An Evaluation of Groundwater Flooding West of Crex Meadows with Recommendations

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A report to the Wisconsin Department of Natural Resources

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Table of Contents

Table of Figures

Table of Tables

Executive Summary

Groundwater flooding and poor well-water quality (high iron, manganese, and tannins) are an issue for residents and property owners in the West Marshland Concern Area ("WMCA"), located west of the Wisconsin Department of Natural Resources (WIDNR) Crex Meadows Wildlife Area ("Crex"). Some residents and property owners hypothesize that Crex water management, particularly water impounded in shallow flowages, is the cause.

My task was to evaluate expressed concerns and available data and reports and to render an opinion as to the role Crex flowages might have in causing or exacerbating groundwater flooding in the 2-mile by 3-mile WMCA. For this evaluation, I compiled 38 statements under 6 themes gleaned from materials assembled by concerned citizens, testimony expressed at Natural Resources Board and other public meetings, and a meeting among concerned citizens Mr. Duke Tucker and Ms. Kerri Harter, several WIDNR staff, and myself. At my request, Department staff collected certain elevation and stream discharge data that were helpful in this evaluation.

Background

The Crex Meadows Wildlife Area ("Crex") is a 30,000-acre property of wetlands, brush prairies, and forests lying on a level landscape in western Burnett County. Open water and naturally occurring wetlands and poorly drained soils characterize much of Crex. The WMCA topography is level to gently rolling, and slopes downward to the west before nearing the St. Croix River. The WMCA depth to groundwater ranges from 0 to about 15 feet below land surface, and mapped wetlands are not uncommon.

Groundwater flooding

Groundwater flooding is the condition where groundwater levels rise and inundate land and structures. Its usual cause is greater than typical precipitation amounts during a period of years. Over the past decade or so, a plethora of Wisconsin groundwater flooding occurrences have come to agency and public attention with no apparent cause other than increased precipitation. But groundwater rise may also be caused by hydrologic alterations, such as impounding water behind a dam.

Concerned citizen statement themes

1. Groundwater flooding affects an area that extends westward of Dike 6 and Erickson flowages for 2.2 or 3 miles. Flooding arises almost instantaneously after water levels are raised in those flowages and dissipates just as quickly when water levels in flowages are lowered.

2. The USGS 2019 study (Haserodt and Fienen 2022) was inadequate and its conclusions about flowage effects on groundwater levels are not valid.

3. Multiple flowages cause a groundwater rise across a large area, with flowpaths that converge on the property of a Crex neighbor ("Crex neighbor") located along County Rd F west of Erickson flowage, according to a May 18, 2023 handout provided by that neighbor.

4. Concerned citizens recommend that WIDNR take certain actions to alleviate water concerns, including lowering flowage levels consistent with what some believe are "natural" groundwater levels, as inferred from 1930s-era data and modern-day groundwater gradients.

5. Well water quality deteriorates when flowages are raised, with increased levels of iron, manganese, and tannins. The deterioration is rapidly or instantaneously coincident with flowage level rises.

6. Diverting water for flood protection from Dike 1 flowage and into the Reed Lake Marsh system has flooding implications for the area west of Crex.

Findings

Finding: Increasing precipitation trends are a sole or partial cause of groundwater flooding in the WMCA.

Precipitation in the Crex area has been rising for 60+ years, but the last decade or so has been particularly wet. Years 2010-2019 averaged 4.3 inches per year more than normal, or an equivalent of an extra 1.6 years' worth of precipitation over 10 years; they encompass four of the five wettest years in the Grantsburg record. Groundwater levels in the vicinity (but sufficiently distant so as not to be plausibly Crex-affected) trend with the long-term precipitation record. Groundwater levels have been rising since the 1930s and especially since 2009 and were at record highs in 2017-2020.

Finding: The 2019 USGS study is sound and has important implications.

The 2019 USGS study (Haserodt and Fienen 2021) focused on flooding in the WMCA potentially due to Dike 6 and Erickson flowages. The most significant findings include:

1. Detectable groundwater level change due to change in flowage levels was "… of minimal spatial extent and likely limited to areas very close to the flowages within the time periods studied."

2. "*There were no detectable responses observed in wells outside of the Crex property…*" [emphasis added] only about 1,500 ft away.

3. "It is possible that during a longer [study] period, the effects of flowage water-level changes could propagate out farther than those observed in this study."

4. While the study <u>qualitatively</u> discerned that the flowages likely affected groundwater levels immediately adjacent to the flowages, the <u>flowage effects were too small to be quantified</u>.

5. Water transmission ("leakage") between flowages and aquifer is restricted, and the flowages may be "perched" at least during parts of the year.

6. Hydraulic gradients near the south part of Dike 6 flowage and near Erickson flowage mostly indicated flow <u>into</u> Crex during the study period.

Finding: 1930s water levels are a poor indicator of "natural" conditions at which current levels should be maintained.

Concerned citizens have advocated that groundwater elevations and flowage levels should be managed at "natural" levels, which they assert are represented by 1930s observations. (I put aside that a "natural" level is not a single number because levels rise and fall naturally with rising and falling precipitation amounts.) The 1930s are a flawed period to benchmark "natural" water levels as precipitation then was the lowest on record and would produce historically low groundwater levels. 1930s water levels are too low to be representative of modern "natural" conditions, even for modern drought periods.

Finding: Concerned citizen hypotheses about how flowages cause groundwater flooding rely on misguided hydrologic concepts and physical impossibilities.

Concerned citizen claims about the amount and rate of groundwater flooding following a flowage water level rise rely on assertions that (1) water transmission from flowages to aquifer is unrestricted and (2) hydraulic gradients are "fixed" from the flowages through the groundwater flow system to the groundwater discharge.

Surface waters in general are not capable of unrestricted transmission of water to aquifers, i.e., a low-permeability layer of some sort almost always restricts transmission. The 2019 USGS study demonstrated that water transfer from studied flowages to the aquifer was quite restricted.

Concerned citizens seem to have a misimpression about how hydraulic gradients work. In their representations, gradients are the control on water levels in an area. Gradients are envisioned as a sort of rigid, fixed thing on a landscape, such that if part of it rises, like the level of a flowage, the entire flow system must also rise. The reality is that gradients do not control water levels this way. When a surface water discharges or "leaks" to an aquifer, it is manifested as a steep water table rise at the surface water's edge that drops off rapidly with distance.

In addition, physical constraints preclude such a hypothesized rapid transmission of groundwater and widespread water level rise. Huge amounts of water would be needed to initially raise water levels to the hypothesized state and then maintain them there, and this much water is not credibly available, even during flooding conditions. Even if sufficient water were available, the aquifer would need to be some thousands of times more permeable or have hydraulic gradients 50 times greater than what actually prevails.

Finding: Flow paths from multiple flowages likely do not follow the Crex neighbor's hypothesized route; flowages are not the likely cause of ponding on his property.

The Crex neighbor bases assertions of groundwater flow from flowages to his property on "apparent gradients" (my terminology) that he calculated from flowages to a test well there. He concluded that the apparent gradients represent hydraulic gradients, and thus indicate to him that groundwater flows from the flowages, travels westward across County Rd F, and then "hooks" back east across his property before discharging near Erickson flowage and causing ponding on his property.

(Again, leakage from flowages to the aquifer has already been shown to be small and incapable of raising groundwater levels for even minor distances.)

The Crex neighbor's apparent gradients are not representative of actual hydraulic gradients in the direction of groundwater flow. Steeper gradients abound between the flowages and nearby potential groundwater sinks, indicating more likely groundwater flow paths than what the Crex neighbor proposes, and sinks that would likely intercept leakage from flowages, should it exist.

Finally, shallow groundwater gradients in the Crex neighbor's vicinity, and thus groundwater flow, more frequently trend west to east, i.e., from the neighbor's vicinity into Crex, rather than the hypothesized east to west and back east again.

Finding: Dike 1 water diversion to the Reed Lake system is unlikely to contribute to WMCA flooding.

The distance from the Reed Lake system to the WMCA is large, about 5.5 miles, compared to other potential groundwater sinks in the Reed Lake vicinity. Iron Creek, which drains the Reed Lake system, is likely an effective groundwater sink if the Reed Lake system were to substantially discharge to groundwater. In addition, the Reed Lake system is less than three miles to the St. Croix River where a steep hydraulic gradient (23 feet per mile) prevails, making it a more likely groundwater discharge path than the WMCA.

Finding: Too little information is available regarding episodic poor well-water quality and no explanatory mechanisms indicate a flowage cause is likely.

Concerned citizens state that well water quality in the WMCA deteriorates (with increased levels of iron, manganese, and tannins) during groundwater flooding periods brought about by flowage level rise, and that the deterioration is rapid or instantaneous. Iron and manganese arise from reducing conditions (i.e., low dissolved oxygen) often brought about by water percolating through wetlands or buried organic deposits in an aquifer. Tannins arise from the same sources. I am informed by limited 1980s survey data, area residents, and Burnett County staff that iron, manganese, and tannins in well water are not uncommon through much of the Town of West Marshland and other locales through Burnett County.

Data to back claims about the timing and magnitude of changing well-water quality seems lacking. Further, I am at a loss as to what mechanism would cause the flowages to rapidly cause a water quality change across the WMCA, especially given that evidence suggests the flowages have small effect on groundwater levels and flow patterns.

Conclusions

I did not see evidence that ties groundwater flooding in the WMCA to Crex flowage management, but evidence does exist indicating that the flowages are not the cause of flooding. Groundwater rise in the WMCA vicinity has certainly been driven by increasing precipitation over decades; a secondary cause, if one exists, remains elusive. Regarding episodic well water quality problems and their causes, the phenomenon is not well documented and lacks a credible mechanism tying it to flowages.

I certainly do not believe that the concerned citizens are imagining a groundwater flooding problem, nor that they are insincere in their belief that Crex is the cause. But if the flowages are not the cause, what is the explanation for how flooding occurs at the same time as certain Crex operations?

I speculate that the large multi-decadal increase in precipitation has raised groundwater levels and left the WMCA "primed" for flooding. Thus, it takes little to cause groundwater to rise to flooding conditions when triggered by snowmelt, runoff, and high precipitation periods – the same conditions needed to raise flowage water levels.

Accordingly I am suggesting that the timing of flooding is correlated with the timing of flowage filling, but "correlation does not imply causation," i.e., these things simply are happening at the same time.

Recommendations

I see no purpose in adopting drastic proposals suggested for flowage management, such as managing for 1930s groundwater levels or dredging, as there is no evidence that the flowages are a cause of groundwater flooding nor that proposed measures would obviate flooding in the WMCA.

It seems to me that the Department has two reasonable and justifiable responses: (1) no further action, or (2) monitoring conditions over time to further evaluate flowage-groundwater interactions. Pursuing monitoring requires a well thought-out consideration of staff and financial commitment, and whether concerned citizens will accept the premise and outcome of a monitoring program.

I. Background

Context, Scope, Concerned citizen statement summary, Groundwater flooding

I was tasked with examining citizen concerns regarding groundwater flooding and poor well water quality in an approximately 2-mile by 3-mile area (“West Marshland Concern Area” or WMCA) west of the Crex Meadows Wildlife Area (Figure 1) in the Town of West Marshland, Burnett County. Those concerns include flooding of roads, pastures, woods, and residential crawlspaces, and well water containing high levels of iron, manganese, and dissolved organics (tannins). Some concerned citizens blame water management within Crex Meadows, particularly its western flowages where water is seasonally impounded for landscape and wildlife management, hunting, trapping, and passive recreation.

The Crex Meadows Wildlife Area (“Crex”) is a 30,000-acre property of wetlands, brush prairies, and forests lying on a level landscape in western Burnett County. Open water, wetlands, and poorly drained soils characterize much of Crex (Appendix A).[1] The WMCA surface topography rises slightly from west of Dike 6 and Erickson flowages and then declines gently for about 2.5 miles before declining steeply near the St. Croix River (Figure 1). Mapped wetlands are not uncommon in the WMCA, appearing to me sometimes as extensions of Crex wetlands or features in closed depressions (Figure 1 and Appendix A).

