Downstream Accounting Future Research
10-18-2022

Background

Using existing GIS techniques and datasets, Zorn et al. (2022) demonstrated the technical feasibility of incorporating (1) watershed-scale accounting (*i.e.*, tallying all flow depletions in the entire watershed upstream of each WMA) and (2) sector-specific return flow percentages into the Water Withdrawal Assessment Program for the entire state of Michigan. They noted,

> "Empirical attempts to achieve a perfect solution statewide would be quite costly and could take decades because it would likely involve long-term monitoring and modeling of climate, flows, and withdrawals in numerous representative Michigan watersheds, each characterized by distinctly changing patterns in land use, climate, water withdrawals, and flow conditions. Even if undertaken, such an endeavor may not produce results much more robust than a GIS modeling effort, with many potentially inappropriate withdrawals likely being permitted during the interim. Thus, **we think that incorporating both improvements (or refined versions of them) in the WWAP will improve the scientific and ecological defensibility of the WWAP** …" [emphasis added] Zorn et al. (2022), p. 6.

They went on to recommend that "… **additional study** to address uncertainties regarding the extent to which flow depletions in headwaters of larger watersheds are propagated downstream **is needed prior to implementation** watershed-scale accounting." [emphasis added] Zorn et al. (2022), p. 6. They warned that "documenting changes in streamflow conditions resulting from registered withdrawals will be difficult to accomplish in the field …" (Zorn et al., 2022, p. 6) for a variety of reasons.

Zorn et al. (2022) recommended two next steps:

1. Use long-term stream gage records to quantify long-term index flow changes relative to precipitation levels for catchments showing different levels of with upstream flow depletion.
2. Review existing research on observed or modeled downstream propagation of streamflow depletions and appropriate spatial scale for quantifying cumulative withdrawal effects in catchments.

Zorn et al. (2022) explored #1 above by comparing the Index Flows at scores of streamflow gages in the state between the period 1971-2000 [the baseline precipitation period for the Index Flow regression model (Hamilton et al. 2008)] and the wetter 2010-2019 decade. Their results showed a distinct regional pattern, with lower Index Flows in northern Michigan and generally higher Index Flows in southern Michigan during the latter period (Figure 1). Noting index flows at several gages in the southwestern Lower Peninsula showed declines or only minor increases in flow during the latter period, despite higher flows at gages in the surrounding area (potentially suggestive of water withdrawal effects), they recommended further investigation of temporal changes in low flow conditions at gages throughout Michigan to better understand associations among trends in low flow conditions, precipitation and cumulative water withdrawals in various regions of the state.

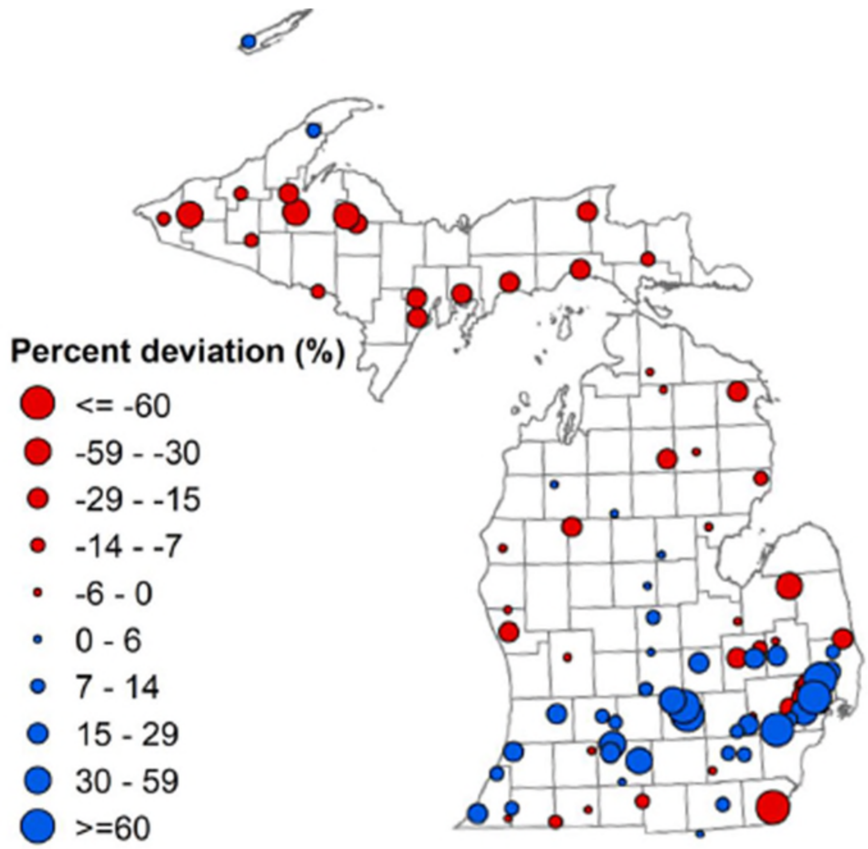

Figure 1. Percent deviation of Index Flow for 2010-2019 from Index Flow calculated for 1971-2000. Modified from Zorn et al. (2022), Figure 9.

