

Water Flows in the Necedah National Wildlife Refuge

Introduction

The Necedah National Wildlife Refuge (NNWR), in Juneau County, Wisconsin (fig. 1), contains extensive wetlands—areas commonly recognized as providing habitat and protection for migratory birds and endangered species. Because of concerns with potential changes to the water resources that supply the Refuge, the U.S. Fish and Wildlife Service and the U.S. Geological Survey undertook a one-year study to characterize the water resources of the Refuge in 1998. That study, which focused on quantifying the surface water and ground-water flows into and out of the Refuge, was intended to serve as a baseline condition of water resources on the Refuge.

The Refuge and its Watershed

Water plays an important part in the history of the area and the Refuge. The sandy sediments and flat topography of the area are a result of Glacial Lake Wisconsin, a pre-historic lake that developed when a glacier blocked the Wisconsin River near Baraboo (Clayton, 1989). This extensive lake occupied large parts of Juneau and Adams Counties, and parts of Wood, Portage, Waushara, Marquette, Columbia, Sauk, Richland, Vernon, Monroe and Jackson Counties. Glacial Lake Wisconsin drained catastrophically about 13,000 years ago when the glaciers retreated (Clayton and Attig, 1989). After the waters had receded, the Refuge area was part of a vast wetland complex of tamarack swamps and sedge meadows that was inhabited by tribes of Native Americans. The wetland, water, and Native American heritage is reflected in the word Necedah, a Ho-Chunk word meaning "land of yellow waters."

Europeans first settled the Refuge area in the early 1700s; their activities consisted primarily of logging. Farming was attempted later, which necessitated draining much of the water that had characterized the area in the past. By the late 1800s, the area was extensively ditched, though farming continued to be difficult because of the short growing season, the poor soil conditions, and the cost of maintaining the extensive ditch system. These factors came to a head in the early 1930s when a series of intense fires ruined the crops and soils, which ultimately caused the abandonment of many area farmsteads. Using legislation intended for economic relief, President Franklin D. Roosevelt created the Refuge in 1939 "as a refuge and breeding ground for migratory birds and other wildlife."

Today the Necedah National Wildlife Refuge consists of 43,656 acres, and is the largest refuge in Wisconsin. The ditch system used in the past to drain the wetlands is now used for enhancing the area for wildlife. Water continues to be important, not only to the Refuge, but also to nearby State of Wisconsin wildlife refuges, cranberry beds, and vegetable agriculture surrounding the Refuge. The goals of these various activities can compete with each other, and the use of water will likely always be a topic of discussion in the Refuge area.

Where Does The Water On The Refuge Come From? Where Does It Go?

In order to manage the NNWR for all uses, the sources and sinks of water must be known. This Fact Sheet gives a brief summary of the various components, then describes in more detail how we calculated where the water on the NNWR comes from, and where it goes. We express these yearly amounts of water in terms of acre-feet, or the number of acres that would be covered by one foot of water.

On average, approximately 85 percent of the water entering the Refuge comes directly from precipitation, either as rain or snow (table 1 and fig. 2a). Streams that flow into the Refuge contribute about 13 percent of the water, while ground-water flow into the Refuge accounts for only 2 percent of the

