February 20, 2020

Supplement to the *Republican River Basin-Wide Plan*

Methodology for MHO C

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Purpose and Background

Statute requires that the *Republican River Basin-Wide Plan* include Measurable Hydrologic Objectives (MHOs) to ensure that reasonable progress is being made toward achieving the goals and objectives of the plan (*Neb. Rev. Stat.* § 46-755). Five MHOs were agreed-upon during the planning process and adopted as part of the basin-wide plan. For MHOs B and C, which are more technically complex than the basin-wide plan's other three MHOs, it was important to members of the Stakeholder Advisory Committee that more specific assessment methodology be developed by the Nebraska Department of Natural Resources (NeDNR) and Natural Resources Districts (NRDs) than was feasible during the stakeholder process. NeDNR and the NRD committed to developing assessment procedures before the basin-wide plan's first annual meeting, to be appended to the basin-wide plan upon completion. This document describes the assessment procedures for MHO C. MHO C is shown in Figure 1, along with contextual information about where it fits within the plan's goals, objectives, and action items.

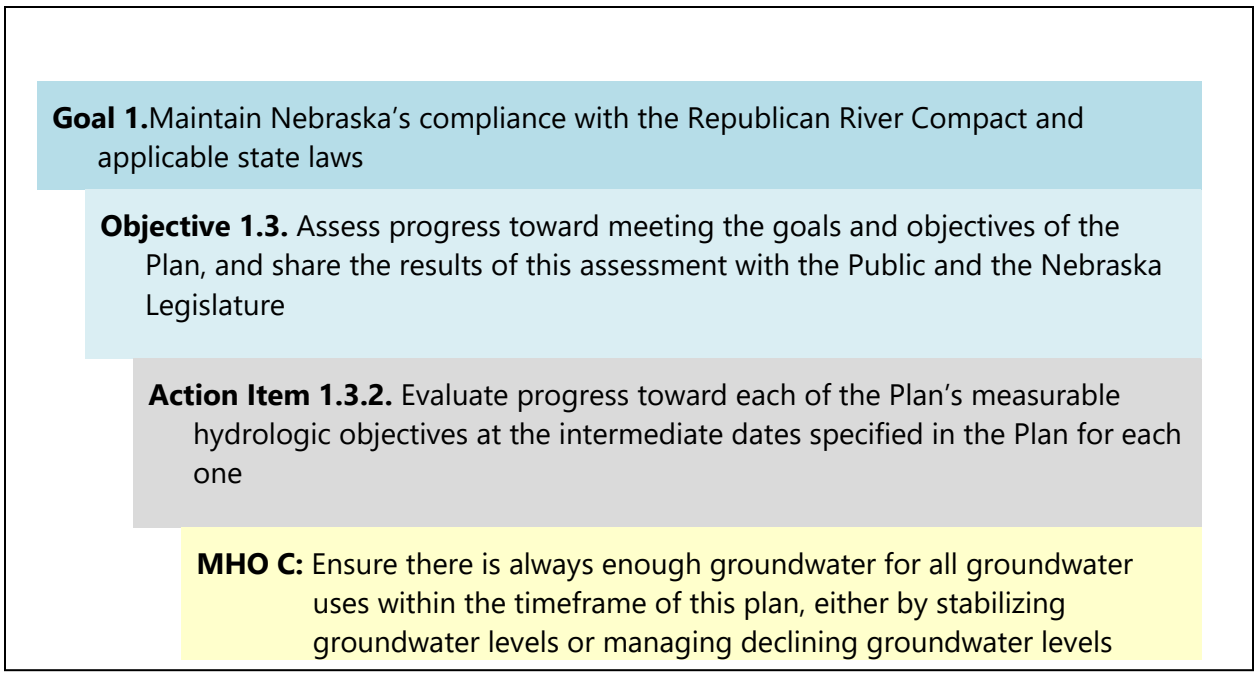

Figure 1. MHO C is one of the *Republican River Basin-Wide Plan*'s Measurable Hydrologic Objectives (MHOs).The MHOs are part of Action Item 1.3.2, Objective 1.3, and Goal 1.