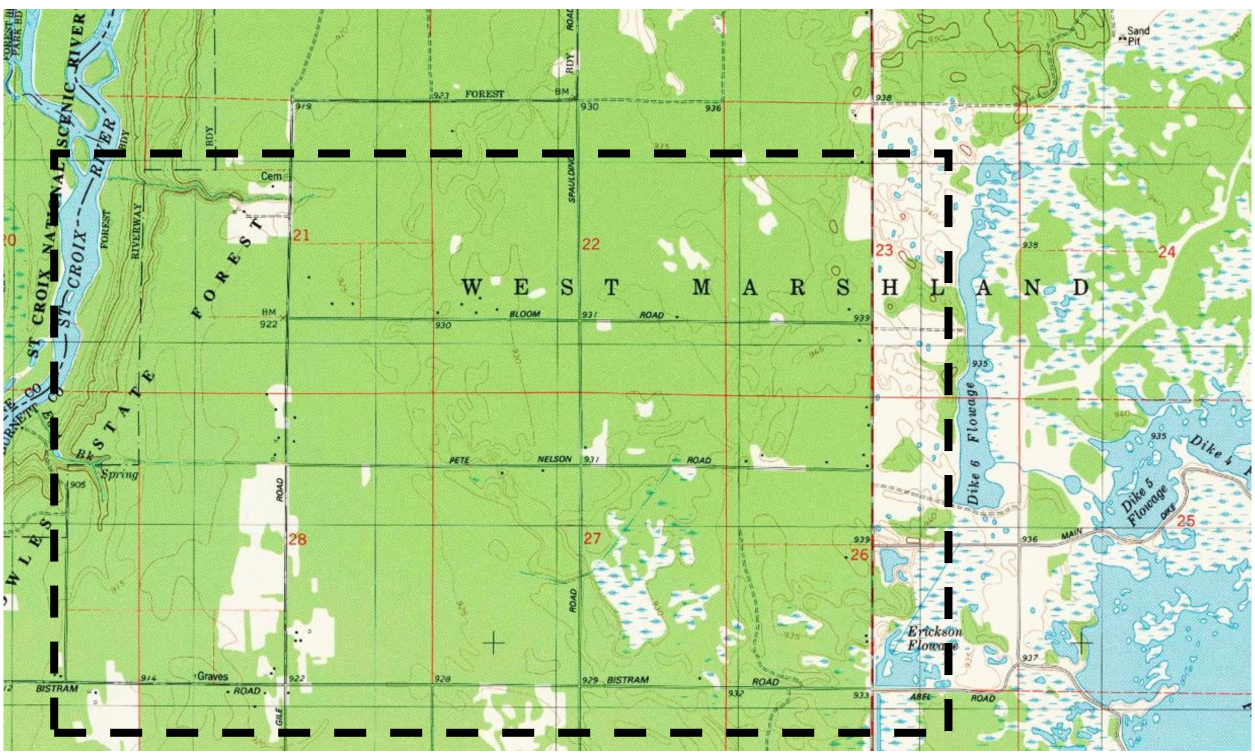


Figure 1. Approximate West Marshland Concern Area west of Crex Meadows Wildlife Area. (USGS 1:24,000 topographic map, Grantsburg quadrangle, 1982).

[1] The wetlands and poorly drained soils are a natural feature and not the result of flowage management.

The regional water table is mapped at about 935 feet AMSL in western Crex and gently falls westerly to 900 ft about 0.5 miles east of the St. Croix (Muldoon and Dahl 1998; Appendix A). The water table depth ranges from 0 to about 15 feet.

Groundwater flooding

Groundwater flooding is the condition where groundwater levels rise and inundate land and structures. Its usual cause, in my experience, is greater than typical precipitation amounts over a period of years. Greater precipitation increases groundwater recharge and prompts a rise in the water table (the upper elevation of groundwater) to accommodate greater amounts of water in the aquifer.

Over the past decade or so, a plethora of Wisconsin groundwater flooding occurrences have come to agency and public attention with no apparent cause other than increased precipitation. These are often in the vicinity of surface waters. They include diverse areas around Wisconsin such as Sunset Lake in Portage County, Silver Lake in Waushara, Rollofson Lake in Waupaca, Pigeon Lake in Bayfield, Devil's Lake in Sauk, and Fish and Crystal Lakes in Dane, to name a few. (This is not to say that precipitation-induced groundwater flooding is absent where surface waters are distant.)

But groundwater rise may also be caused by hydrologic alterations, such as impounding water behind a dam. The height and extent of an impoundment-induced rise, as discussed by Haserodt and Fienen in their 2021 Crex report ("2019 USGS study"), depends on land relief, height of water rise in the impoundment, and aquifer properties. An impoundment-induced rise in groundwater level, assuming an adequate impoundment-groundwater connection, would be expected to equal the impoundment level at the impoundment edge, and decline with distance from the impoundment. The 2019 USGS study, quoting Mioduszewski (2011), indicated a 3.3 ft impoundment rise would increase groundwater elevations no farther than a few dozen meters from the impoundment in silty soils. As Crex area soils are likely more permeable than silts, a somewhat more extensive effect would be expected.

An example of a more extreme impoundment-induced rise can be found for the Arrowhead Lake impoundment in Adams County, due to its substantial depth (43 ft) and highly permeable geology. A groundwater flow map for that area (WGNHS 1981) suggests that the impoundment raises groundwater levels discernably up to a half mile from the impoundment. This might be helpful to frame a sort of worst-case scenario relative to the Crex situation.

Concerned citizen statements

For this review I compiled concerned citizen statements garnered from reading their assembled materials, listening to testimony expressed at Natural Resources Board and other public hearings, and participating in a meeting with concerned citizens Mr. Duke Tucker and Ms. Kerri Harter and several WIDNR staff. The resulting 38 statements were organized under six main themes that I consider in this evaluation (Appendix B):

1. Groundwater flooding affects an area that extends westward of Dike 6 and Erickson flowages for 2.2 or 3 miles. Flooding arises almost instantaneously after water levels are raised in those flowages and dissipates just as quickly when water levels in flowages are lowered.

2. The USGS 2019 study (Haserodt and Fienen 2022) was inadequate and its conclusions about flowage effects on groundwater levels are not valid.

3. Multiple flowages cause a groundwater rise across a large area, with flowpaths that converge on the property of a Crex neighbor ("Crex neighbor") located along County Rd F west of Erickson flowage, according to a May 18, 2023 handout provided by that neighbor.

4. Concerned citizens recommend that WIDNR take certain actions to alleviate water concerns, including lowering flowage levels consistent with what some believe are "natural" groundwater levels, as inferred from 1930s-era data and modern-day groundwater gradients.

5. Well water quality deteriorates when flowages are raised, with increased levels of iron, manganese, and tannins. The deterioration is rapidly or instantaneously coincident with flowage level rises.

6. Diverting water for flood protection from Dike 1 flowage and into the Reed Lake Marsh system has flooding implications for the area west of Crex.

I take these statements as sincerely held beliefs assembled according to their observations of local phenomena. Few non-hydrologists, though they may be greatly skilled in professions and trades, have the background needed to collect, organize, and correlate data for a rigorous hydrologic analysis. I recognize that several concerned citizens have immersed themselves in hydrology to explain the conditions they perceived in the WMCA.

II. Increasing precipitation trends are the sole or partial cause of groundwater flooding in the WMCA

Precipitation in the vicinity has been rising for 60 years; groundwater levels mirror this trend.

Precipitation in the Crex area (Grantsburg weather data) has been rising for 60 years (Figure 2), and the last decade or so has been particularly wet: Years 2010-2019 contain four of the five wettest years in the 70-year Grantsburg record, averaging 4.3 inches per year more than normal, or an equivalent of an extra 1.6 years worth of precipitation over 10 years. Years 2020 and 2021 provided a respite from excessive precipitation amounts, being 3-4 inches below the long-term average, but 2022 was again above average, by nearly 3 inches.

Groundwater levels in the Crex vicinity have apparently responded accordingly, judging by the USGS monitoring well at Webster (BT-39/16W/17-0002).[2] The groundwater level record there (Figure 3) mirrors the long-term precipitation record; levels at Webster have been rising since the 1930s and especially since 2009. 2017-2020 levels were at record highs, and though they have declined from that peak (presumably due to lower precipitation in 2020 and 2021), they remain well above the long-term average.

Thus, precipitation and water level trend evidence indicate long-term increasing precipitation is solely or partially the cause of WMCA groundwater flooding.

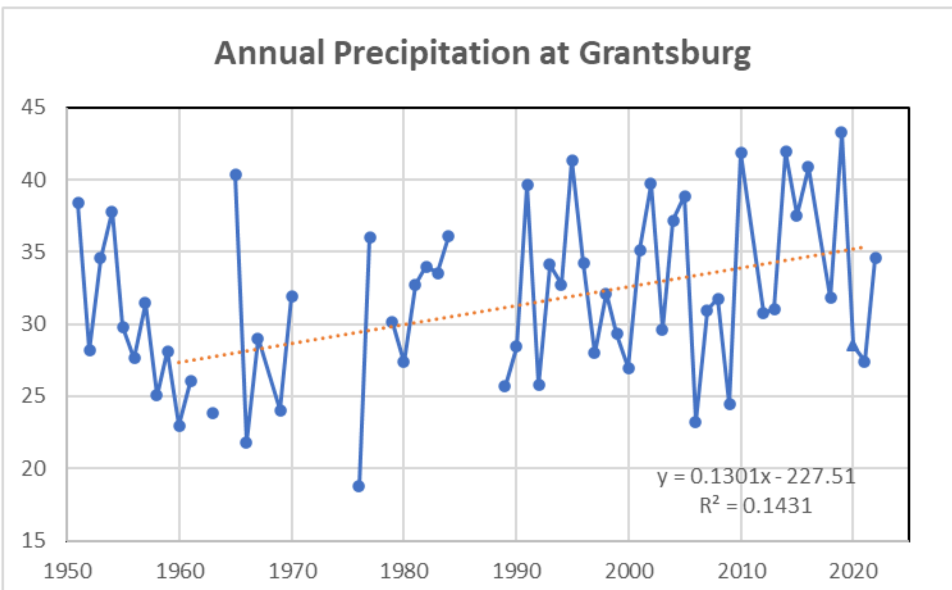


Figure 2. Annual precipitation at Grantsburg, 1951-2022. Note: the 2020 datum was inferred as an average of stations at Luck, Spooner, and Brook Park, as Grantsburg data were not available.

[2] The Webster well is 15 miles east-northeast of Dike 6 Flowage and cannot plausibly be affected by water management at Crex.

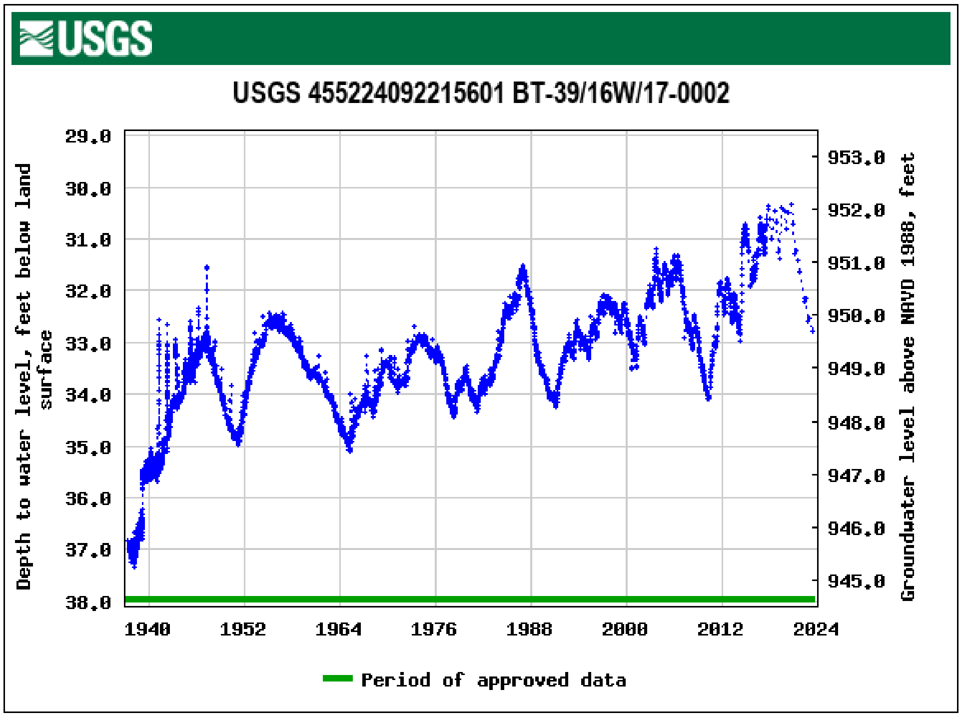


Figure 3. Water levels in USGS monitoring well at Webster, May 1937-April 2023. Water levels hit an 86-year peak in 2020, coincident with a period of historically high precipitation.

III. The 2019 USGS study is sound and has important implications for how the flowages interact with the groundwater flow system

The study indicates flowage effects on groundwater levels are small and constrained to a small area and that water transmission from flowages to aquifer is limited.

Brief description and findings

The 2019 USGS study (Haserodt and Fienen 2021) focused on flooding in the WMCA potentially due to Dike 6 and Erickson flowages. This field study was three months (June-October 2019) with the apparent purpose of "evaluat[ing] if managed water levels in Crex have detectable effects on groundwater elevations outside the property boundary." The study design comprised manipulating flowage water levels and then observing groundwater level responses in 11 monitoring wells located 0 - ~2.3 miles away.

The most significant findings include these:

1. Flowage effects on groundwater levels were "… of minimal spatial extent and likely limited to areas very close to the flowages within the time periods studied."