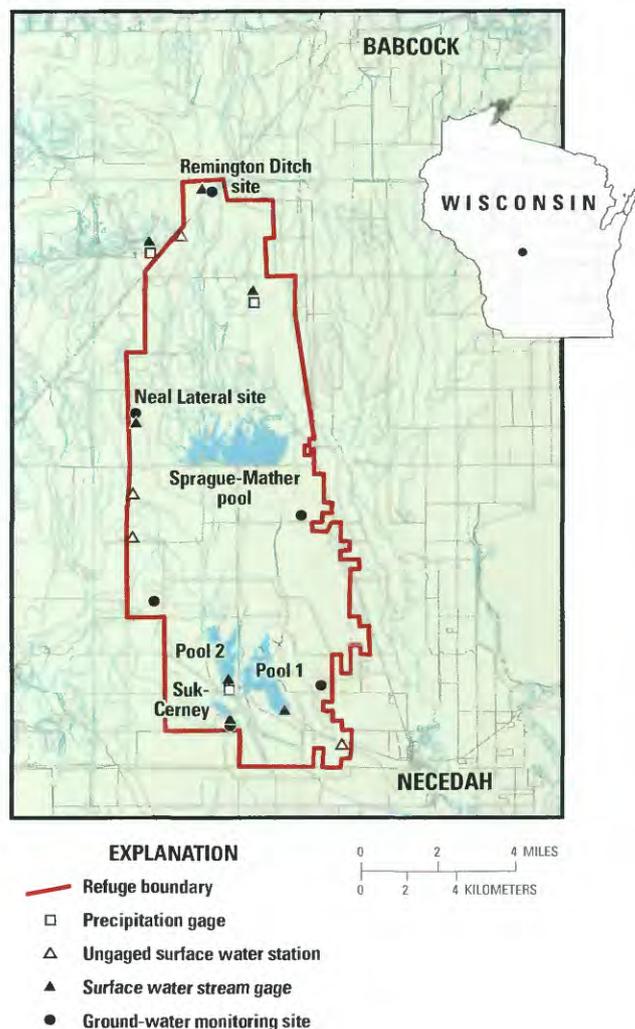


Figure 1. Location of Necedah National Wildlife Refuge with monitoring locations, 1998–99.

water—due largely to the interception of ground water by the extensive drainage networks surrounding the Refuge.

Of the water leaving the Refuge, about 62 percent is lost to evaporation from the pools or transpiration of water vapor back to the atmosphere from plants (table 1 and fig. 2b). Surface-water outflows from the Refuge, mostly through Rynearson Pools 1 and 2 and Suk-Cerney Pool, constitute about 36 percent of the total outflows; ground-water flows out of the Refuge are about 2 percent of the total annual outflows. This small amount of ground-water outflow, along with larger surface water outflows, demonstrates the efficiency of the extensive drainage network within the Refuge boundaries!

Water Budget of the Refuge

The “water budget” of the Refuge is much like a household budget or bank account balance. If the additions (inflows) are larger than the subtractions (outflows), the water levels rise the same as the increases in a bank account balance. Similar to other budgets, water budgets can be calculated for different periods, such as a month or a year. In this study, the data used to characterize the surface-water and ground-water flows through the Refuge were collected from May 1998 until April 1999.

Table 1. Summary of water sources and sinks for the NNWR (May 1998–April 1999)

| Water sources | Annual flow (acre-ft) |
|--|-----------------------|
| Precipitation | 118,700 |
| Surface water inflow | 19,600 |
| Ground water inflow | 2,300 |
| Total water in | 140,600 |
| Water sinks | Annual flow (acre-ft) |
| Evapotranspiration loss | 85,400 |
| Surface water outflow | 51,500 |
| Ground water outflow | 2,700 |
| Total water out | 139,600 |
| Change in storage (water inflow – water outflow) | 1,000 |
| Percent of water inflow | 0.7 |

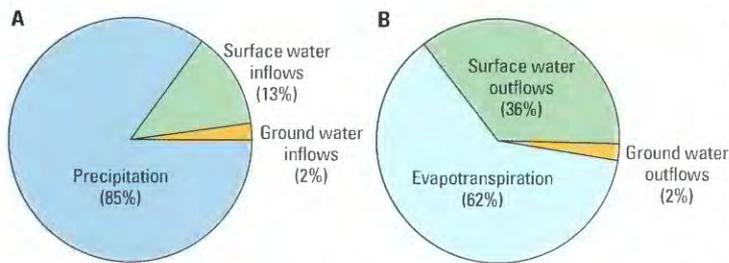


Figure 2. (A) Sources of water entering the Refuge annually (as percentage of total inflow); (B) Losses of water leaving the Refuge annually (as a percentage of total outflow).