Introduction

MHO C is to "Ensure there is always enough groundwater for all groundwater uses within the timeframe of this plan, either by stabilizing groundwater levels or managing declining groundwater levels." Developing methodology for MHO C requires setting parameters for how the terms in MHO C will be evaluated.

Groundwater Levels and Observation Well Data

Groundwater levels in the basin are evaluated using spring average groundwater observation well data that have been exchanged between the NRDs and NeDNR or are publicly available through the USGS or University of Nebraska-Lincoln Conservation and Survey Division databases. For MHO C, each observation well is initially evaluated individually to determine whether groundwater levels have declined.

For each well, each year's spring average groundwater observation well data are calculated for by averaging any spring groundwater level observations collected from that well between February 24 and May 15. This date range was selected based on historical observation frequency and known data collection practices. Calculating an average value for each year allows continuous, non-continuous, and intermittent observations to be assessed in the same manner as each other, across all observation wells. Using only spring data is a common practice for evaluating long-term groundwater level trends. This is because spring groundwater levels are

less affected than fall groundwater levels by the short-term effects of groundwater pumping, which can vary considerably from year-to-year depending on irrigation water requirements.

Note that while in most locations, spring groundwater level observations are usually the best option for evaluating long-term groundwater level trends, as described in the preceding paragraph, there are situations that make spring groundwater levels at certain observation wells unsuitable for use for this analysis. Examples would include observation wells located very near a site where groundwater is either being extracted or recharged during the winter or spring months. Any observation wells determined by NeDNR and the NRDs to be unsuitable for the use of spring observation well data, due to their location, are excluded from this analysis.

Stable Groundwater Levels or Managed Declining Groundwater Levels

MHO C provides for two ways in which NRDs can comply with the objective of ensuring there is enough groundwater for all uses within the plan's timeframe: 1) stable groundwater levels, or 2) managed declining groundwater levels. This assessment takes a multi-phased approach. In the first phase, we evaluate each well to determine which observation wells have stable groundwater levels and which wells have had consistently declining groundwater levels over the time period of the analysis. During the second and third phases we further investigate the areas containing wells with consistently declining groundwater levels to determine which of those wells have groundwater levels that are declining at such a rate that there will not be enough groundwater available for all groundwater uses within the timeframe of the plan.

The assessment period begins from 2008 for Upper Republican NRD, Middle Republican NRD, and Lower Republican NRD, and from 2013 for Tri-Basin NRD. These assessment periods for MHO C were selected for consistency with the assessment periods for MHO B. The analysis of "stable groundwater levels" examines trends in groundwater levels observed during all years within the assessment period. The analysis of "managing declining groundwater levels" considers expected water availability at the end of the basin-wide plan's timeframe (i.e., 2044).

Statistical Trend Analysis

Groundwater levels are assessed for stability by the trend analysis statistics discussed in this section. These are the same statistical methods used to determine trends in groundwater depletions to streamflow for MHO B. The statistics are applied to each groundwater level observation time series for each observation well evaluated.

Mann-Kendall Trend Test

The trend test used for this analysis is the **Mann-Kendall Trend Test**[1,2] (MK test). The MK test is a nonparametric test for monotonic, linear or non-linear trends. "Non-parametric" means that no assumptions need to be made about the distributions of the observation well data. "Monotonic" means that the trends detected will be consistently increasing or decreasing. "Linear or non-linear" means that the test will detect changes that are well represented by a line or are step changes. In addition to these features of the MK test, it has the advantage of not being dependent on the magnitude of the groundwater level changes, i.e., the presence of a trend will not be skewed by the magnitude of any extreme groundwater level values. A limitation of the MK test is that, as with many other statistical trend tests, statistical confidence increases with size of the dataset; however, the MK test is one of the few statistical trend tests that is recommended for use on small datasets like those being analyzed here.