2. "*There were no detectable responses observed in wells outside of the Crex property…*" [emphases added] only about 1500 ft away.

3. "It is possible that during a longer period, the effects of flowage water-level changes could propagate out farther than those observed in this study."

4. While the study <u>qualitatively</u> discerned that the flowages likely affected groundwater levels immediately adjacent to the flowages, the <u>flowage effects were too small to be quantified,</u> according to one of the authors (Appendix C).

5. Water transmission between the flowages and aquifer is restricted, and flowages may be "perched" (bottom sediments are above aquifer water levels), at least during parts of the year.

6. The gradients of shallow groundwater west of Crex, along County Rd F near the south part of Dike 6 flowage and Erickson flowage, were often west to east, indicating shallow groundwater flow was often from west to east, i.e., into Crex rather than out of Crex.

In brief, the study found groundwater level anomalies immediately adjacent to the test flowages which indicated some sort of detectable flowage-aquifer interaction, but it was too small to quantify and did not extend beyond Crex boundaries. The authors left the door open that a longer observation period might produce an observable flowage effect off site. However, I am dubious that the speculated off-site effect would be quantifiable, given that the effect was unquantifiable at the flowages' edges. The finding that water transmission between flowages and aquifer is restricted becomes important for evaluating claims regarding how fast a water level rise from a flowage can be conducted through the WMCA.

Concerned citizen issues with USGS study

Concerned citizens expressed these issues with the 2019 study, though there could be others:

1. The study was of too short a duration.

2. The study should have taken place during a period when groundwater levels were constant.

3. The study should have taken place at a different time of year.

4. Some sort of discrepancy between the elevation datum used by USGS compared with that used by WIDNR for flowage levels causes some sort of uncertainty that I am not understanding.

5. "Likely" isn't good enough, as in the conclusion that changing flowage levels are "…likely limited to areas very close to the flowages.…"

6. Higher USGS administration, though not the report authors, expressed to the concerned citizens that WIDNR is misusing study conclusions.

I can provide opinion on all matters but (6).

1. The length of the study period, in my opinion, was adequate for the study purpose and design. The authors used a standard type of hydrologic procedure of putting a "stress" on the groundwater system (in this case, manipulating flowage levels) and observing effects (changes in groundwater levels near and far from the flowages).

2. Waiting for a period when groundwater levels are constant is near futile because groundwater levels are always changing in response to precipitation and the lack of precipitation. The authors used a valid approach to assess and separate precipitation-induced groundwater level rise from flowage effects.

3. Time of year is not important to the study design as long as sufficient water is available to carry out the procedure. (I understand that water is insufficient much of the year to raise flowage levels.)

4. Elevation datum discrepancies, if they exist, are not problematic according to one of the study's authors (Haserodt; see Appendix C). I am inclined to believe her.

5. I understand citizens' desire for certainty and their discomfort with the word "likely." However, the word "likely" is commonly used by scientists; rarely will they say something is "certain" or "definite," because good science is always open to revision and some uncertainty always exists. I interpret "likely" in this case to mean "we're reasonably confident, but we leave the door open to the possibility that a longer stress period might propagate effects farther than what we observed."

In brief, I believe the USGS study was a good piece of work and its conclusions sound.

IV. Concerned citizen conceptual model of how Crex flowages cause groundwater flooding

Concerned citizens have proposed a conceptual model for how Crex flowages cause groundwater flooding, but it has inaccuracies that undermine conclusions about flooding.

A "conceptual model" describes how one thinks something works. It might consist of a few words about causes and effects and the proverbial sketch on the back of an envelope. In hydrology pursuits, a conceptual model might be assembled as: water in an area originates as rain, some runs off to streams, some evaporates, some recharges groundwater, and groundwater discharges to streams. Hydrologists might then improve and test the conceptual model by making it quantitative, i.e., adding numerical values (32 inches of rain, of which 2 inches runs off, 20 inches evapotranspires, etc.) and process dynamics (e.g., runoff equations or groundwater flow equations).

My understanding of the concerned citizen conceptual model is demonstrated by their visual (https://www.glgp-plan.com/how-is-flooding-caused), shown in Figure 4. Key elements, stated or implied, seem to be these:

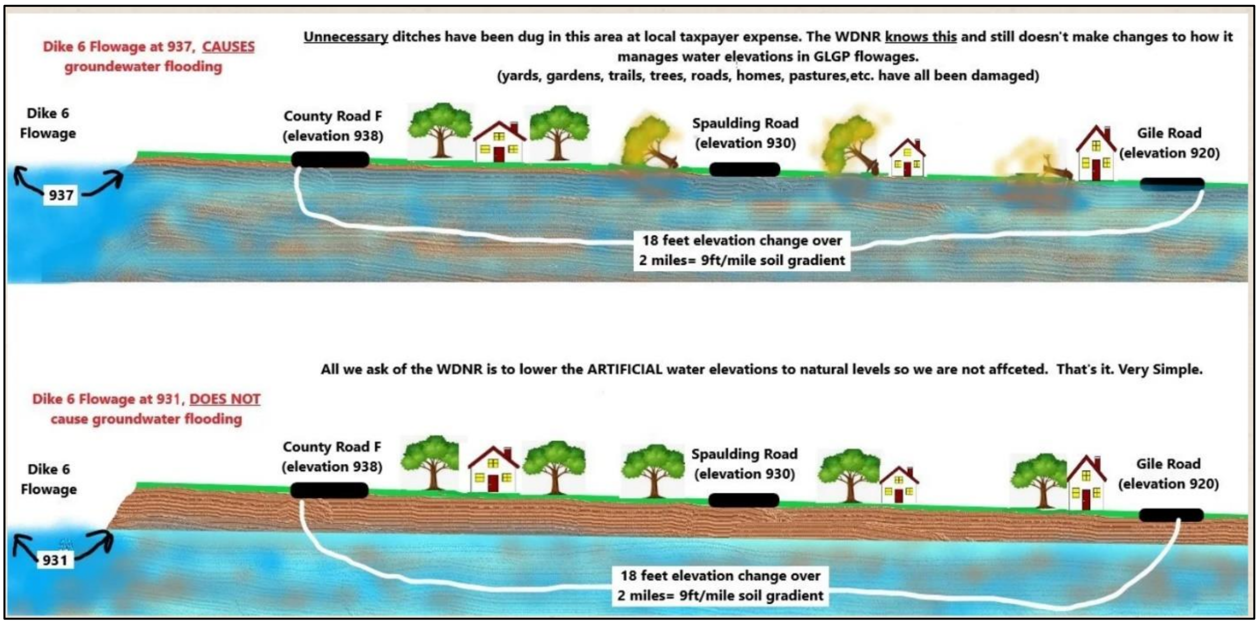


Figure 3. Screen capture of image showing citizen conceptual model for how flowage levels cause groundwater flooding in the WMCA https://ww.glgp-plan.com/how-is-flooding-caused.

1. The flowages (in Figure 4, Dike 6 flowage) are in perfect communication with the aquifer – i.e., no low-permeability sediments at the flowage bottom restrict water transfer, so water may pass instantaneously from flowage to aquifer and aquifer to flowage.

2. A natural groundwater hydraulic gradient exists for the area west of Crex (5-7 feet per mile) and seemingly for other areas too.

3. That natural gradient is constant spatially and somehow enforced at all times.

4. Because of (2) and (3), if a point in the flow system experiences a water level rise or a decline, the area's water table instantaneously rises or declines. ("When flowages are raised up or down...the ground water table moves up & down with the flowages at a downward gradient of 5-7 feet per mile.") Almost like an iron beam attached at one end to a mechanism that moves up and down, forcing the entire beam to move the same way.

5. "The soil [surface] elevation [west of Crex] lowers at a rate of 9 feet per mile, the groundwater elevation is flatter at 5-7 feet per mile … that's why residents are flooded."

6. The flowage-induced groundwater rise affects the area west of Crex to at least Gile Rd or to the St. Croix River.

Problems with this conceptual model

1. Surface water bodies are rarely in perfect communication with an aquifer – some low-permeability sediments almost always exist and restrict aquifer-to-surface water transfer. Even the permeability of the aquifer restricts water transfer. The empirical evidence from the 2019 USGS study (section III) effectively indicates the studied flowages are poorly connected to the aquifer and that water transfer between flowage and aquifer is restricted.

2. Hydraulic gradients are not fixed in the way proposed by the citizen conceptual model, but rather vary spatially and temporally depending on causes that include changing precipitation.

3. Because gradients are not fixed nor constant, the water table throughout the entire area does not rise and fall in unison with changing flowage levels. A water level rise in a flowage would be expected to be accompanied by a steeper groundwater gradient near the flowage that dissipates with distance (see Groundwater Flooding in section I).

4. The surface topography in the WMCA is not quite as simple as represented. Yes, there's a general decline going westward from Crex to the St. Croix, but the general decline masks that there are high and low spots, and I presume it is the low areas that tend toward flooding.

5. It is true that where surface topography intersects groundwater, ponding occurs, but the water table slope and the surface topography slope are not exactly constant as the conceptual model implies.

6. The conceptual model does not explain west to east shallow groundwater gradients along County Rd F near Dike 6 and Erickson flowages that indicate shallow flow there is dominantly into Crex and not the other way around (section III, USGS study finding [6]).

Other problems left unconsidered by the citizen conceptual model and taken up in section V are whether:

1. sufficient water is available to raise and maintain hypothesized water levels, and
2. realistic aquifer parameters would be able to convey such a volume of water at a hypothesized gradient of 5-7 feet per mile.

V. The concerned citizen conceptual model of groundwater flooding is not supported by water availability nor reasonable aquifer properties

Concerned citizen statements about the extent and immediacy of groundwater flooding are not supported by principles of conservation of mass and groundwater flow laws.

Citizen statements assert that groundwater flooding occurs almost instantaneously following water level increases in Dike 6 and Erickson flowages, that the flooding extends westward for either 2.2 miles (Giles Rd. and the distance to USGS well BT-39/19W/28-0982) or 3 miles (the St. Croix River), and when flowage levels are lowered, floodwaters dissipate just as quickly as they rose.

This section evaluates whether the asserted groundwater rise (section IV) is physically possible given water availability (whether sufficient water exists to raise and maintain hypothesized water levels) and the required aquifer characteristics.

For this evaluation, the WMCA west of Dike 6 flowage and its groundwater flow system are approximated as shown in Figure 5. The flow system width (north to south) is 1.2 miles, lengths (east to west) are 2.2 miles, coinciding with the distance to Gile Rd., or 3 miles, the distance to the St. Croix River. An aquifer thickness of 100 feet is assigned, based on a sampling of well construction reports. Two impoundment rises are evaluated, 2 and 6 feet, with 2 feet perhaps being about where levels have been managed in recent times, and 6 feet being that shown in Figure 4. The northern and southern lateral boundaries are treated as impermeable, i.e., they do not leak or receive water from the remainder of the domain.

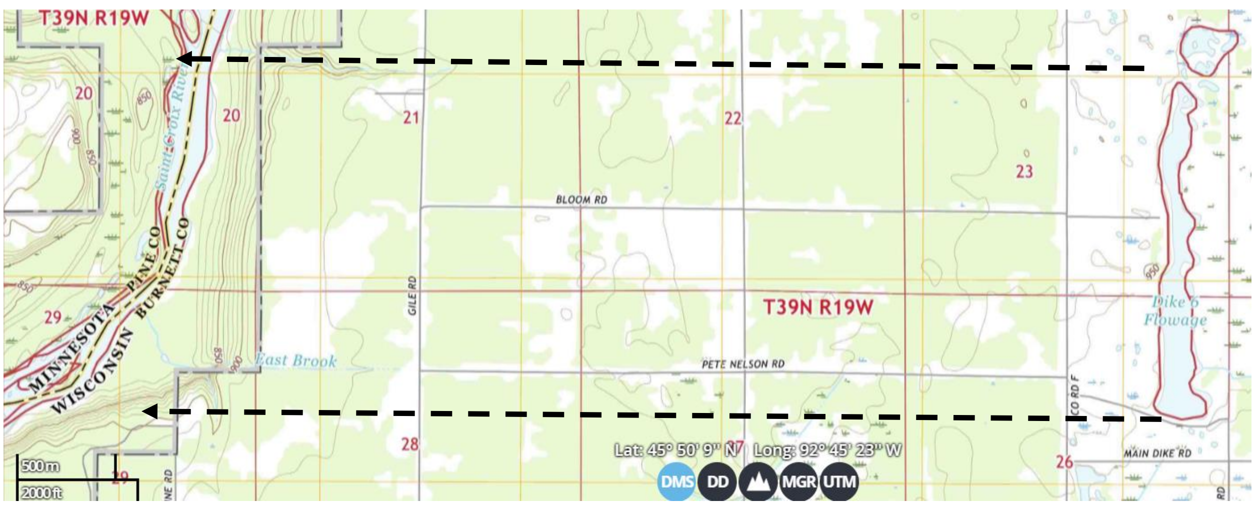


Figure 5. Illustration of simplified groundwater flow model west of Dike 6 flowage. A rectangular groundwater flow system is assumed, originating at Dike 6 flowage and extending to the St. Croix about 3 miles away. The flow system has a width of 1.2 mi.