The hydrologic budget of the Refuge can be described by additions and subtractions of water, and expressed by the following equation:

$$\Delta S = P + SW_{in} + GW_{in} - ET - SW_{out} - Gw_{out}$$

Where:

ΔS is the change in water stored on the Refuge,

P is precipitation falling directly on the Refuge,

SW_{in} is surface-water flow into the Refuge from streams and overland flow,

GW_{in} is ground-water seepage into the Refuge,

ET is water evapotranspired from the Refuge,

SW_{out} is the surface-water outflow from the Refuge, and

Gw_{out} is ground-water seepage out of the Refuge.

The difference between water inflows and water outflows at the end of the year of data collection was close to that measured at the start of the study (table 1). Therefore we assumed that the amount of water stored on the Refuge did not change during our study. The remaining components of the annual water budget are described in more detail below.

Precipitation

Rainfall was measured by automatic recording rain gages at 3 sites on the Refuge (fig. 1). Two of the rain gages, RG-1 at East Branch Spencer Robinson Creek and RG-2 at Meadow Valley Outlet, were in the northern part of the Refuge, and RG-3 at Pool 2 Outlet was in the southern part of the Refuge. Data from three rain gages were supplemented by data from the National Oceanic and Atmospheric Administration (NOAA) weather station at Necedah, Wisconsin, approximately 5 miles southeast of the Refuge. Precipitation on the northern half of the Refuge was calculated as the average precipitation measured at RG-1 and RG-2. Precipitation on the southern half of the Refuge was assumed to equal the average of precipitation at RG-3 and the NOAA weather station. The recording gages measured only rainfall during warmer-than-freezing air temperatures—not freezing rain, sleet, or snow. Hence, data from the recording gages was not available for the “frozen-precipitation period”, which was defined for this study as November 15, 1998 through March 15, 1999. Precipitation on the Refuge from November 15, 1998 through March 15, 1999 was assumed to equal that measured at the NOAA weather station.

Rainfall during the period of non-frozen precipitation was greater in the southern part than in the northern part of the Refuge: the total precipitation during the non-freezing part of the year was 30.5 inches in the south and 27.8 inches in the north. Precipitation at the NOAA weather station during the November 16, 1998 – March 15, 1999 frozen precipitation period was 3.5 inches. Average precipitation on the entire Refuge during the monitoring year (May 1, 1998 – April 30, 1999) was 32.6 inches; this value is near the long-term average annual precipitation at the NOAA weather station (31.5 inches).

Evaporation and Transpiration

Water is lost to the atmosphere by two processes: evaporation and transpiration. Evaporation is water lost to the atmosphere from open-water surfaces such as lakes and streams. Transpiration is the water lost to the atmosphere through vegetation pathways. We often combine these mechanisms into “evapotranspiration”—the total loss of water to the atmosphere from an area. This quantity can be defined as the sum of evaporation from free water surfaces, moist soil, and consumptive use of water by vegetation.

About 7 percent of the Refuge area is open water. Evaporation from these open-water surfaces was estimated to be about 28 inches annually, as determined from a regional map of average annual lake evaporation (Kohler and others, 1959). The other components of evapotranspiration are difficult and expensive to measure directly. Therefore we assumed that overland flow was minimal due to flat topography and permeable soils, and estimated that annual evapotranspiration from upland and marsh areas of the Refuge equaled precipitation minus ground-water recharge. From ground-water modeling of the Refuge (discussed below in “Ground-Water Flows”), annual recharge was estimated to be 9.5 inches. Hence, evapotranspiration was 32.6 inches (precipitation) minus 9.5 inches (ground-water recharge), or 23.1 inches. This value agrees well with the findings of Weeks and Strangland (1971), who reported evapotranspiration values for nearby agricultural areas ranging from 15 to 20 inches per year, with higher rates expected in areas containing water-tolerant vegetation.