Recommendations

The Models Committee recommends that the 2022 report from the WUAC to the Michigan Legislature include a recommendation that the Department of Environment, Great Lakes and Energy contract with the Partnership for Ecosystem Research and Management (PERM) at Michigan State University (which has already done considerable some streamflow data compilation work for #2 below) to conduct the following research:

1. **Complete an exhaustive literature review of research on observed or modeled downstream propagation of streamflow depletions.**
2. **Examine relationships between long-term changes in index flows and index flow yield (e.g., inches of runoff for the catchment divided by inches of precipitation in the catchment for an appropriate time period) relative to climatic conditions at gaged streams throughout Michigan.** Annual index flow yields should be tracked for catchments in different regions and with varying climatic trends and levels of water withdrawal. The analysis should include gages with at least 10 years of data, and all gages with a period of record of 50+ years.

   In addition, recent stream gage data (minimum of ten years of record) for southwest Michigan streams should be used to attempt to quantify streamflow reductions in downstream areas potentially associated with upstream flow depletions. The spatial distribution of appropriate stream gages makes this type of analysis problematic. According to Miller and Lusch (2014), four of the top six irrigated counties in Michigan are in southwest Michigan. They determined the 2012 irrigated acreage in these counties to have been: St. Joseph (185 mi^2), Cass (75 mi^2), Branch (65 mi^2), and Kalamazoo (58 mi^2). According to NWIS https://waterdata.usgs.gov/mi/nwis/rt, there are at least 26 gages in southwest Michigan that have periods of record that are 10 years or more. Hence, every effort should made to complete this task within St. Joseph, Cass, Branch, and Kalamazoo counties, at a minimum.

   In addition to the WWAP's defined Index Flow metric, other metrics may be useful (e.g., mean August flow, mean August or July to September flow, etc.). Initial analyses such as correlation will likely be needed to determine the appropriate period for quantifying precipitation (e.g., March-September, June-September, August-September, etc.), to determine whether lags occur between precipitation and index flow and the appropriate precipitation period to use for calculating index flow yield values. If there are no detectable lag or storage effects, it would likely be most appropriate to match flow and climate periods for yield calculations. The Michigan State Climatologist's Office (https://climate.geo.msu.edu/index.html) shall be consulted to identify the best precipitation data sources for this work and to obtain insight on appropriate data summary periods. Yield values should initially be plotted annually for the entire period (Figure 2). Data can be grouped into other time periods (e.g., 5-year, 10-year, etc.) as appropriate. If possible, trends should be developed for all gages in Michigan having adequate data. At a minimum, trends in yield should be plotted and described for (a) different regions of Michigan, (b) areas where the climate has been wetter vs. drier in recent years, (c) streams that differ in hydrologic source (i.e., runoff dominated vs. groundwater dominated), and (d) streams in the same region that share precipitation patterns but differ in the magnitude of nearby water withdrawals.

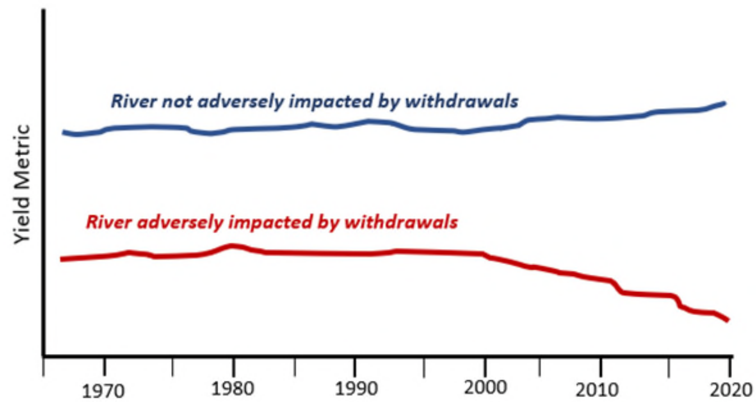

Figure 2. Hypothetical example of a yield metric plotted annually for the period of record for two streams. Top (blue) one showing no withdrawal impacts. Bottom (red) one exhibiting withdrawal impacts.

3. **Conduct literature review and empirical analyses to identify and provide underlying support for the appropriate spatial scale (e.g., WMA, entire upstream catchment of the WMA or a lesser portion of the WMA's catchment) for totaling cumulative withdrawals that potentially affect the index flow of each WMA.** Zorn drafted an initial approach to addressing this issue that may provide a starting point for developing a detailed plan for addressing this issue (Appendix). We recommend the research team use it as a starting point for developing and implementing a refined approach to address to this issue. Such an effort would complement and inform the more generalized but mechanistic modeling approach proposed by Reeves.