Water volume required to raise the water table by 2 or 6 feet

The required water volume to raise water levels (V_r) can be calculated as:

$$V_r = (\text{flow system length}) \times (\text{flow system width}) \times (\text{impoundment rise}) \times (\text{aquifer specific yield}).$$

Specific yield is the amount of water rise in the aquifer per unit of water introduced. A value of 0.2 is assumed. The result is that the water required to raise levels through the flow system by 2 or 6 feet amounts to 29 to 120 million cubic feet (Table 1).

Table 1. The amount of water required to initially raise water levels under two scenarios of flow system length and amount of rise.

Flow System Length (mi)	**Flow System Width** (mi)	**Impoundment Rise** (ft)	**Aquifer Specific Yield**	**Required Volume** (million ft^3)
2.2	1.2	2	0.2	29.4
2.2	1.2	6	0.2	88.3
3	1.2	2	0.2	40.1
3	1.2	6	0.2	120.4

Flow rate required to "fill" and maintain hypothesized water levels

The water inflow rate from the flowage to the aquifer needed to fill and maintain hypothesized water levels requires an estimate of "fill time." Concerned citizens contend water rises are "instantaneous," but I will assume 7 days as an approximation. A more rapid fill time would require a greater inflow rate.[3]

Flow rates required to fill and maintain water levels (Table 2) were calculated by dividing required volumes in Table 1 by 7 days. This leads to estimates of flow rates required to raise and maintain hypothesized groundwater flooding levels of 49-199 cubic feet per second (cfs).

This flow of water is not trivial; it is roughly the average flow of the Namekagon River at Leonards, which drains a 126 square mile watershed. By comparison, the watershed area of Dike 6 flowage is on the order of four square miles (estimated by inspection).

Could this much water be available in the Dike 6 flowage system? Certainly, this much water is not routinely available, i.e., during non-runoff periods. Limited Dike 6 low flow data were gathered by WIDNR staff at my request in May and June 2023, revealing inflow rates of 0.12 to 0.67 cfs and outflow rates of 0.3 to 4.0 cfs (Appendix D).

[3] A possibly subtle point is that it is insufficient just to have adequate water for raising the groundwater levels to the hypothesized heights. Water levels need to be continuously replenished by more inflow because groundwater will continually discharge from the aquifer about as fast as it is entering.

What about during high flow periods? With no direct high flow data available, estimates were calculated using statistics at four nearby USGS gages (Appendix D). High flow estimates for Dike 6 flowage revealed that the Q_{01} (flows that are exceeded only 1% of the time) ranged from 11.6 to 35.2 cfs, much smaller than the required flow rates (Table 2).

Table 2. Flow rates required to provide and maintain required hypothesized water levels.

Flow System Length (mi)	**Flow System Width** (mi)	**Impoundment Rise** (ft)	**Required flow rate (Q)** (cfs)
2.2	1.2	2	48.7
2.2	1.2	6	146.0
3	1.2	2	66.4
3	1.2	6	199.1

My judgement is that normal and high flows to Dike 6 flowage are much too small to provide the water needed to raise and maintain hypothesized groundwater levels, even if the flowage and aquifer were sufficiently permeable to allow it.

Aquifer parameters needed to support required flow rates

If sufficient water were available, would an aquifer with reasonable parameters of hydraulic conductivity and hydraulic gradient be able to transmit the required flows (Table 2)?

To answer this question, Darcy's Law, the fundamental relationship of flow rates to hydraulic conductivity and gradient, can be invoked to calculate Q, the "required flow rates" in Table 2.

Q = (K, hydraulic conductivity) x (A, area through which water flows) x (dh/dl, hydraulic gradient)

Hydraulic conductivity (K) is the ability of the aquifer material to transmit water. Hydraulic gradient (dh/dl) is the change in the groundwater elevation over a given length.

In a first case, I back-calculated the hydraulic conductivities (K) required if concerned citizens' estimates of hydraulic gradient (dh/dl = 6 ft/mile) were imposed. In a second case, I back-calculated a hydraulic gradient after imposing a high hydraulic conductivity value. The chosen hydraulic conductivity value was 0.00328 ft/s (0.001 m/s), typical for highly permeable outwash sands and too large for Crex-area geologic materials. The choice of too large a K would produce gradient values more likely to be consistent with citizen hypotheses (6 ft/mile).

I found that either unrealistically high K values or gradient values would be required to transmit this much water (Table 3).

Table 3. K and dh/dl under four scenarios of system length and impoundment rise.

Flow System Length (mi)	**Flow System Width** (mi)	**Impoundment rise** (ft)	**Required flow rate** (cfs)	**K with a fixed dh/dl (gradient)** (ft/s)	**dh/dl(gradient) with a fixed K** (ft/mi)
2.2	1.2	2	48.7	0.068	124
2.2	1.2	6	146.0	0.20	371
3	1.2	2	66.4	0.092	169
3	1.2	6	199.1	0.28	506

In the first case, K values constrained by concerned citizens' fixed gradient of 6 ft/mile ranged 0.068 to 0.28 ft/s (5,800 to 24,000 feet/day), which are at the extreme of all granular geologic materials and likely about 1,000 or more times greater than what predominates at Crex. In the second case, gradient values capable of supporting a high value of K fixed at 0.00328 ft/s ranged 124-506 ft/mile, unreasonably high and in great excess of the concerned citizens' 6 ft/mile estimate.

In summary…

Sufficient water is not available to raise and maintain hypothesized water levels, and realistic hydraulic conductivity and hydraulic gradient values are unable to transmit this much water even if that water were available. I conclude that hypotheses about immediate, or even rapid, groundwater level rise following flowage rise are not physically possible.

VI. A suggested improved conceptual model for flowage-aquifer interaction

A conceptual model that envisions aquifer-flowage interaction as leakage or water transmission controlled by head differences between aquifer and flowage and flowage sediment hydraulic conductivity is proposed.

The conceptual model and hypothesis that the water table west of Crex is controlled by impoundment water level and permanently enforced gradients extending from them is negated by experimental evidence, hydrologic realities, and physical limitations (sections III-V).

A perhaps more helpful conceptual model is to consider the flowage-aquifer system as a surface water body lying above (perched) or intersecting the water table, with leakage occurring from the flowage to the aquifer when flowage levels are higher than the water table, or from the aquifer to the flowage when the water table is higher than flowage levels. If flowages are not perched, leakage is controlled by the 1) hydraulic conductivity of the flowage sediments and 2) difference between the surface water and aquifer heads. If perched, then leakage is controlled by 1) the hydraulic conductivity of the sediments separating the flowage from the aquifer and 2) the head difference between the flowage and the bottom of the low permeability sediment.

This interaction is roughly, though imperfectly, illustrated in Figure 6 for perched conditions, as it lacks a sloping water table. But nonetheless, it conveys the idea that it is the leakage rate from the surface water to the aquifer, not a gradient controlled by the surface water elevation, that creates a groundwater rise, or what is often termed "groundwater mounding." The 2019 USGS study implies that the leakage rate from the flowages is small.

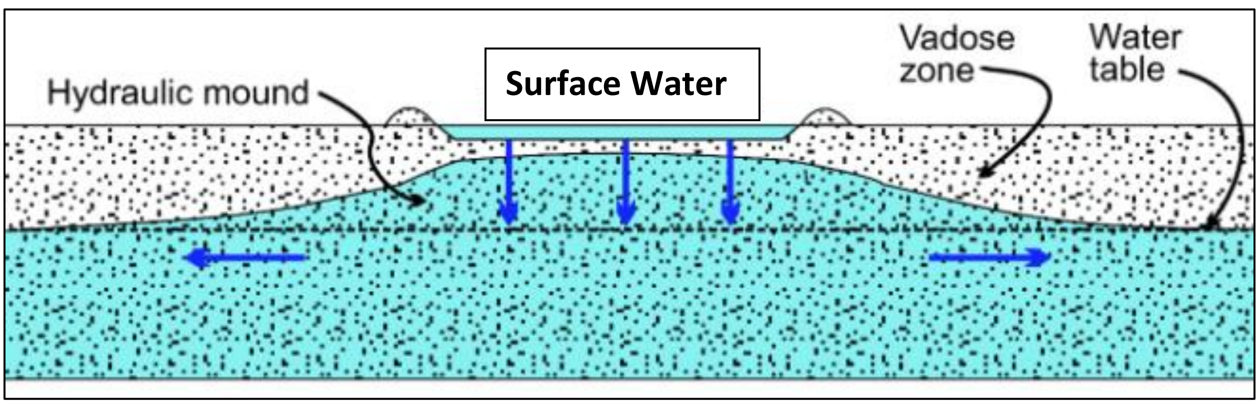


Figure 6. Illustration of leakage from a surface water body to groundwater. (Modified from Maliva 2020.)

VII. Hypothesized flow paths from multiple flowages and the cause of ponding on the Crex neighbor's property

Hypotheses of groundwater movement from flowages to west of County Rd F and as a cause of flooding on the Crex neighbor's property are contraindicated.

Handout distributed May 18, 2023

The Crex neighbor distributed a handout (graphic displayed as Figure 7, entirety in Appendix E) in which he represents water conditions prevailing on May 6, 2022 and these observations:

1. Flowage elevations.
2. The groundwater elevation in a 2" test well on the Crex neighbor's property.
3. Standing water elevations 75 ft south of this test well and also in the vicinity of County Rd F and Bistram/Abel Roads.
4. Calculated "apparent gradients" (my terminology) between the flowages and the Crex neighbor's test well.
5. An assertion that the Crex neighbor's gradients fall within USGS findings.
6. An observation that water runs west to east from the Crex neighbor's property into Dike 9 flowage.
7. Various representations of groundwater "natural elevations" which the Crex neighbor asserts can be inferred from 1930s-era observations.

From which he postulates:

1. Dike 5 and Dike 6 flowages (but not Erickson flowage) are held at elevations that raise the groundwater table, flood his property, and affect his drinking water quality.
2. Groundwater flow paths from Dike 6 flowage, Dike 5 flowage, and perhaps Phantom Lake (the drawing is somewhat ambiguous) result in groundwater flowing westward across County Rd F, and then hooking eastward through the Crex neighbor's property before discharging into Erickson flowage ("Dike 9 flowage").
3. Water levels at which Crex flowages should be managed, inferred from 1930s water level data and modern-day hydraulic gradients, that would preclude flooding on his property.

Evaluation of handout's conclusions

Leakage rates and gradients

The Crex neighbor's conclusion that Dike 5 and Dike 6 flowages are flooding his property relies on assumptions that the flowages have substantial leakage (contraindicated in section IV and V) and that an "apparent gradient" (again, my terminology) he calculates between flowages and his test well indicates groundwater flow from the flowages to the test well. The "apparent gradient" is calculated as the difference between flowage and test well head divided by the distance between them.

A problem exists with the Crex neighbor's "apparent gradients" and his interpretation of them. A hydraulic gradient is the rate of head change per distance in the direction of groundwater flow. It is true that sometimes hydrologists use the term loosely and will calculate "components of the gradient" that represent only partially the direction of groundwater flow. I have to wonder if the Crex neighbor was

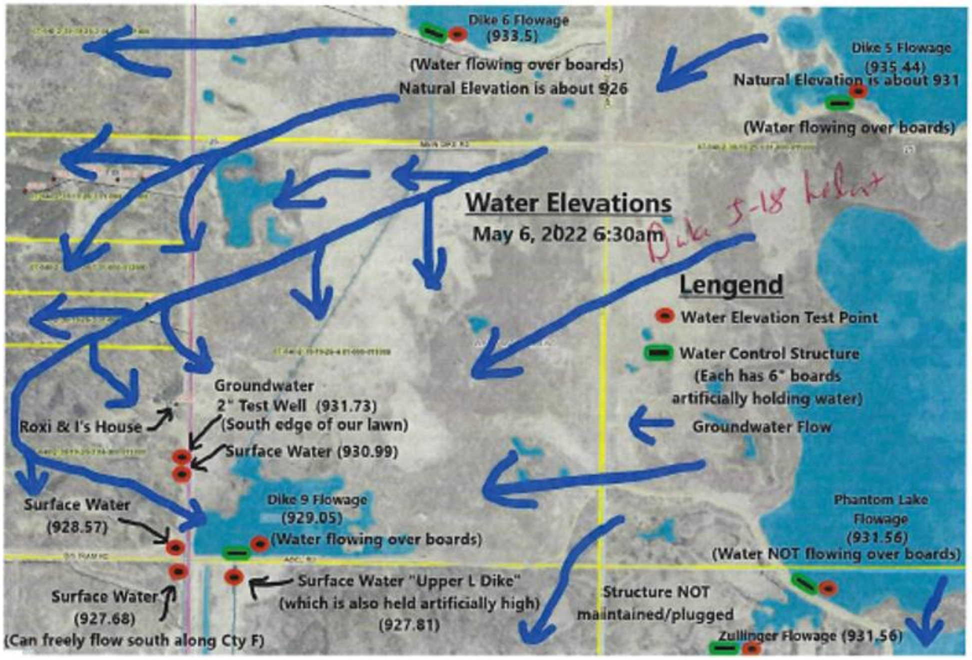


Figure 7. Illustration from the Crex neighbor's handout distributed on May 18, 2023. Note in lower left the 2" test well and two surface water elevations that the Crex neighbor references.

misled with the calculations of gradient in the 2019 USGS report. Certainly, hydrologists would understand the context of what the authors were trying to communicate, but I see how this would be ambiguous for non-hydrologists.