Surface-Water Flows

Measurable quantities of water enter and leave the Refuge as surface flow in several ditches. Flow in four main inflowing ditches and three main outflowing ditches was monitored continuously during this study (fig. 1). These seven monitoring sites were situated at U.S. Fish and Wildlife Service (FWS) hydraulic control structures. Instrumentation was installed to measure water level (stage) continuously upstream of these structures. Through the use of the continuous stage record and stage-discharge relations determined for various gate-opening configurations at these structures, a continuous record of flow was calculated. In addition to the continuous-flow monitoring sites, flow was measured intermittently at four ditches, three flowing into the



Accurate surface water flows require sophisticated techniques and equipment. Continuous measurements of stream level (or stage) are related to periodic measurements of flow (or discharge). This relation allows calculation of stream flow for all levels of stream stage.

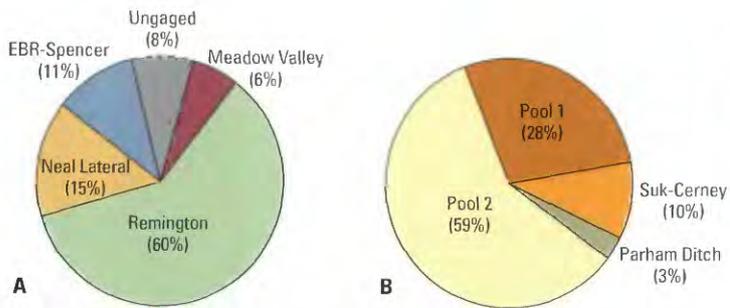


Figure 3. (A) Relative contributions from streams that (A) flow into the NNWR; and (B) flow out of the NNWR during the period May 1998–April 1999.

Refuge (Johnson, Avery, and Bewick laterals), and one (Parham Ditch) flowing out of the Refuge (fig. 1). A continuous record of flow at these four sites was estimated by an analysis of ungaged/gaged watershed area ratios in conjunction with the intermittent instantaneous discharge measurement data. More information on surface-water flows for the period of study can be found in Holmstrom and others (1999 and 2000).

Remington Ditch was the largest inflowing stream, contributing 60 percent of the surface water flow into the Refuge (fig. 3a). This flow, however, is just 8% of the total water flow into the Refuge. Neal Lateral, East Branch Spencer Robinson Creek, and Meadow Valley Flowage Outlet contributed 15, 11, and 6 percent, respectively, of surface flow into the Refuge. The combined flow from the three small ungaged watersheds that flow into the Refuge from the west accounted for 8 percent of the surface inflow to the Refuge (fig. 3a).

Rynearson Pool 2 Outlet was the most important outflowing stream for the Refuge system (fig. 3b). It conveyed 59 percent of the surface-water flow from the Refuge. Rynearson Pool-1 and Suk-Cerney Outlets accounted for 28 and 10 percent, respectively, of the surface flow from the Refuge. Flow from the Refuge through Parham Ditch (the ungaged, out-flowing ditch) accounted for 3 percent of the total outflow from the Refuge.

Ground-Water Flows

The ground-water system can be thought of as a large, underground sponge where subsurface water fills voids. The top of the ground-water system is called the water table, which can be simply defined as the water level that would be found in a hole dug into the ground. Water-table levels were measured at six locations around the Refuge (fig. 1) during the non-freezing period using automatic recorders. Water levels around the Refuge can vary substantially throughout the year (fig. 4) as additions to the ground water (e.g., snowmelt and rain) and losses from the ground water (draining of the subsurface by the ditch system or that lost by plant transpiration) occur. During times that the inputs to the ground-water system are larger than the outputs—such as occurred during late June, 1998—the ground-water levels