The MK test is calculated by pairwise comparisons of each annual spring average groundwater level to each previous annual spring average groundwater level. If the later groundwater level is greater than the earlier groundwater level, 1 is added to the MK test statistic. If the later groundwater level is less than the earlier groundwater level, 1 is subtracted from the MK test value. If the pair of groundwater levels are the same, the MK test value does not change. If after comparing all pairs, the MK test value is a large positive number, then an upward trend in groundwater levels is shown. If the MK test value is a large negative number, then a downward trend in groundwater levels is shown. If the MK test value is near 0, then no trend is shown.

The significance of the MK test value depends on the number of years in the test. If the number of years is less than or equal to 10, then the MK test value is compared directly to a table of probabilities.[3] If the number of years is greater than 10, then the variance of the MK test value is calculated as a function of the number years and the number of identical groundwater levels. The MK test statistic is then calculated as a function of the MK test value and the variance of the MK test value. The MK test statistic is then compared to the corresponding Z value for the desired significance.[4] For the MHO C assessment, a p-value of 0.05 is used as the threshold to determine significance. Example MK test results are shown in Figure 2.

[1] *Statistical Methods in Water Resources* by D.R. Helsel and R.M. Hirsch, chapter 12 'Trend Analysis'. Book 4 in the Hydrologic Analysis and Interpretation Series by USGS (https://pubs.usgs.gov/twri/twri4a3/twri4a3.pdf).
[2] Pacific Northwest National Laboratory Visual Sample Plan (VSP) 6.0 documentation, Mann-Kendall Test For Monotonic Trend (https://vsp.pnnl.gov/help/Vsample/Design_Trend_Mann_Kendall.htm)
[3] Pacific Northwest National Laboratory Visual Sample Plan (VSP) 6.0 documentation, Mann-Kendall Test For Monotonic Trend (https://vsp.pnnl.gov/help/Vsample/Design_Trend_Mann_Kendall.htm)
[4] Pacific Northwest National Laboratory Visual Sample Plan (VSP) 6.0 documentation, Mann-Kendall Test For Monotonic Trend (https://vsp.pnnl.gov/help/Vsample/Design_Trend_Mann_Kendall.htm)

