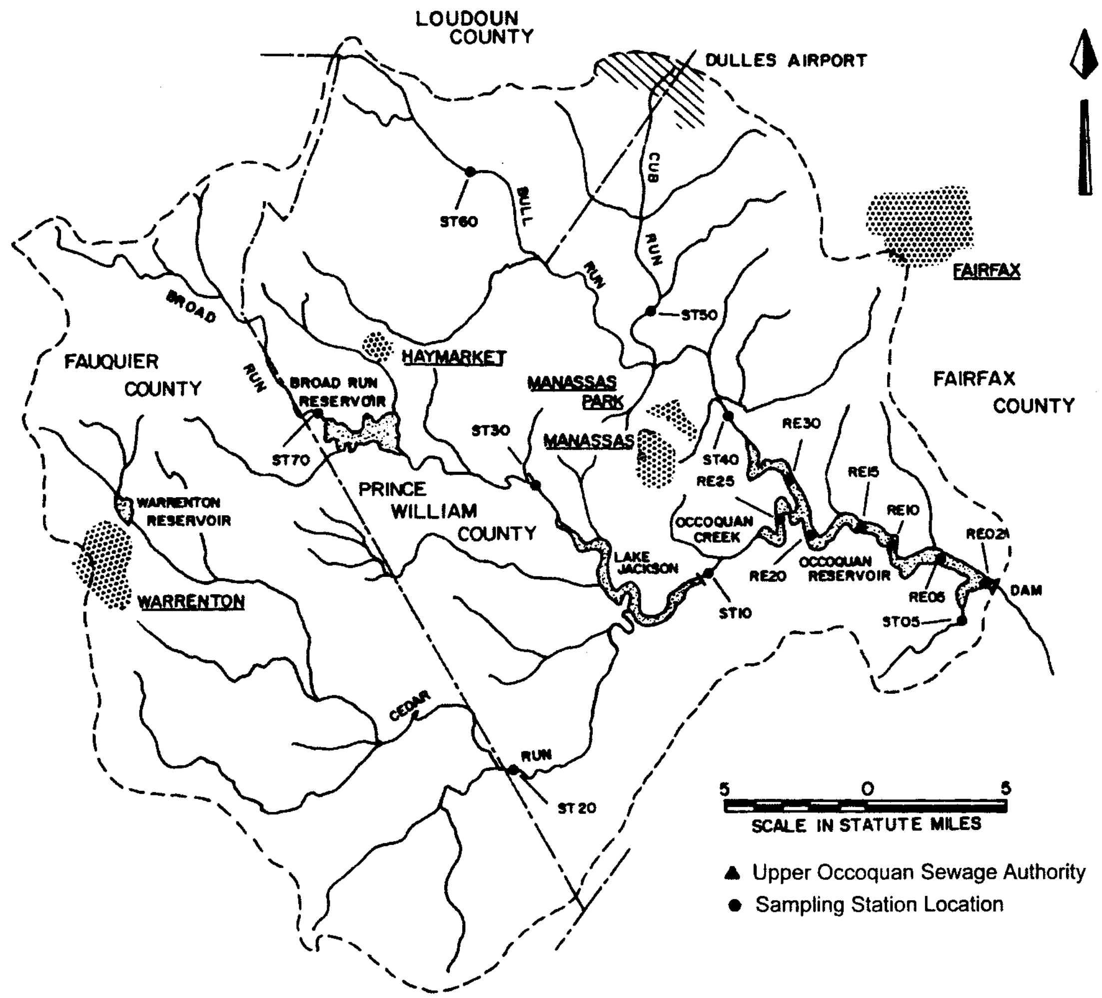

Figure 1-1. The Occoquan Watershed with boundaries and sampling stations shown. (Taken from OWML, 1998)

In the 32 years since the *Occoquan Policy* was adopted, not only has the UOSA water reclamation facility (WRF) begun operations, but much additional effort has been directed toward controlling nutrient fluxes to the surface waters of the Occoquan Basin from urban runoff and other nonpoint sources. Local jurisdictions in the watershed have adopted erosion and sediment control regulations since 1982 and were among the first jurisdictions in the eastern United States to begin mandating the installation of best management practices (BMPs) to control pollutants in urban stormwater (Grizzard, 2002).