But the fact remains that gradient and groundwater flow direction cannot simply be inferred by just dividing the head difference between two points of interest by their distance.[4] Stronger gradients, and thus more likely groundwater flow paths, exist between flowages and potential groundwater sinks in the Crex neighbor's drawing, for instance between Dike 5 flowage and Phantom Lake, Dike 5 flowage and Dike 6 flowage, Dike 5 flowage and the ditch connecting Dike 6 and Erickson flowages, and southern Dike 6 flowage and the connecting ditch. The ditch seems to be acting as an intercepting drain for shallow groundwater moving toward it from the east.[5] (To be fair, the Crex neighbor does show some Dike 5 water entering the ditch.)

Groundwater flow paths across the Crex neighbor's property

My interpretation of the Crex neighbor's figure is that it seeks to explain why the water level in his test well is:

- 0.84 ft higher than the surface water on his property 75 feet southward,

---

[4]To illustrate the point, a false gradient could be calculated this way between the flowages and Lake Michigan, but that does not mean water from the flowages moves toward Lake Michigan nor that it raises groundwater levels along the way.

[5] Bottom and water ditch elevations contemporaneous with the Crex neighbor's measurements are unavailable, but a survey conducted by WIDNR during the week of June 25, 2023, revealed ditch bottom elevations of 929.68 south of Main Dike Rd. and 926.06 at the inlet channel to Erickson control structure. Water elevations were 930.60 and 928.54 at the same two sites. This supports, but does not prove, that the ditch was a groundwater discharge area for shallow groundwater moving eastward.

- 2.42 feet higher than the surface water a few hundred feet southward, and
- 2.7 feet higher than across the road in Erickson flowage.

He suggests the explanation is that leakage from Dike 5 and Dike 6 flowages moves westward beyond County Rd F and then "hooks" eastward through his property before ultimately discharging to Erickson flowage. He further implies that the greater water level in his test well compared with nearby ponds on his property indicates groundwater is discharging to the surface.

Again, the studied flowages thus far have been shown to have a limited ability to leak surface water to the aquifer. But the water elevations on the Crex neighbor's map make it more likely, in my opinion, that shallow groundwater in the area is being captured by local sinks rather than traveling extensively. Further, the hypothesized shallow groundwater flow component moving westward from the flowages and across County Rd F is challenged by the demonstrated west to east shallow gradient that prevailed much of the time in the vicinity (Figure 8) during May 2019 through August 2020.

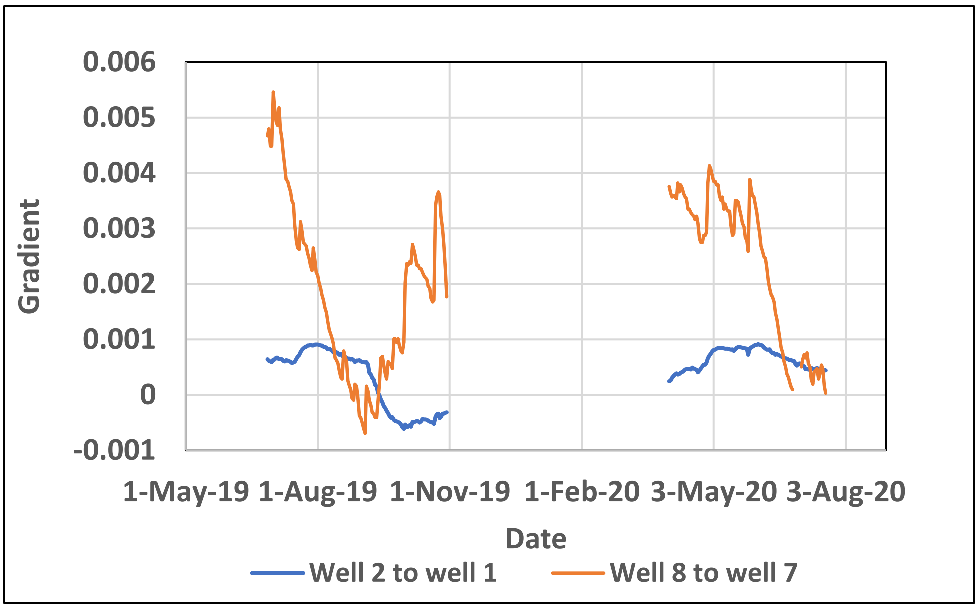


Figure 8. Gradient between 2019 USGS study wells near Dike 6 flowage (well 2 to well 1) and Erickson flowage (well 8 to well 7). Positive values indicate west to east gradients (into Crex) and negative indicate east to west gradients (out of Crex). Gradients and groundwater flow were predominantly west to east during the available record. Locations of wells can be seen in Figure 10.

The Crex neighbor's hypothesis that the ponding he observed south of his test well is due to groundwater discharging to the surface is certainly possible, though I am unable to rule out the potential role of spring runoff. But in any case, this is irrelevant to any role played by the Crex flowages.

VIII. 1930s water levels are a poor indicator of "natural" conditions

The 1930s were a time of extreme drought and low water levels and make a poor benchmark for assigning modern-day "natural" levels.

Concerned citizens have suggested that groundwater elevations and flowage levels should be managed at "natural" levels, which they assert are represented by 1930s water level observations. (I put aside for now that a "natural" level is not a single number because levels rise and fall naturally with rising and falling precipitation amounts, as demonstrated by the monitoring well record at Webster [Figure 3]).

The 1930s are a flawed period to benchmark modern-day "natural" water levels. 1930s precipitation amounts were catastrophically low and thus produced anomalously and historically low groundwater levels (Figure 3). Northwest Wisconsin precipitation during 1929-1940 (Figure 9) averaged only 27.8 inches during 1929-1940 (1901-2000 average = 30.59), with only two of 12 years reaching average or above (Wisconsin State Climatology Office 2023). The preceding 1908-1928 years were also dry. No other similarly severe dry period is apparent in the record.

Clearly, 1930s water levels are not representative of modern era "natural" conditions, not even for modern drought, and should not be used as a "natural condition" reference.

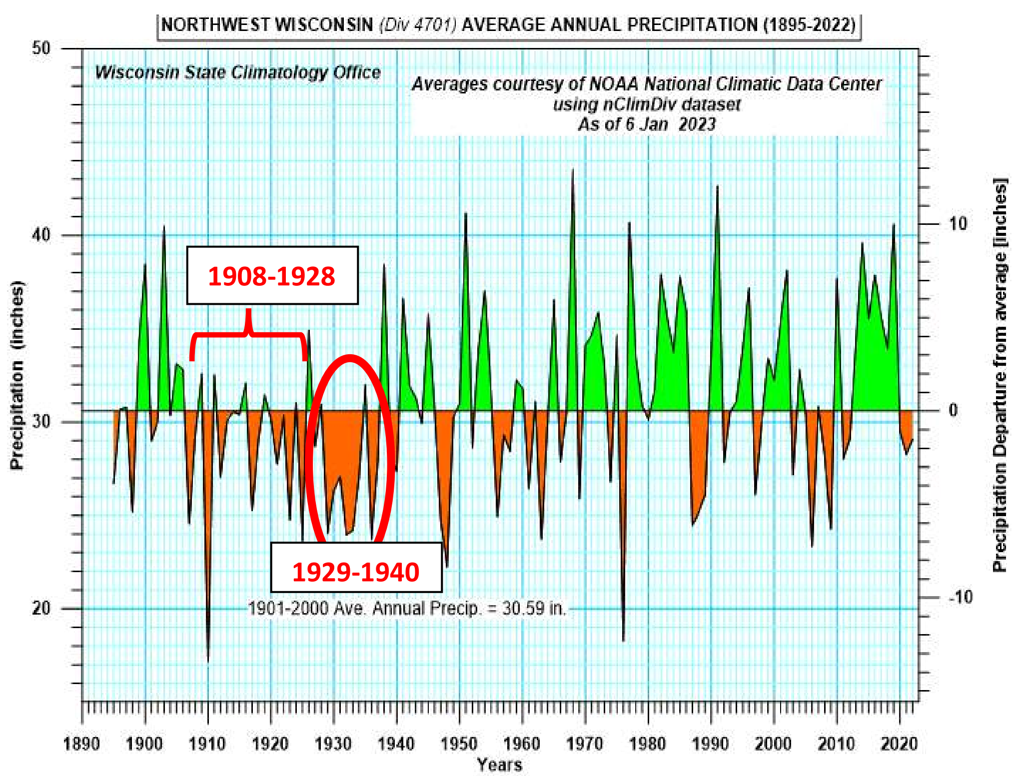


Figure 4. Precipitation record for northwest Wisconsin, 1895-2022. The extreme dry period of the 1930s and relatively dry 1908-2928 period are indicated.

IX. Dike 1 flowage pumping

Flood control pumping from Dike 1 flowage is unlikely to increase flooding in the WMCA.

In a meeting with two concerned citizens, a concern was expressed that water pumped for flood control during spring 2023 from Dike 1 Flowage and diverted to the Reed Lake Marsh – Monson Lake – Curry Flowage – Iron Creek ("Reed Lake") system might be exacerbating water level problems in the WMCA. The 2023 diversion, according to Crex property manager Kyle Anderson, amounted to 22,000 gallons per minute for 213 hours over 9 days, for a total of about 280 million gallons and an average pump rate of 48 cfs. Mr. Anderson maintains that this diverted water filled Monson for a time, as it was low from the previous year, but then exited to the St. Croix through Iron Creek.

An in-depth evaluation on this topic is beyond my immediate work scope, but several factors argue against the water diversions to this system affecting the WMCA. The distance from the Reed Lake system to the concerned citizens' locale is large, about 5.5 miles. Iron Creek, which drains the Reed Lake system, is likely an effective groundwater sink if the Reed Lake system were to substantially recharge groundwater. Finally, the Reed Lake system to St. Croix River distance is less than three miles, and a steep hydraulic gradient (23 feet per mile) exists between them, making it a more likely groundwater discharge path.

X. Episodic poor well-water quality

Data are lacking to document, evaluate, and explain citizen assertions that iron, manganese, and tannins in drinking water wells increase after flowage levels are raised. I am unable to postulate a mechanism by which that could happen.

Concerned citizens assert that well water quality in the WMCA deteriorates (with increased levels of iron, manganese, and tannins) during groundwater flooding periods brought about by flowage level rise, and that the deterioration is rapid or instantaneous.

Iron and manganese arise from reducing conditions (i.e., low dissolved oxygen) often brought about by water percolating through wetlands or buried organic deposits in an aquifer. Tannins also arise from organic materials. I am informed by a 1980s water quality survey (Kammerer 1981), area residents, and Burnett County staff that iron, manganese, and tannins in well water are common through much of the Town of West Marshland, and indeed in other locales through Burnett County.

However, data backing claims about the timing and magnitude of changing water quality conditions seem absent, and I have no hard information on which to base an evaluation.

Further, I am at a loss as to what mechanism might cause rapid water quality changes, and how the Crex flowages could be responsible. Perhaps concerned citizens believe problematic solutes are being transported from Crex flowages to their wells via groundwater? Or that flowages induce high water levels that somehow alter the groundwater flow field and transport manganese, iron, and tannins to home wells from nearby wetlands? I don't know.

But given that rapid water table rise and substantial leakage from flowages to WMCA groundwater are doubtful, mechanisms for flowages to alter well water quality are lacking.

During my years as a UW-Extension water specialist, I had dozens of inquiries about water quality changes occurring during changing wet and dry conditions. So I believe that the phenomenon of changing water quality with changing water levels is potentially real, but just not attributable to flowage management.

XI. Conclusions and recommendations

Flowage flooding claims

I have seen no compelling evidence supporting claims that flowage level manipulation in Dike 6, Erickson, and Dike 5 flowages causes rapid and widespread groundwater flooding in the WMCA. Either that evidence remains undiscovered, or the phenomenon does not exist.

Evidence does exist arguing against a flowage cause of groundwater flooding:

1. Water transmission from flowage to aquifer is apparently hindered by low permeability sediments, as indicated by the USGS 2019 study.