Approach

The above study will be accomplished via a post-doc to working in Dr. Dana Infante's lab at Michigan State University at a rate of $90,000 per year. We propose a 2-year project which would enable integration of additional factors (e.g., landcover changes) into these broad-scale temporal analyses and attraction of a highly qualified candidate for the project. A 2024 project start or date at least six months into the future will allow time for finding a suitable candidate. Overhead cost rate is 56.5%, but indirect cost rate can potentially be waived if EGLE provides a written statement specifying that the contractual arrangement is with MSU PERM (Partnership for Ecosystem Research and Management) which has a 0% overhead rate. Thus, 2-year project cost would be $281,700 with normal overhead or $180,000 with PERM.

PERM scientists shall confer regularly with developers of this proposal (i.e., Zorn, Lusch, Burroughs) and interested members of the Models committee of the WUAC, especially in the beginning 6 months of the project as analysis methods, approaches and scope iteratively develop.

References

Miller, S. and Lusch, D. 2014. Irrigation potential in Lower Michigan. Unpublished report to the Southwest Michigan Water Resources Council. 9 p.

Zorn, T., Ross, J., Infante, D., Yu, H., and LeBaron, A. 2022. Incorporation of watershed-scale accounting and water use sector-specific return flows in the Michigan Water Withdrawal Assessment Program's streamflow depletion accounting process: a statewide analysis. Workgroup report to the Water Use Advisory Council, February 2022. 20 p.

Appendix 1. Potential approach to consider for evaluating appropriate scale for accumulating streamflow depletions.

Analysis idea: Analytic approach for identifying the appropriate distance upstream of a WMA to accumulate streamflow depletions

Background:

- It's not feasible to address this question with new gages because long-term records are needed for many locations and answers to these questions cannot wait 40+ years for additional long-term data to come online. **Question**: What level of watershed-scale accounting best explains observed changes in index flows (IFs) between the WWAP's baseline modeling period (1971-2000) and the last decade (2010-2019)?
    - o We know that looking 0 miles upstream is wrong. For example, a 130 cfs flow depletion in a middle Muskegon River WMA does not magically disappear when going downstream and crossing a WMA line.
    - o 100% of the catchment may not provide the best fit to observed IFs. However, 100% makes the most sense, especially when return flow rates explicitly define the portions of the flow removed that may return to the system. What doesn't return (e.g., 90% of water withdrawn for irrigation) is consumed and cannot return, as demonstrated in studies reviewed by Shaffer (2009). If flow increases downstream, it would not result from return of withdrawn water that has been consumed. So it must have come from elsewhere.
    - o Need data from an array of watershed impact levels (e.g., 10% of watershed with Zone D, 80% of watershed with Zone D, etc.)
    - o Need a balanced sampling design so "no effect" scenarios (e.g., U.P.) don't swamp effects of interest.

Approach:

1. Identify gages to work on. Exclude the northern half of MI due to lack of flow depletions. Exclude gages installed for reasons that would make them anomalies. Possibly stratify gages by size (Small, Medium, Large) and % of watershed in Zone D (maybe 4 levels) to get even representation of conditions.
2. Estimate pre (1971-2000) vs post (2010-2019) changes in precipitation for watersheds of study gages. Consult with State Climatologist's Office on this. An alternate source (personal communication with Justin Titus (NWS)) on accessing long-term precipitation data is: https://xmacis.rcc-acis.org. Directions are: "Use the single station drop down menu and select monthly summarized data. From there select precipitation. After that, in the last set of option for location first change CWA (Essentially just the weather office covering the location). Use MQT for the Marquette office, which covers most of the UP, and APX for the eastern UP and northern lower. After selecting the CWA, select any stations in that area." Another possible contact is Andrew Gronewold drewgron@umich.edu, who is working on Great Lakes climate-related modeling.
3. For all study gages (possibly by size group) estimate:
    a. IFpost = f(IFpre, change in precip, cumulative flow depletions at an X km radius upstream of WMA). Save predicted IFpost values for each gage. To start, let X=20 km.

   b. Calculate absolute value difference between EstIFpost and ObsIFpost for each gage.
   c. Compute mean (or sum) of these differences (like a sum of squares).
4. Repeat step 3 for each accounting level, looking at various distances (radii) upstream of each gage. Starting at 0 (no accounting), incrementing up to 100% watershed-scale accounting (maybe 300 km, whatever it takes).
5. Plot mean of differences (y-axis) vs # km of upstream accounting for each scenario. Distance upstream where lowest difference occurs approximates the level of upstream accounting that best explains current IF's, given changes in precipitation over time and existing flow depletions.