The effluent limitations placed on the UOSA water reclamation plant discharge have been revised somewhat in the nearly 24 years of its operation, but it is safe to say that they remain among the most stringent in the world, as may be seen from the following minimum requirements (VSWCB, 1990):

Parameter	Value
Chemical Oxygen Demand (COD)	10 mg/L
Total Suspended Solids (TSS)	1 mg/L
Total Phosphorus (TP)	0.1 mg/L
Unoxidized Nitrogen (TKN)	1 mg/L
Turbidity	0.5 NTU
Fecal Coliforms	2 cfu/100 mL

As noted above, the nitrogen (N) requirement was based on unoxidized forms (ammonia (NH_3-N), ammonium (NH_4^+-N), and organic nitrogen), which are measured as total kjeldahl nitrogen (TKN). Under normal operating conditions, in order to meet the nitrogen permit limit, the UOSA WRF is required to biologically oxidize reduced forms of nitrogen to nitrate (NO_3^--N). This operating protocol came about because OWML observed the beneficial effects of oxidized nitrogen inputs in reducing phosphorus (P) release from the deposited sediments of the Occoquan Reservoir (Sherman, 1983; OWML, 1998). Because of these beneficial effects, at the present time UOSA only operates the treatment facilities to remove oxidized nitrogen when the ambient concentrations of the oxidized forms (NO_2^--N + NO_3^--N) in the vicinity of the raw water intake are equal to or higher than 5 milligrams per liter as N (VSWCB, 1990). This exception to the permit has been determined necessary in order to insure that nitrate concentrations do not exceed the maximum contaminant level (MCL) set by the U.S. Environmental Protection Agency (USEPA) for drinking water (Grizzard, 2002). At this writing, the MCL of 10 mg/L NO_3^--N (EPA, 2001) has been determined to be protective against the induction of methemoglobinemia, which is known more commonly as the *blue baby* syndrome (National Research Council, 1995).

As noted above, the Occoquan Watershed drains eastward to the Potomac River, which is the second largest tributary to the Chesapeake Bay (OWML, 1998). The Potomac River is also the second major source of nitrogen and phosphorus loads to the Bay (Belval and

Sprague, 1999). By the early 1980s, loads of nitrogen and phosphorus had been determined to be the primary pollution problem in the bay, and in response to this conclusion the Governors of Maryland, Virginia, and Pennsylvania; the Mayor of the District of Columbia; and the U.S. Environmental Protection Agency signed the first Chesapeake Bay Agreement in 1983. This agreement set forth a vision of regional cooperation to restore and protect the water quality and living resources of the Chesapeake Bay, which is one of the Earth's great estuaries. The second Chesapeake Bay agreement was signed in 1987, and in addition to affirming the regional watershed management approach adopted in 1983, it set some specific water quality management goals, including a key provision for the reduction of nitrogen and phosphorus loads entering the bay. The nutrient reduction plan set a goal—to be achieved by the year 2000—of having a basin-wide strategy to achieve at least a 40 percent reduction of nitrogen and phosphorus entering the main stem of the Chesapeake Bay. The reduction would be calculated based on the point source loads present in 1985, and on nonpoint source loads in an average rainfall year. The signatories to the Bay Agreement have each established a *Tributary Strategy*, which include watershed-based plans to diminish nutrient loads by advance-treatment techniques, best agricultural management practices, resource protection, non-point source management, urban runoff control, and growth management activities (USEPA, 1997).

In the Northern Virginia region, the state government oversaw the development of the Tributary Strategy through the Department of Environmental Quality (DEQ), with self-adopted guidelines of adopting nutrient control plans that are practical, cost-effective, and fair. The end result was a list of recommended control options, one of which was to require retrofits of all wastewater treatment plants in the region with a design capacity equal to or greater than 0.5 million gallons per day (MGD) to achieve removal of nitrogen. Plant operators were given a choice of using biological nutrient removal (BNR) or equivalent technologies. The only plant in the region that was exempted from this recommendation was the WRF operated by UOSA.