2. Flowage effects on groundwater appear limited to their immediate adjacency and are small.

3. Aquifer physical realities do not allow water transmission capable of causing such flooding.

4. Insufficient water is available to raise and maintain groundwater at hypothesized levels.

5. In parts of the WMCA near Crex where data are available (southern Dike 6 and Erickson flowages area), observations so far indicate shallow groundwater is likely to flow eastward into Crex much of the time.

6. Increasing precipitation over decades, but especially historic precipitation amounts in the 2010s, are a proven sole or partial cause of groundwater flooding in the WMCA.

Natural groundwater levels

Claims that "natural" groundwater levels can be inferred from 1930s levels should be rejected. A single value cannot represent "natural" levels as levels change all the time in response to precipitation, but more importantly, the 1930s were an anomalously dry and low water level period and in no way reflect modern realities. 1930s low water levels are not even representative of modern-day drought levels.

Well water quality deterioration

Data are lacking to back up claims that well water iron, manganese, and tannins spike because flowage levels are raised and induce groundwater flooding. High concentrations of these constituents in the WMCA and much of Burnett County are not uncommon. The mechanism by which the flowages might cause water quality to deteriorate eludes me.

Until flowages are somehow implicated in flooding and more detailed time series water quality data become available, a path forward for further exploration seems elusive.

So what's going on?

I certainly do not believe that the concerned citizens are imagining a groundwater flooding problem, nor that they are insincere in their belief that Crex is to blame. But if, as evidence indicates, the flowages are not the cause of groundwater flooding in the WMCA, what is the explanation and how could it be confused with operations at Crex?

To be clear: I am speculating here but launch the following as my best hypothesis of the phenomenon. (To be clear once more: If my hypothesis is shown false, this does NOT mean the Crex flowages are the cause of flooding, just that my hypothesis is invalid.)

I believe confusion with Crex operations stems from groundwater levels in the WMCA that are pre-primed for flooding. That is, decades of increasing precipitation have raised groundwater levels ever higher and nearer to the ground surface. This is well documented (Figure 2, Figure 3, and Figure 9). With a system primed by high water, it takes little to cause water levels to rise critically during snowmelt, runoff, and high precipitation periods, causing flooding of lowlands, crawl spaces, and some structures.

My understanding is that snowmelt and runoff periods are also the times when sufficient flow exists to raise flowage levels – they cannot be raised during times when only one or two cfs of streamflow are available to fill flowages.

What I am getting at is that the timing of flooding is correlated with the timing of flowage filling. But that does not mean that flowage filling is the cause of the flooding; “correlation does not imply causation.”

Again, I am being somewhat speculative here, but it is my best effort at explaining why some believe that flowage rise and groundwater flooding are linked.

Recommendations

I see no purpose in adopting suggested drastic proposals for flowage management to ease WMCA flooding, such as managing for 1930s groundwater levels or dredging impoundments. No compelling evidence indicates that the flowages are the cause of groundwater flooding or that the proposed measures would cure flooding.

Excluding the drastic and almost certainly futile suggested management proposals, it seems to me that WIDNR has two other options: (1) no further action, and (2) monitoring.

No further action would be a reasonable option, given that the flooding issue has been deeply explored without turning up a flowage-flooding connection.

Monitoring, on the other hand, might provide concerned citizens with some security and WIDNR with some protection from accusations of doing harm. Of course, this needs to be balanced against cost and staff time. I make no judgement on whether monitoring is justifiable.

The purpose of monitoring would be to further demonstrate the relation or lack thereof between flowages and off-Crex water levels. A simple network for this purpose could comprise flowage levels and groundwater levels (1) immediately adjacent to flowages, (2) at a property boundary, and (3) at a reference location. A monitoring well network comprising current and former USGS monitoring locations 1, 2, and 10 or 7, 8, and 10 would fit the bill, as would a pairing of locations B and A with Well 10 (Figure 10).

Weekly water level observations would be adequate, in my view. Perhaps after an initial period of developing familiarity, observations could be backed off to monthly during summers and winters when water level change is slow.

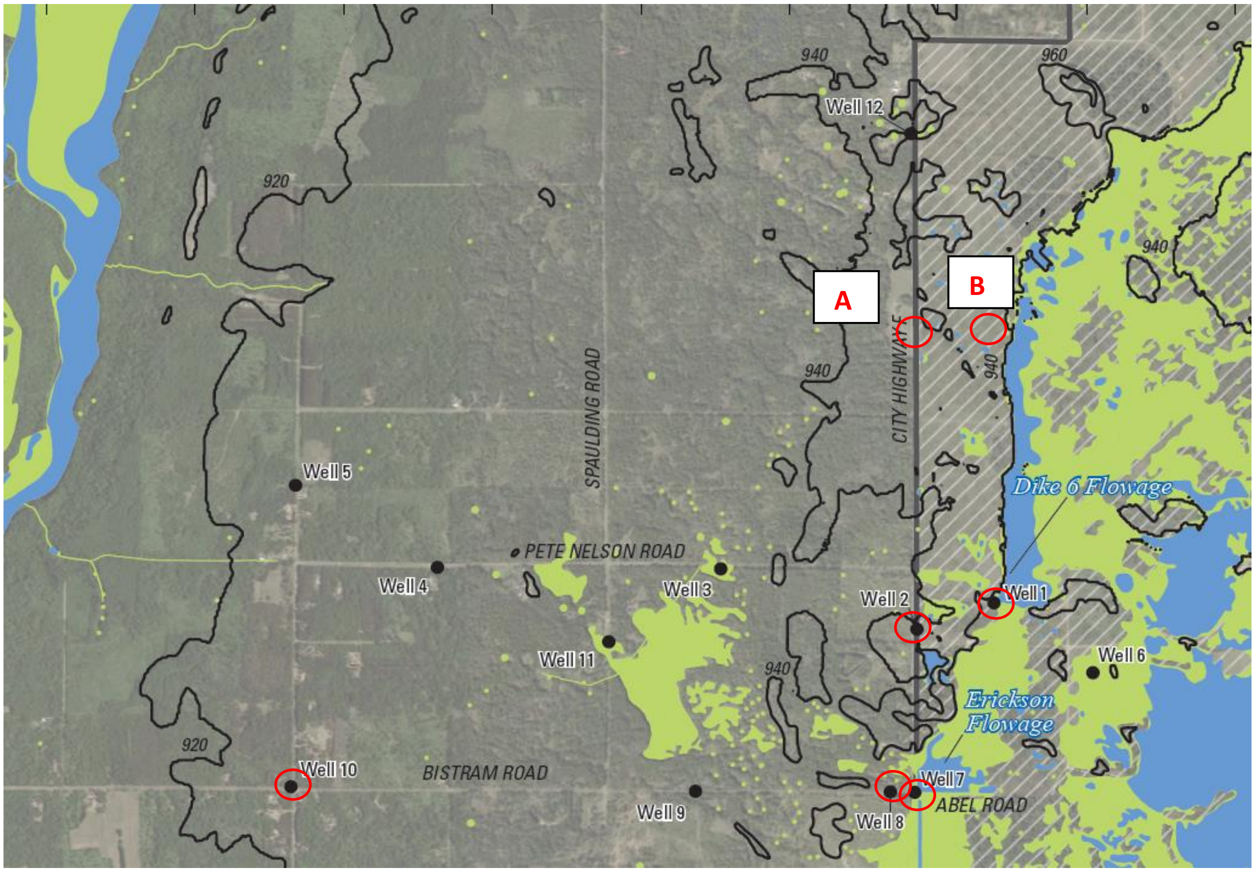


Figure 5. Screenshot of monitoring well locations from 2019 USGS report (black) with potential long-term monitoring sites indicated (red open circles).

An important consideration is, for how long would such a monitoring program need to continue? I think the reality is that concerned citizens would want to see it continue for multiple wet and dry cycles, implying many years or maybe even decades. This implies a great cost in staff time and physical resources.

A few community relations items need to be made clear if a monitoring option were chosen. Among them is the groundwater level reference site. I have little doubt that well 10 is an adequate reference site incapable of being materially affected by flowage management. But concerned citizens have expressed that they believe well 10 is flowage-impacted. More distant sites could be used, but with distance comes “noise” in the water level signal that could hamper data interpretation. If concerned citizens do not accept this as a reference site, a monitoring project becomes pointless.

Further, concerned citizens would need to understand that the correlations among water levels will not be perfect, but that lack of perfection in itself is not an indication of something amiss, like a flowage effect.

Finally, an issue exists as to who would be the arbiter of a flowage effect or no flowage effect. Certainly WIDNR staff are technically capable of performing the needed statistical analyses. And of course so are USGS staff and myself. But concerned citizens seem distrustful of both agencies at this point, and I suspect that my status as “trusted” will be downgraded when this report becomes public.

Once more, I make no judgement as to what option the Department should pursue at this point, and my intent is only to reveal some pros and cons of each.

XII. Literature Cited

Haserodt, M. and M.N. Fienen. 2020. Assessment of groundwater trends near Crex Meadows, Wisconsin. Scientific investigations report 2020-5149. USGS Publications Warehouse. https://pubs.er.usgs.gov/publication/sir20205149

Kammerer, P.A. 1981. Ground-water-quality atlas of Wisconsin. Information circular 39. US Department of the Interior Geological Survey. 24 pp. https://wgnhs.wisc.edu/catalog/publication/000289/resource/ic39

Maliva, R.G. 2020. Surface Spreading System—Infiltration Basins. In: Anthropogenic Aquifer Recharge. Springer Hydrogeology. Springer, Cham. https://doi.org/10.1007/978-3-030-11084-0_15 .

Mioduszewski, W. 2011. Water reservoirs, effects on soil and groundwater in Gliński J., Horabik J., Lipiec J. (eds) Encyclopedia of agrophysics: Encyclopedia of earth sciences series. Dordrecht, Springer, p. 973–975. Cited in Haserodt and Fienen 2020.

Muldoon, M.A. and M.V. Dahl. 1998. Generalized water-table elevation map of Burnett County Wisconsin. Wisconsin Geological and Natural History Survey misc. map 45.

Wisconsin State Climatology Office. 2023. https://www.aos.wisc.edu/~sco/clim-history/division/4701-R.html.

WGNHS (Wisconsin Geological and Natural History Survey). 1981. Irrigable lands inventory. https://wgnhs.wisc.edu/catalog/publication/000467.

XIII. Brief statement of author’s background and qualifications

George J. Kraft is a Wisconsin licensed hydrologist, soil scientist, outreach educator, and water policy authority with four decades of experience, presently in private practice servicing select clients and nonprofit causes.

His educational background includes a PhD from the University of Wisconsin – Madison (major in soil chemistry, minor in hydrogeology), and MS and BS degrees from the University of Wisconsin – Stevens Point. He has further attended numerous short courses in subjects including contaminant remediation, bioremediation, groundwater flow modeling, and groundwater model parameter estimation.

Most of his career has been spent as a Professor of Water Resources and Director of the Center for Watershed Science and Education at the University of Wisconsin – Stevens Point / Extension. There he supervised a water analysis laboratory and outreach staff of 10 plus numerous student workers, conducted public interest outreach programs, directed research, and performed classroom teaching. Teaching included courses in hydrogeology, hydrology, contaminant hydrogeology, groundwater flow modeling, and soil science. Kraft’s outreach programming involved policy work regarding the quality and quantity of Wisconsin’s groundwater, as well as servicing local governments and citizen organizations with groundwater related matters.

Kraft’s research subjects include nitrate pollution and its impacts on Wisconsin groundwater, penetration of nitrate and pesticide residues into aquifers, and groundwater pumping impacts on lakes and streams. He authored or co-authored numerous reports and research papers on these and other subjects that have been published in prestigious scientific outlets such as *Groundwater Journal* and *Journal of Environmental Quality.* Kraft was early to bring attention to widespread nitrate groundwater contamination and its evaluation using mass-balance methods, and the first to connect low streamflows and lake levels to excessive groundwater pumping in the Wisconsin Central Sands.

Previous career experiences include hydrogeologic studies of Superfund and other sites requiring environmental clean-ups.

Professional service areas included the University of Wisconsin System Groundwater Research Advisory Committee, Wisconsin Initiative on Climate Change Impacts, Wisconsin Groundwater Coordinating Council – Governor’s representative, Wisconsin Groundwater Advisory Council Technical Committee implementing 2003 Wisconsin Act 410 on groundwater pumping, and Wisconsin Joint Assembly -Senate Groundwater Working Group.

Kraft has been honored with awards including Wisconsin Idea Fellow (UW-System), Distinguished Service Award (American Water Resources Association - Wisconsin), University Scholar (UW-Stevens Point), College of Natural Resources Outstanding Outreach, Outstanding Environmental Contribution (Wisconsin Stewardship Network), River Champion Award (River Alliance of Wisconsin), and Outstanding Service Award (Wisconsin Society of Professional Soil Scientists)

Appendix A. Soil drainage class map for Town of West Marshland, Wetland mapping for WMCA, Water table elevation map for area including the WMCA.