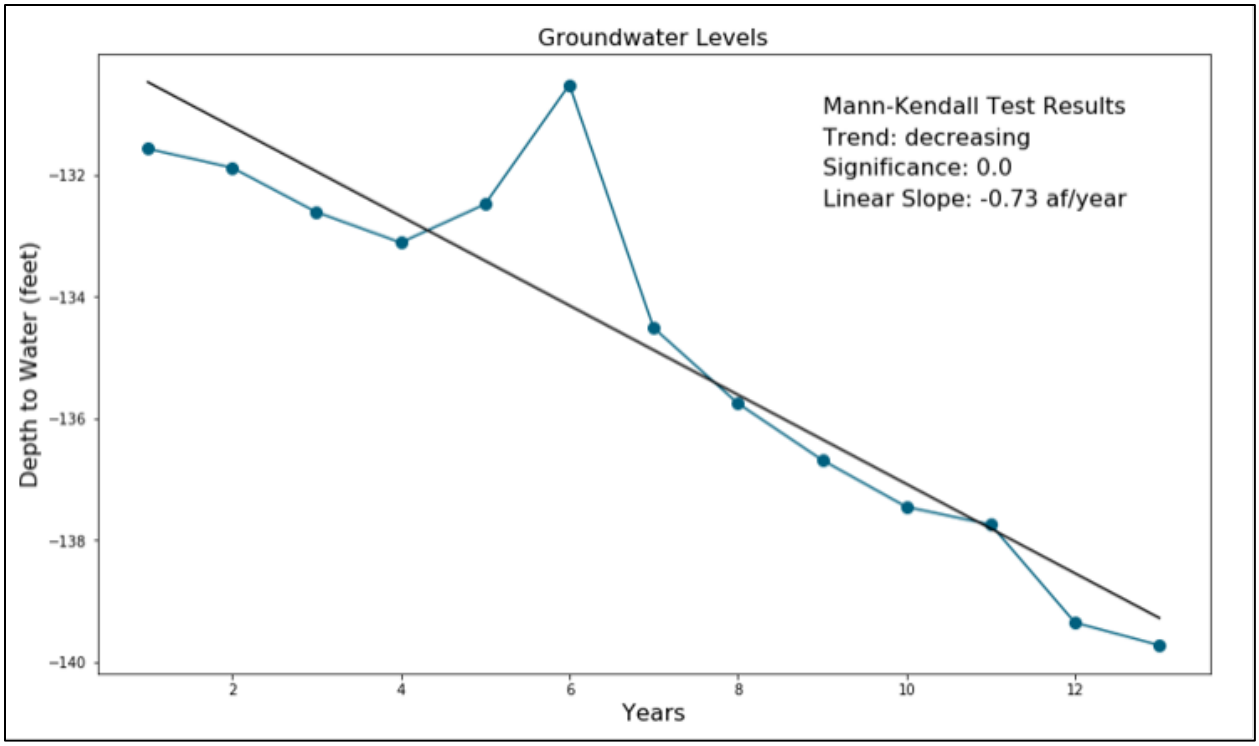

Figure 2. Example Mann-Kendall test results using made-up data.

In addition to indicating which observation wells have declining groundwater levels, the results of the MK test also include the slope of the trend observed. For each well that is identified by the MK test as having consistently declining groundwater levels, the linear trend of those observations can be projected to 2044 to estimate groundwater availability at the end of the plan's timeframe.

Future Work

NeDNR is working with NRDs to share and combine well attribute and groundwater observation data in order to more quickly and easily update records for MHO C assessments.

Assessment of Whether Management Actions are Needed

As described in the basin-wide plan, if NeDNR and the NRDs determine that an MHO is not being achieved, they will determine what actions to take to achieve that MHO in the future. The process described below summarizes the decision framework that is followed to determine whether an NRD needs to take management actions as a result of this analysis of MHO C. The full decision framework is shown in Figure 3.

There are four phases in the decision framework for MHO C: three screening phases, and management actions. Figure 3 includes details about each phase, including its purpose and timeframe, the decisions that are made during each phase, and what is reported as a result of it.

The first screening phase takes place as part of each five-year technical analysis for the basin-wide plan. During the first screening phase, NeDNR and the NRDs use the MK test to determine which observation wells have experienced a statistically significant decline in groundwater levels. Wells that have not experienced a statistically significant decline are meeting MHO C because they have experienced stable or increasing groundwater levels; therefore, no further analysis of these wells is needed after the first screening phase. For wells that have experienced a statistically significant decline in groundwater levels, the MHO C analysis moves to the second screening phase.

It is not possible to set one basin-wide, meaningful, numerical trigger to determine whether MHO C is being met, because what constitutes "enough groundwater for all groundwater uses" varies considerably from one area to the next depending on factors such as groundwater demands and hydrogeologic conditions. For this reason, the second and third phases of this decision framework provide a guide for evaluating each area with declining groundwater levels individually to determine whether MHO C is being met or management actions are needed.

The second screening phase takes place within approximately one year of when the five-year technical analysis results are presented. During this phase, NeDNR and the NRDs expand their focus to include a large enough geographic area to provide context for interpreting the observation well results. NeDNR and the NRDs determine whether it is obvious that the decline indicated by the MK test does not indicate a potential limit to groundwater availability by 2044, or whether a more in-depth investigation is needed. For areas where the NRDs and NeDNR determine that more investigation is needed, the MHO C analysis moves to the third screening phase.

The third screening phase takes place within approximately two years of when the five-year technical analysis results are presented. During this phase, NeDNR conduct an in-depth evaluation of projected groundwater availability and groundwater demands and determine whether there will be insufficient groundwater availability in 2044.

If the third screening phase identifies that an NRD needs to take management actions because MHO C is not being achieved, the NRD will begin the selected management action or actions no later than the annual meeting that takes place three years after presentation of the five-year technical analysis.