During the development of the *Tributary Strategy* for the Potomac River, the state technical assistance team received information from UOSA that expressed concern about undesirable water quality impacts in the Occoquan Reservoir if the existing nitrogen management strategy were to be abandoned in favor of nitrogen removal. Because of the use of lime treatment for high performance removal of phosphorus and inactivation of viruses, UOSA expressed concern that the alkalinity production from a biological denitrification process would result in an approximate lime dosage increase of 150 - 200 percent. UOSA staff felt that there were a number of other process problems that would result, including a proportional increase in chemical sludge production, and a considerable degradation of water quality being applied to multimedia filtration and activated carbon adsorption systems. UOSA staff concluded that the overall effects would be significantly higher costs and a poorer reclaimed water discharge into the reservoir.

UOSA staff also noted that OWML's data showed that a significant amount of nitrate in the WRF effluent was removed in the reservoir and, therefore, would never reach the Potomac River or the Chesapeake Bay. OWML (1998) has concluded that long-term removals of total nitrogen in the Occoquan Reservoir have approached 40 percent of the load entering the reservoir annually. *In situ* observations in the Occoquan Reservoir and laboratory microcosm studies by OWML have suggested that nitrate serves as an alternate electron acceptor for certain bacteria after oxygen is depleted from the hypolimnetic waters during the period of stratification. This may be contrasted to truly anaerobic conditions, where no inorganic electron acceptor is available, and the oxidation-reduction potential (ORP) drops to values too low to prevent the reduction of ferric iron, and the subsequent liberation of iron-bound sediment phosphorus. In the former case, nitrate reduction occurs at ORP values that are still higher than those at which iron is reduced, resulting in a condition that maintains ferric iron (and its phosphorus retention capacity) at the sediment-water interface as long as nitrate is present (OWML, 1998). According to the *Tributary Strategy* for the Potomac River, the estimation of nutrient loads from the Potomac basin to the Chesapeake Bay assumed that the entire amount of the discharged nitrogen and phosphorus from UOSA reached the tidal tributaries. To be consistent with the *in situ* observed data and laboratory microcosm studies, the estimation of nitrogen load should take into account the transformation of nitrate in the Occoquan Reservoir.

OWML postulated that a principal mechanism for the observed removal of nitrate entering the surface waters of the Occoquan Watershed is biological denitrification during the period of anoxia, or when anoxic conditions exist near the sediment-water interface. OWML has also concluded that the ORP-*poising* effects of the WRF discharge nitrate are so important that it would be unwise to begin removal of oxidized nitrogen in the plant discharge under most operation conditions. In 1995, staff meetings among representatives of OWML, UOSA, EPA, and DEQ reviewed and discussed the observed data, and, with the concurrence of the Virginia Technical Assistance Team, it was concluded that operation of nitrogen removal facilities at the UOSA WRF would only be required when two conditions occurred simultaneously (Grizzard, 2002): (1) extreme drought to offset natural dilution of the UOSA WRF effluent, and (2) vertical mixing (unstratified) conditions in the reservoir which result in the presence of molecular oxygen throughout the water column, thereby cutting off *in situ* denitrification. The trigger point to operate the biological denitrification system is already in place, and as noted earlier, it is determined by the reservoir ambient nitrate concentration in the vicinity of the FCWA intake point being equal to or greater than 5 mg/L as N.

In order to further document the complex relationship(s) between sediment phosphorus release and the presence of nitrate in the reservoir water column, UOSA agreed to sponsor additional study of the loss of nitrate in the Occoquan Reservoir, and to evaluate the "delivery factor" that might be used to characterize the removal of nitrogen as a fraction of all nitrogen sources in the watershed. This information will be of value in estimating the Shenandoah-Potomac baseline loads to date and in the future (Virginia Secretary of Natural Resources, Virginia Chesapeake Bay Local Assistance Department, Virginia Department of Conservation and Recreation, and Virginia Department of Environmental Quality, 1996).

This study has been supported, in part, by UOSA, in an attempt to more accurately determine the "delivery factor" for nitrate entering the Occoquan Reservoir, and also to investigate the impacts on the reservoir from operating BNR. To this end, a series of microcosm studies were conducted to simulate the reservoir condition during summer stratification. The system was fed with a representative sample of the Occoquan Reservoir tributary into which the UOSA WRF discharges. The objectives were to enhance understanding of nitrate-sediment-phosphorus interactions by (1) developing microcosm operating protocols that would adequately simulate the upper reaches of the Occoquan Reservoir, and (2) developing estimates of the denitrification-rate constant to be used as an input to the reservoir water quality model CE-QUAL-W2 (USACE WES, 2000).