Manual of Water Supply Practices

M73

Groundwater Management

American Water Works Association

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Manual of Water Supply Practices—M73, First Edition

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Preface

Manual M73, Groundwater Management, is the culmination of efforts by members of AWWA's Groundwater Resource Committee to identify and demonstrate the value of using computer modeling tools to help utilities better manage their groundwater resources in light of greater competition for water and dwindling supplies in many parts of the world. In North America, we see acute issues developing in the Plains states, Rocky Mountains, desert Southwest, and even along parts of the Eastern Seaboard. In many of these cases, deep and often confined aquifers are being tapped for irrigation and potable supplies, but there is little hope these aquifers can recover their supplies in our lifetime. That creates the potential for serious economic and social consequences later in the 21st century for communities whose wells may run dry and have no backup options. To this end, this manual includes a discussion on the sustainability of groundwater supplies; overdrafting; and the need for groundwater protection, planning, and evaluation efforts that have evolved in the past 10 years. While groundwater management was incorporated to a small degree in the 2014 version of M21, Groundwater, the committee felt the topic has developed considerably over the past 10 years and that a more detailed and focused manual for groundwater management was timely. M21 will now focus primarily on operations.

M73 provides the reader with a general understanding of the principles involved with groundwater, its movement and character, and the subsequent impact these characteristics have on the development of groundwater resources systems and their long-term sustainability for water utilities. This manual should be considered a companion to M21. There are more detailed books available in the AWWA catalog on well drilling procedures, well maintenance, groundwater treatment, and injection programs that are tangential to groundwater management but are relevant to utilities that rely on groundwater for supplies. We encourage interested readers to pursue additional information, some of which is by the authors of this manual. There are also highly technical texts that deal with the mathematics of groundwater, but the math is generally beyond the scope of this manual (see Bloetscher et al. 2005, for example, for these details).

We have specifically not provided much detail on specific groundwater models since they change and anything included would be outdated before this manual was published. Most of the groundwater models are based on the US Geological Survey (USGS) model code, MODFLOW. Added packages that have been developed to complement MODFLOW include SEAWAT, MT3D, MODPATH, and others. Many commercial software providers have taken these base models and incorporated sophisticated pre- and post-processing capabilities to make the models easier to interpret for professionals and policymakers alike. Examples of the results are included in Chapter 7. Modeling has evolved to the point where many water-use projects include a modeling exercise.

Chapter 1 includes a case study of what can go wrong, an overview of groundwater for those not familiar with the topic, and what will be accomplished in this manual. Chapter 2 is an overview of the hydrologic cycle as it relates to the occurrence of groundwater, as well as a discussion of sustainability of groundwater supplies in light of regional competition for water resources and climate change. Chapter 3 starts with a discussion of issues associated with water quality of groundwater and potential impacts from aquifer declines; water quality and contaminant transport resulting from organic, inorganic, and bacteriological pollution; and concepts for addressing source water protection and cleanup. Chapter 4 outlines regional groundwater topics on groundwater recharge, water budgets, characterizing the aquifer, aquifer yield, and some discussion on the regulatory environment. Chapter 5 outlines the monitoring to support management of regional groundwater systems. This includes identifying data and the completeness of same in anticipation of further analysis.

The discussion of using the data from Chapters 1 to 5 to construct a model of the groundwater system begins in earnest in Chapter 6. An outline of common modeling software is included as part of the discussion. The chapter is designed to offer enough detail about how the models are constructed and operate without getting into details of actual software that will inevitably change and therefore be of limited value in a few years. To show the power of these models, Chapter 7 outlines a series of applications of groundwater models. Note: Many of these are fairly complex and may be beyond the needs of small utilities, but as the cost of software drops, the ability to create dynamic system models even for small communities increases. This gets beyond the analytical calculations currently used, which have severe limitations when dealing with confined aquifers. The intent of this chapter is to provide a series of modeling case studies from places in North America, using different aquifers and modeling for different purposes. Recharge with reclaimed water (indirect potable reuse potential) along with risk is included in the last case study.

Chapter 8 summarizes the current status of groundwater management and suggests pathways to improve our understanding and policy decision-making with respect to this often-limited resource. This manual should help managers and engineers gain enough background on groundwater management to improve their decision-making, and determine when models should be used and the complexity that should be included. The manual should help these professionals answer many of their questions about complex aquifer systems and improve their ability to manage concerns. The Groundwater Resource Committee is hopeful that this manual will meet the industry needs of the new millennium.