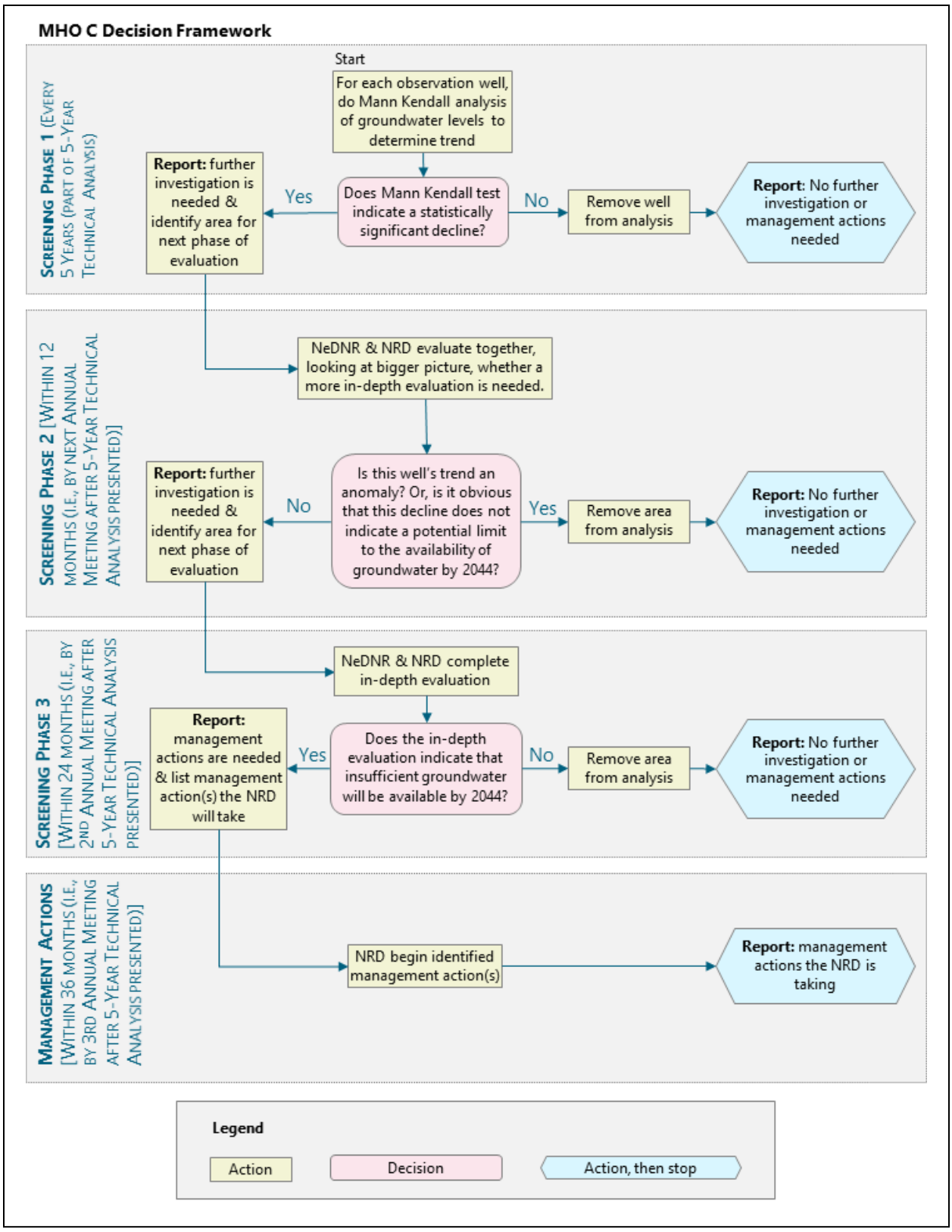

Figure 3. Decision framework for MHO C, outlining details about each phase of the analysis, including its purpose and timeframe, the decisions that are made during each phase, and what is reported as a result of it.