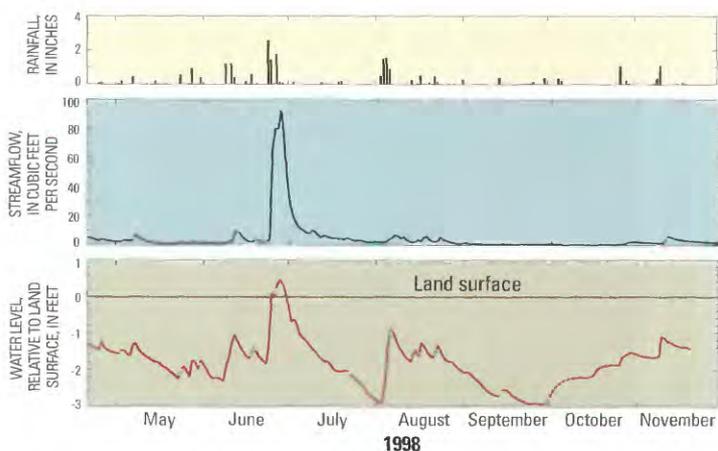


Figure 4. Precipitation, streamflow, and ground-water level for the Neal Lateral site.

rise. When the losses from ground water are larger than the additions, the water levels drop (for example, in July and September, 1998). Generally, the water table is within a few feet of the land surface throughout much of the Refuge area, but its level can vary more than 3 feet during the growing season.

Measuring how much ground water flows into an area and determining where that water originates can be difficult, so ground-water investigators commonly use mathematical models to simulate a simplified version of the natural system on a computer. The computer code relies on two basic principles to perform this simulation. The first is that water flows “downhill”, or more exactly, from areas of high potential to areas of low potential. The second principle is that water cannot be created or destroyed, thus what flows into a system either has to flow out or is stored in the system (which is reflected by changes in water levels). Using these principles, as well as information about site geology, locations of streams, and wetlands in the area being studied, the natural world is simplified and represented in a mathematical model. It should be noted that, while seemingly simple in principle and operation, modeling of ground water can be complex due to uncertainty in important model inputs such as material in the subsurface, timing of water additions and subtractions, and the effects of poorly constrained model inputs such as plant transpiration.

A mathematical model of the ground-water flow in the Refuge area was constructed using the computer program GFLOW (Haitjema, 1995). The model inputs included such factors as the amount of rain and snow that “recharges” the ground-water system (that is, the amount of precipitation minus the amount of runoff to streams and removed by plant uptake). In addition, the locations of streams, ditches, and pools in the Refuge area were entered into the model. The model was run using the average estimated recharge, and the output (the simulated water-table levels and flows into the surface-water streams) was compared to the actual average water table levels (Spring 1998 – September 1998) and stream flows measured during the study period (Spring 1998 – Spring 1999). Using a trial-and-error approach, the various model inputs were varied until the “modeled world” closely approximated the average conditions of the “real world”. Although water levels varied more than 3 feet during the period of measurement, the simulated water levels were, on average, within 8 inches of the average ground-water levels measured at the six sites. Average stream flows simulated by the model were also close to those measured on the Refuge (fig. 5).