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Definitions

1. *Annulus/annular space.* The space between the borehole wall and the well casing, or the space between a casing pipe and a liner pipe.
2. *Aquifer.* A rock formation that will yield water in a usable quantity to a well or spring.
3. *Aquifer mining.* The occurrence whereby the aquifer levels are drawn down with time at a rate faster than recharge.
4. *Artesian aquifer.* Confined aquifer where the water level rises above the top of the aquifer.
5. *Artificial recharge.* Occurs where a well, series of wells, or large basin is created for the purpose of putting water back into a formation. This is different from aquifer storage and recovery, where injection and withdrawal from the same well is planned as a cyclical process.
6. *Bridging*. The development of gaps or obstructions in either grout or filter pack materials during placement or development.
7. *Capillary fringe*. The subsurface layer in which groundwater seeps up from a water table because of tension saturation.
8. *Casing (well).* The vertical pipe that is inserted after drilling, often cemented in place, to give the well structural integrity while sealing off portions of the aquifer that are not part of the production zone. There may be multiple casings in a well.
9. *Conductor casing.* Outer casing used for stability or to seal off a formation to prevent formation collapse or vertical cross-contamination within the well.
10. *Confined aquifer.* An aquifer that is not open to the surface because of some overlying formation.
11. *Confining layer.* Formations that water cannot flow through easily.
12. *Conjunctive use.* Relates to the combined use of groundwater and surface water. The idea of this management approach is to use surface water when the water table is high and change to groundwater when the water table is low, and vice versa. Other sources (reclaimed water) can be incorporated as well.
13. *Decay.* A chemical concentration decrease over time in groundwater, often because of microbial action when related to organics and nutrients.
14. *Dispersion.* The spreading of a contaminant plume from highly concentrated areas to less-concentrated areas.
15. *Filter pack.* Sand, gravel, or glass beads that are uniform, clean, and well-rounded that are placed in the annulus of the well between the borehole wall and the well intake to prevent formation material from entering through the well intake and to stabilize the formation.
16. *Finite difference models.* These computer models convert ordinary linear differential equations or nonlinear partial differential equations into a system of equations that can be solved by matrix algebra techniques, which makes finding the solution well suited to modern computers. The finite difference model is set up using a grid of rectangular grids.

17. *Finite element models.* These computer models convert partial differential equations into a system of equations that can be solved simultaneously in a nonrectangular grid (labeled "elements").
18. *Flowing artesian well.* An artesian well in which the water level stands above the land surface.
19. *Grout*. A fluid mixture of neat cement and water, possibly with various additives or bentonite, of a consistency that can be forced through a pipe and placed in the annular space between the borehole and casing to form a seal.
20. *Head.* Pressure in a formation and/or elevation of water in the formation.
21. *Hydraulic conductivity*. The ability of water to flow through the porous media; referred to as hydraulic conductivity (K).
22. *Permeability*. A measure of the ease with which water can move through a porous rock.
23. *Pressure grouting/sealing.* A process by which grout is confined within the borehole or casings by the use of plugs or packers and by which sufficient pressure is applied to force the grout slurry into and within the annular space or aquifer zone to be grouted.
24. *Sanitary seal.* The top covering of a well, designed to keep insects, surface runoff, small animals, dirt, and debris from entering the well and contaminating the aquifer.
25. *Screen/well intake.* A screening device or length of pipe that is used to keep materials other than the aquifer fluids (groundwater) from entering the well.
26. *Slot size.* The width of the slots machined into a slotted well casing (screen) that allows aquifer fluids (groundwater) into the well.
27. *Sorption.* A physical and chemical process by which one substance becomes attached to another.
28. *Sublimation.* A chemical process where a solid turns into a gas without going through a liquid stage.
29. *Transmissivity.* The hydraulic conductivity multiplied by the aquifer thickness.
30. *Unconfined aquifer*. Shallow formations that have no overlying barrier to direct recharge from precipitation.
31. *Vadose zone.* Includes surface soils, the unsaturated material below the soil, and the capillary fringe (area where water can rise), but is not part of any aquifer system.
32. *Well liner.* Vertical pipe that is inserted inside the casing pipe, connected to the production zone.

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Chapter 1

Introduction

COASTAL CAROLINAS – WHAT CAN GO WRONG?

The eastern Carolinas have long used groundwater as their source water because the aquifer was deep (250–400 ft), confined, stable with respect to water quality, and required little treatment. The communities from Greenville, N.C., through Kinston and Jacksonville, N.C., Myrtle Beach, S.C., and as far south as the communities around Mount Pleasant and Charleston, S.C., withdrew water from formations labeled the Middendorf and Black Creek aquifers. The aquifers were highly productive (calibrated transmissivity values of 400–11,000 ft^2/d for the Black Creek aquifer and 300–30,000 ft^2/d for the Middendorf aquifer), so water was easy to withdraw. In addition, the water required no treatment so communities bragged about the quality of their water that needed no treatment. Richlands, N.C., claimed to be the "Town of Perfect Water."

The Black Creek aquifer is composed of the Cretaceous Black Creek and Middendorf formations (Winner and Coble 1996). The Black Creek aquifer extends across most of the region. It consists of very fine to fine "salt and pepper" sands (NCDENR 2008). The thickness of Black Creek aquifer ranges up to 442 ft. In North Carolina, the Surficial, Castle Hayne, Yorktown, and Peedee aquifers overlie the Black Creek aquifer, and the Upper Cape Fear aquifer underlies the Black Creek (Lautier 2001). The potentiometric or hydraulic head levels of the Black Creek aquifer have been recorded since 1917 (Cooke 1936), and potentiometric maps have been published by Hockensmith (2008, 2003a, 2003b, and 1997), Stringfield and Campbell (1993), and Aucott and Speiran (1985a and 1985b). While the Black Creek aquifer is a source of high-quality drinking water, the presence of saltwater prevents the aquifer from being used for water supply immediately along the coast.