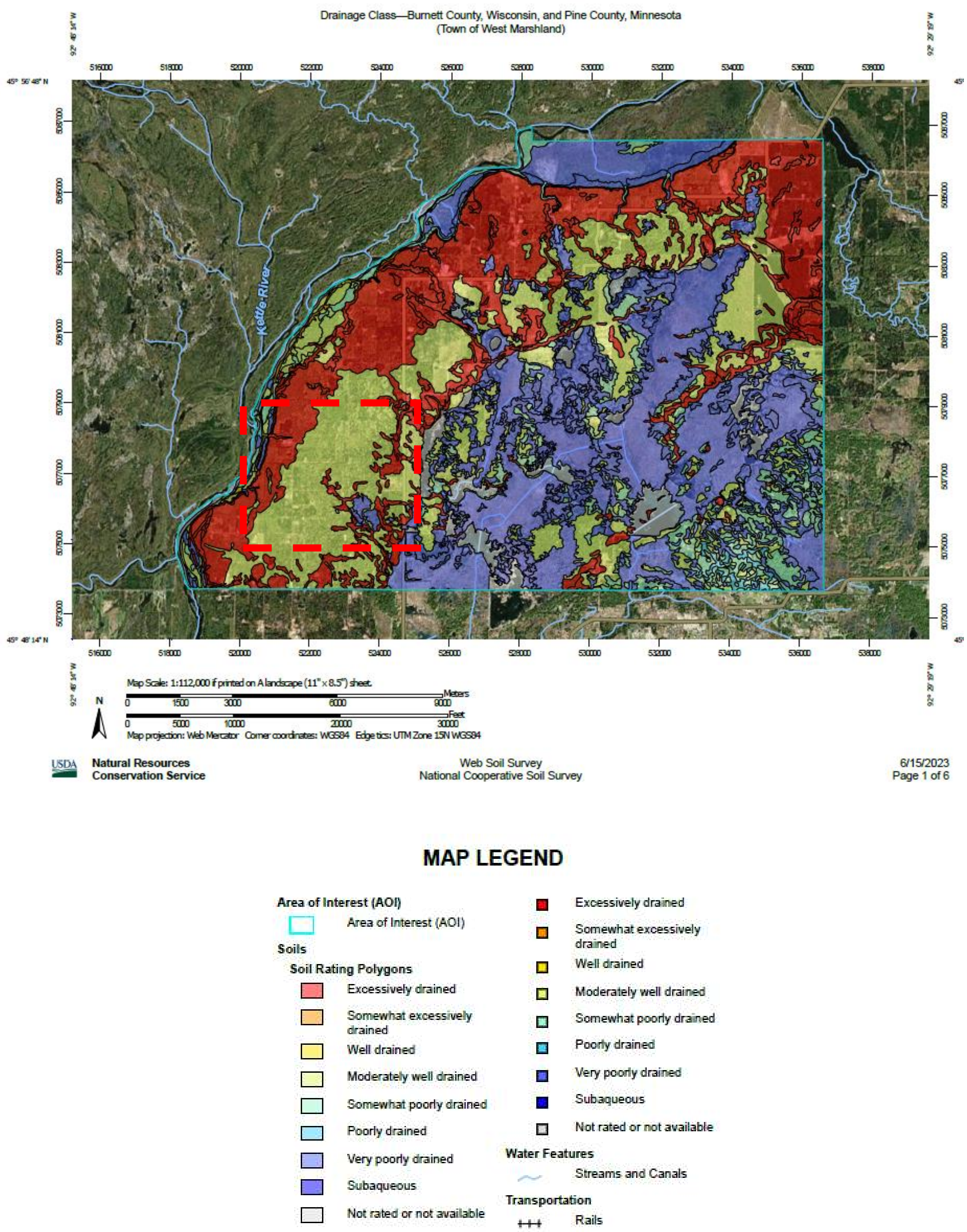


Figure A1. Screenshot of soil drainage class map for the Town of West Marshland, with general location of WMCA West Marshland Concern Area in red. Most of Crex Meadows Wildlife Area is poorly and very poorly drained with standing water. Source: NRCS Web Soil Survey [Web Soil Survey - Home (usda.gov)](#)

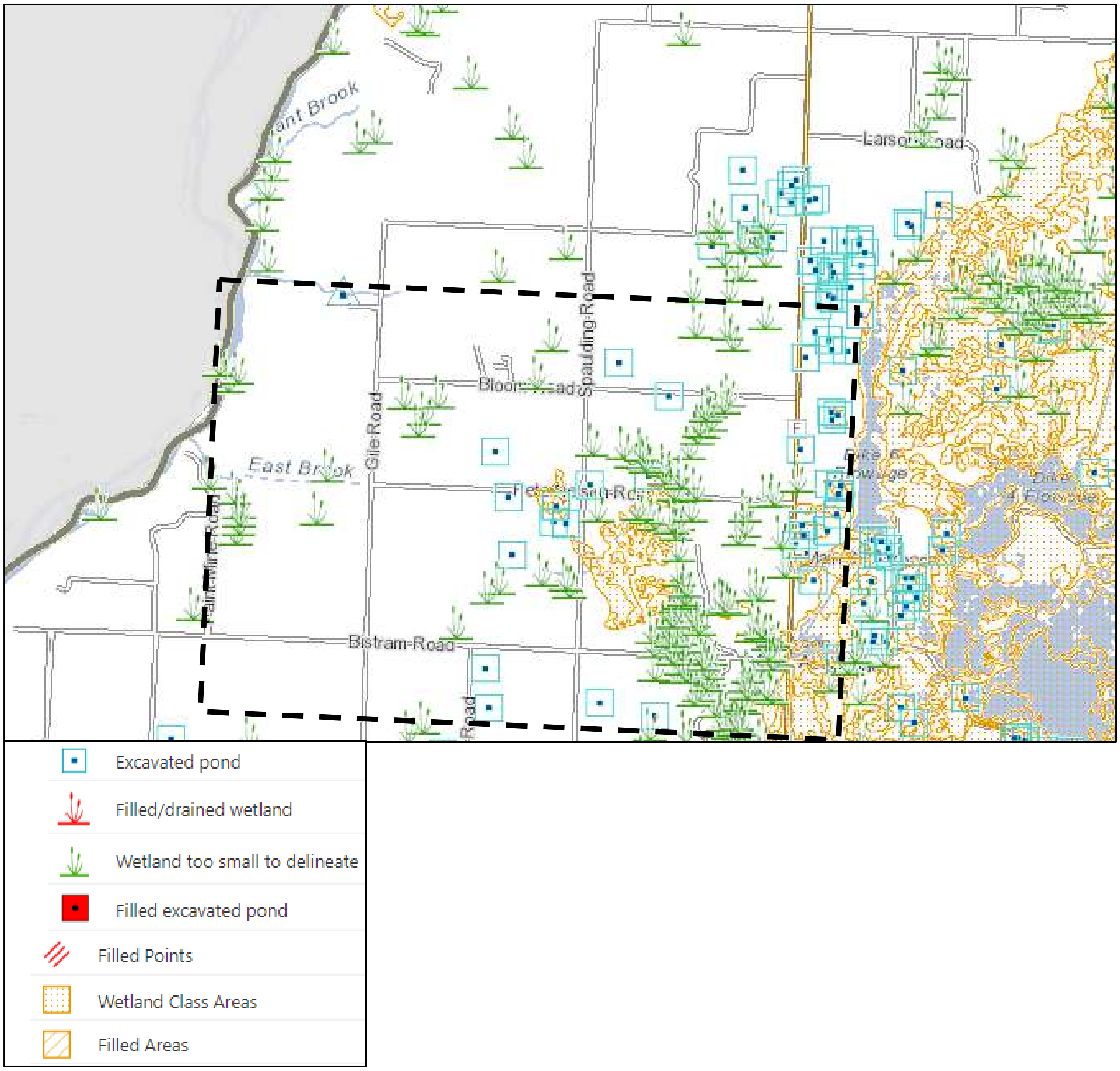


Figure A2. Screenshot of wetland mapping for WMCA. From WIDNR Surface Water Data Viewer. Source: WIDNR Surface Water Data Viewer, https://dnrmaps.wi.gov/H5/?Viewer=SWDV

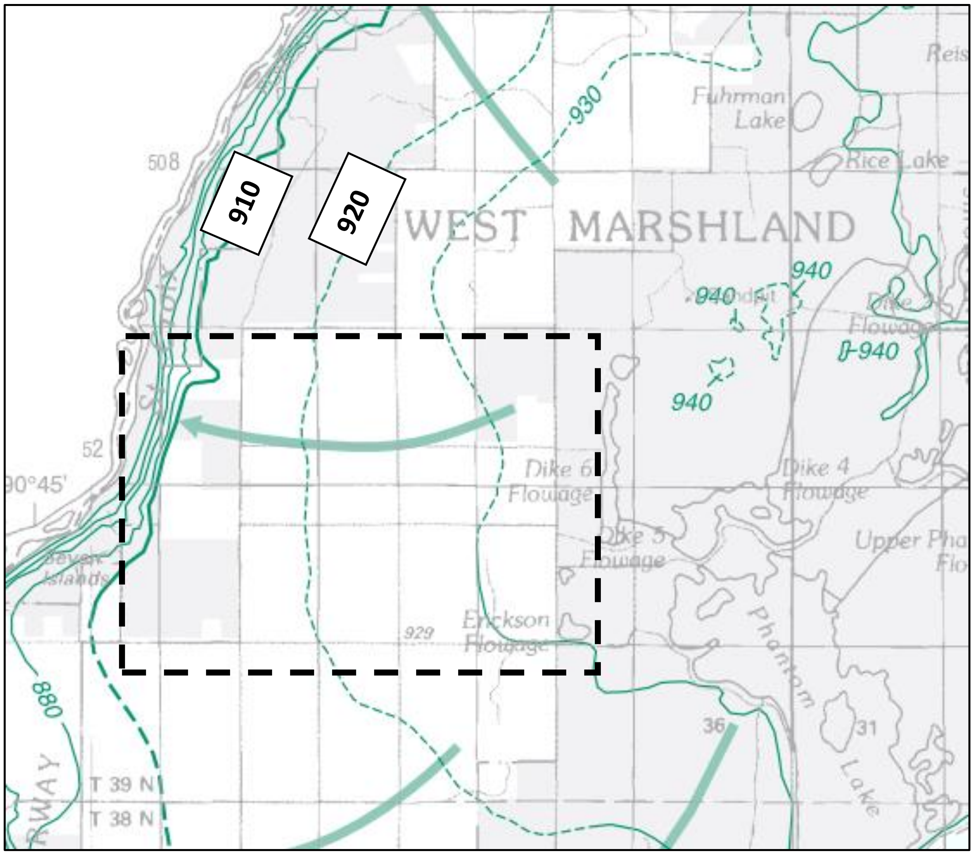


Figure A3. Regional water table elevation map for a portion of Burnett County around the WMCA. (Muldoon and Dahl 1998.)

Appendix B. Flooding and water quality related statements from concerned citizens, binned into categories.

Note or comment number	Note, claim, or comment
	How and when groundwater flooding occurs, its extent and its causation: Flooding affects an area extending westward of Dike 6 and Erickson flowages 2.2 miles (Giles Rd. and the distance to USGS well BT-39/19W/28-0982) or 3 miles (the St. Croix River). Flooding arises almost instantaneously after when water levels are raised in those flowages and dissipates just as quickly when water levels in flowages are lowered.
1	When water levels are raised in Dike 6 and Erickson flowages, area groundwater levels rise and cause extensive flooding.
2	Some concerned citizens profess that water management across the entirety of Crex, not just Dike 6 and Erickson flowages, is responsible for the flooding. (Water management over the entirety of Crex is beyond the scope of this memorandum).
3	Flooding and well water quality problems caused by Dike 6 and Erickson flowages propagate westward at least 2 miles, and perhaps as much as 3 miles, to the St Croix River.
4	Flooding and well water quality problems accrue rapidly (days?) after boards are placed into control structures.
5	When boards are removed and water levels drop, flooding and poor water quality abate just as rapidly as they came on.
6	Raise boards by 2-ft and you will see a 2-ft increase in the test wells. Relational response.
7	Water levels correlated with poor water quality. Duke and Kerri observe water quality issues days after boards are put in.
8	Kerri noted that in the winter of 2010 they were flooded and dike 6 was maintained at 938.
9	2019 = The flowage boards were out for 2 months, and we received a lot of rain, but the groundwater levels went down. Boards in Sept 1 of that year and water levels responded.
10	2021 = Water levels went up in Erickson flowage and Duke's well went up 4-6 inches and that rise was seen nowhere else.
11	When water levels go up in the flowages, water levels go up in our wells. Raise boards by 2-ft and you will see a 2-ft increase in the test wells. Relational response.
12	The USGS well at Bistrom Road (USGS 454953092432502 BT-39/19W/28-0982), 2.3 miles to the west, measures changes in water levels when the boards in the Crex flowages are adjusted.
13	If WIDNR keeps flowage elevations high Duke and his neighbors would be flooded forever.
	Well water quality deteriorates when flowages are raised, with increased levels of iron, manganese, and tannins. The deterioration is rapidly or instantaneously coincident with flowage level rises.