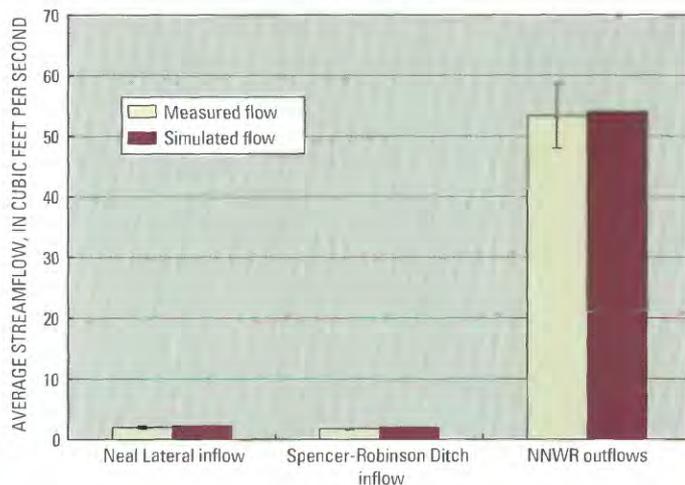
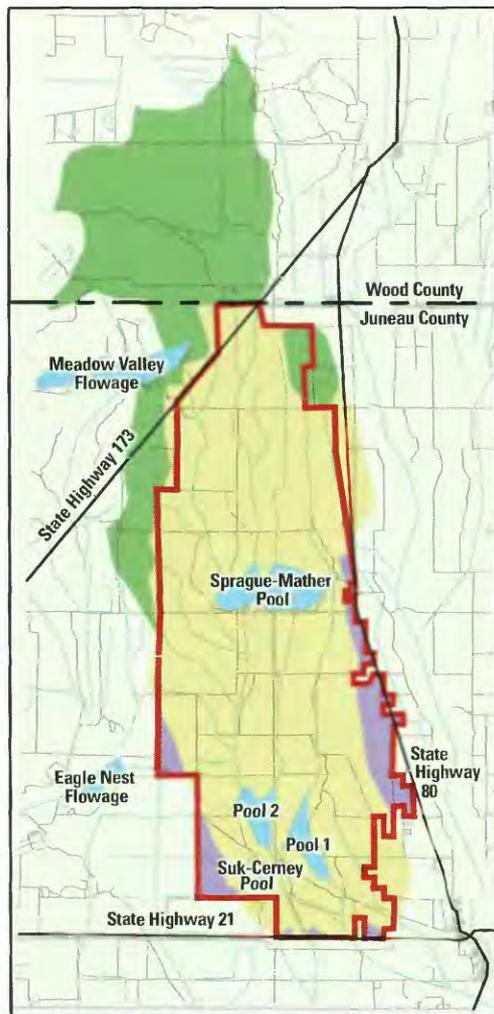


Figure 5. Ground-water flow model results showing the comparison of measured stream baseflow to flow simulated by the computer model. A 10 percent error bar is shown around measured data to reflect measurement uncertainty.

Once the model is constructed, it can be used to trace mathematical particles of water to see where the ground water goes (if we track forward in time) or where it came from (if we track backward in time). This approach was used to define the area around the Refuge that supplies ground water to the wetlands, ditches, and pools on the Refuge (fig. 6). Areas where ground water moves out of the Refuge (shown in purple in fig. 6) constitute a small portion of the Refuge and demonstrate the strong effect that the surface-water drainage systems have on ground-water flow within the Refuge. The area



- EXPLANATION**
- Ground water captured by inflowing tributaries
 - Ground water captured by refuge ditches
 - Ground water flowing out of refuge
 - Hydrologic feature
 - Refuge boundary
 - Secondary road

Model information:

Horizontal hydraulic conductivity = 7.2 ft/d

Ground water recharge = 9.5 in./yr

Aquifer thickness = approx. 260 ft.

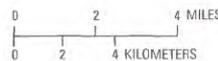


Figure 6. Results of ground-water flow simulations showing areas where ground water and surface water originate and areas where ground water flows out of the Refuge.



Large control structures manipulate the amounts of water leaving the Refuge. Changes in operation of the structure can drastically change water levels and complicate relations of water level stage and discharge.



Remington Ditch, located on the northern boundary of the Refuge, is the most important surface water inflow in the water budget. The flow is much smaller, however, than the amount of water the Refuge gained from rain and snow precipitation.

where ground water is captured by the ditches and pools on the Refuge (the yellow areas in fig. 6) approximately coincides with the boundaries of the Refuge—indicating that the Refuge can, for the most part, control the quality of its ground water by using good land-use practices within the Refuge boundary. This is not the case, however, for the quality of water in the tributaries that flow into the Refuge. These tributaries (located north and northwest of the Refuge) capture substantial amounts of water from outside the Refuge boundaries: thus, their water quality will depend on the land-use practices conducted in the green area in figure 6. The model simulations estimate that it can take from tens to hundreds of years for the ground water to move from the area where it enters the ground to the stream where it ends up. This “lag time” between changes on the land surface and the time for these changes to be reflected at the streams can make assessing the effects of changing land use difficult.

Acknowledgments

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