14	Well water manganese, iron, and perhaps tannins increase to intolerable levels, triggered by Crex water level rises.
	Multiple flowages cause a groundwater rise across a large area that converges on the Crex neighbor's property, according to a May 18, 2023, handout.
15	Dikes 5 and 6 are held at elevations that raise the groundwater table, which in turn floods property and affects the groundwater they drink.
16	Water can be running east from our property into Dike 9 flowage, due to Dikes 5 & 6 holding the water table artificially high. If you'd like to come see it…great…if you want a video, I have one available.
17	I have hired an independent contractor, who has been hired in the past by WIDNR for similar work, to shoot all of these elevations and verify my work for accuracy.
18	The gradient between Dike 5 and my 2" well calculates to 4.52 feet per mile.
19	The gradient between Dike 6 and my 2" well calculates to 3.11 feet per mile.
20	Both calculated gradients fall within USGS well data / gradient findings.
21	2019 & 2020 USGS Test Well Data shows the groundwater gradient ranging from 1.9 to 7 feet per mile in the area.
22	My 2" test well is .57 mile from Dike 6 flowage and is .82 miles from Dike 5 Flowage.
23	The water elevation difference between Dike 5 and from within my 2" well is 3.71 feet.
24	The water elevation difference between Dike 6 and from within my 2" well is 1.77 feet.
25	The water elevation difference between Dike 9 and the surface water near my 2" well is 1.94' (water is higher on our side of the road).
26	The natural ground water elevation in the location of my 2" well is about 923, per a WIDNR groundwater inventory conducted in the mid-1930s.
27	The "Upper L Dike" is currently at 927.81. The natural water elevation in this area is roughly 924.
	Concerned citizens recommendations to WIDNR actions they believe will alleviate water concerns, such as lowering flowage levels to what they believe are "natural" levels (as inferred from 1930s era data and modern-day groundwater gradients). Other recommendations also.
28	DNR should backwards engineer water levels for their management plan based on the groundwater gradients and "natural" levels.
29	Duke offered to have a well installed on his land or to use his well to measure water levels.
30	If WIDNR wants more water in the flowage they should dredge the flowages, not adjust the boards / increase water elevation.
	The USGS 2019 study was inadequate and its conclusions about flowage effects on groundwater levels are not valid.
31	Don't disagree with the report data / trends, Duke and Kerri disagree with the report's conclusions.
32	Conclusions don't match the physical data collected for the report.
33	USGS higher ups said WIDNR might be misinterpreting the conclusions.
34	Using the calculated gradient, Dike 6 flowage would need to be no higher than 924.77 to not affect our property. (This number matches up within reason of WIDNR findings from the 1930s.)
35	USGS study and WIDNR elevation datum don't match and so …????

36	USGS study done at wrong time of year, should have been done longer
37	Use of the word “likely” in the conclusions. Likely is not good enough.
	The diversion pump that was running to alleviate flooding was causing problems for the area west of Crex.
38	(Above statement captures the idea).

Appendix C. Responses and clarifications from M. Haserodt of USGS.

Q. In discussion with some concerned citizens, some dismissed your study because of a 10.5 inch elevation discrepancy in regard to your well 1 or well 6. Do you have any insight?

A. “If I recall correctly this may have been associated with comments that the staff gage elevation (used to get flowage elevations) was off by some inches. Those data were provided by DNR and plotted in the report to show general timing of flowages up and down. But, we didn't compute well gradients to the flowage elevations and our analysis on trends was all between our USGS wells which we surveyed in using an RTK GPS. There was a statement in the report about the flowages being perched based on the DNR data and our well data. I did confirm that the flowage was perched relative to the groundwater level in the well by measuring depth to water in the well and then depth to water in the flowages (well was on the flowage edge so I could just measure down from the well casing). That measurement confirmed perching at those well location on the order of several inches to maybe even a foot.”

Q. Your report documented that three monitoring wells out of 11 showed anomalies, two likely due to a flowage level manipulation effect, and one possibly due to something else. However, you did not estimate the magnitude of the water level rise – an inch, a foot, or many feet. Do you have some ideas how well levels were affected during the drawdown or raising periods?

A. “The short answer is our methods were designed to "assess if groundwater to the west of Crex is detectably affected by the flowage water levels." Basically, are the flowages affecting water levels and how far out do we see those affects? We weren't looking to get an exact magnitude of that affect because that is a tough thing to estimate from the overall trends in the hydrograph, especially if the responses are very small.

“The longer answer is the only ways we saw any potential deviations in the well responses were with analyses that amplified the well signal - like cumulative departure from the mean (figure 11 in Haserodt and Fienen 2021) and the regression scatter plots (figure 6 in Haserodt and Fienen 2021). And these methods don’t give a magnitude of the difference as feet of water at a point in time, just that the wells are behaving differently. The other thing I would mention is each well even outside the raising and lowering periods responded with varying magnitudes to the same rain events and dry periods, likely due to different water table depths, where the wells were topographically in the landscape & the associated water table slope in those areas, etc. So, it is not possible to estimate the flowage affects by just assuming the affect is the difference in water level changes between different wells. Doing so would lead to an erroneous result because you would see large differences both during and outside the raising/lowering periods. This is why we focused on comparing rates of water level change between wells v. feet of water level differences.”

Appendix D. Non-flood flow for Dike 6 flowage; estimated median and high flows inferred from nearby streams

Non-flood flow measurements for Dike 6 flowage

At my request, WIDNR staff measured discharges into and out of Dike 6 flowage on three occasions (Table D1) during May 23 to June 21. Inflow discharges were 0.67 cfs or less; outflow discharges were similar, except for the May 23 measurement which was 4.0 cfs. I would characterize these flows as about what is typical for summers and winters, but not for major runoff periods.

Table D1. Non-flood discharges into and out from Dike 6 flowage on three dates in 2023.

Date	Inflow cfs	Outflow cfs
May 23	0.67	4.0
June 15	0.20	0.6
June 21	0.12	0.3

High to median flows

No high to median flow measurements are available for Dike 6 flowage to my knowledge. To infer these, I used statistics at four nearby USGS gages (Table D2). The Q_{01}, Q_{03}, Q_{10}, and median flows, where Q_{XX} is the flow exceedance frequency, were downloaded from the USGS Stream Stats website for each gage (https://www.usgs.gov/streamstats). Q_{01} is the flow that is exceeded only 1% of the time, Q_{03} is the flow that is exceeded only 3% of the time, etc. Gages were normalized by dividing by their watershed area, and then applied to Dike 6 flowage by multiplying the normalized flow statistic by the Dike 6 flowage estimated area of 4 mi^2 (Table D3).

Table D2. Statistics for four gages used to estimate Dike 6 flowage high and median flows.

Gage	USGS No.	Watershed Area	Years of record	Q_{01}	Q_{03}	Q_{10}	Q_{50}
		(mi^2)			-------- cfs -------		
St. Croix River near Danbury	5333500	1580	87	4580	3320	2170	1070
Namekagon River at Leonards	5331833	126	15	428	296	189	102
Bois Brule River at Brule	4025500	118	70	499	362	249	182
Nemadji River near S Superior	4024430	420	42	3700	2140	901	139

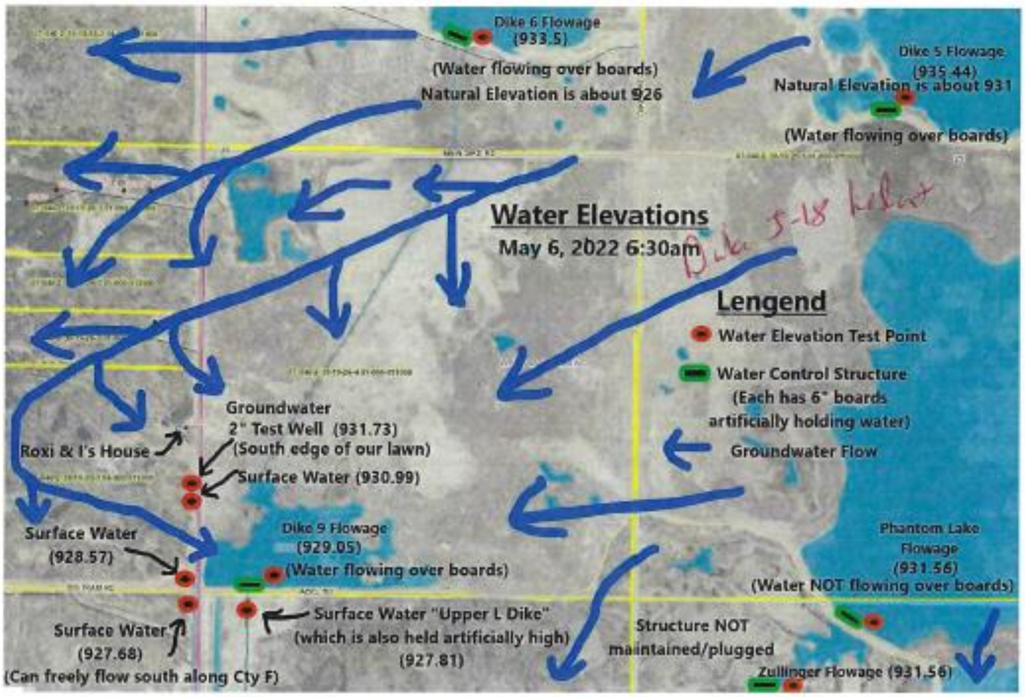
Table D3. Flow frequencies estimated for Dike 6 flowage by comparison to four river gages.

Gage	Q_{01}	Q_{03}	Q_{10}	Q_{50}
		-------- cfs -------		
St. Croix River near Danbury	11.6	8.4	5.5	2.7
Namekagon River at Leonards	13.6	9.4	6.0	3.2
Bois Brule River at Brule	16.9	12.3	8.4	6.2
Nemadji River near South Superior	35.2	20.4	8.6	1.3

Statistics for three of the four watersheds were consistent, with the Nemadji River near South Superior having about double the Q_{01} and one third the Q_{50}, indicating it is a flashier watershed. It matters little as to which best represents Dike 6 flowage, as the point is to determine if sufficient water is available to fill and maintain hypothesized groundwater levels in the WMCA. Recall that 48.7-199.1 cfs were needed to sufficiently raise water levels in the hypothesized scenarios (Table 2). All gages indicate that sufficient water is not available.

Appendix E. Handout from concerned citizens distributed on May 18, 2023.

Notes and underline in red are mine.



- 2019 & 2020 USGS Test Well Data shows the groundwater gradient ranging from 1.9 to 7 feet per mile in the area.
- My 2" Test Well is .57 miles from Dike 6 Flowage, and is .82 miles from Dike 5 Flowage. Also note, the groundwater elevation in my 2" test well is higher than the surface water test point just 75' south of it.
- The water elevation difference between Dike 5 and from within my 2" well is 3.71 feet.
- The water elevation difference between Dike 6 and from within my 2" well is 1.77 feet.
- The water elevation difference between Dike 9 and the surface water near my 2" well is 1.94' (water is higher on our side of the road)
- The gradient between Dike 5 and my 2" well calculates to 4.52 feet per mile.
- The gradient between Dike 6 and my 2" well calculates to 3.11 feet per mile.
- Both calculated gradients fall within USGS well data/gradient findings.
- The "natural" ground water elevation in the location of my 2" well is about 923, per a WDNR groundwater inventory conducted in the mid-1930s.
- Using the calculated gradient, Dike 6 Flowage would need to be no higher than 924.77 to not affect our property. (This number matches up very closely with WDNR findings from the 1930s)
- Using the calculated gradient, Dike 5 Flowage would need to be no higher than 926.71 to not affect our property. (This number matches up within reason of WDNR findings from the 1930s)
- Dikes 5 & 6 are held at elevations that raise the groundwater table, which in turn floods our property and affect the groundwater quality we drink.
- Water can be witnessed running east from our property into Dike 9 flowage, due to Dike's 5 & 6 holding the water tabl artificially high. If you'd like to come see it... great...if you want a video, I have one available.
- The "Upper L Dike" is currently at 927.81. The natural water elevation in this area is roughly 924. It is totally reasonable to assume that 3-4 feet of water is being held back by the "Upper L Dike". I have started studying that area as a side project. What I am demonstrating with this point, the water elevation on the south side of Abel Rd...most likely would have the same groundwater elevation today as found in the 1930s, IF the "L Dikes" were not holding back water artificially.
- I have hired an independent contractor, who has been hired in the past by the WDNR for similar work, to shoot all of these elevations and verify my work for accuracy.