Evaluation of streamflow depletion effects downstream through a stream network

Introduction

Streamflow depletion apparent in upstream parts of a stream network are hard to discern in downstream streamgage records. The current Michigan water-withdrawal assessment tool only estimates the local impact of surface-water or groundwater withdrawals on streamflow and only alerts the user to withdrawals that might cause a local adverse impact. If upstream depletions propagate downstream without any compensation in the system or dissipation along the network, then there is a potential for adverse impacts at downstream locations from accumulated upstream withdrawals that do not have direct local adverse impacts. Moreover, the water-withdrawal assessment process is based on peak depletion rates. For intermittent withdrawals, the streamflow depletion may be attenuated such that the peak rate reduced while its duration is increased. This attenuation conserves the volume of water removed from the stream network and lessens the likelihood of adverse impact. **The proposed study is designed to investigate how streamflow depletions might propagate downstream and combine to effect downstream reaches.**

Problem Statement

Given local, intermittent, streamflow depletion by a direct surface-water withdrawal or pumping well, how does the depletion propagate downstream? Does the stream network attenuate the response of the system such that peak depletion rate is not observed downstream in the network? What is the mechanism for this attenuation?

Hypotheses:

1. Hydraulics of flow in the channel and geomorphic dispersion by the stream network attenuate the stream depletion response leading to lower peak rates over longer periods such that, although mass is conserved, the peak depletion rate is not observed.
2. Exchange of water with groundwater allows the stream to access additional storage. This storage attenuates the peak depletion while lengthening the response time in the system. The mass removed is conserved, but peak rates are not observed.

Approach:

To test the hypotheses, a series of modeling analyses is proposed. These analyses will test mechanisms that would lead to attenuation of the stream depletion rates. By isolating the mechanisms, key features of the surface-water/groundwater system that help propagate or attenuate upstream depletion response can be identified. By better understanding these features, we may identify stream networks in the state that are more susceptible to upstream withdrawal and those that may be more buffered from upstream withdrawals. Identification of potential mechanisms also can help inform analysis of existing data or design of future data collection.

Stream hydraulic and river network effects testing (hypothesis 1) can build upon work by Wondzell and others (2007) and Fonley and others (2015). Wondzell and others (2007) looked at how the downstream propagation of daily signals in headwater streams can be used to characterize flows in stream networks. They noted that for stream networks with high baseflow and high flow velocity that the headwater signals tend to stay coherent downstream in the network and the daily signal is observed. For stream networks with low baseflow and low flow velocity, the daily signals become out-of-phase and the downstream signals tend to have lower peaks. In these lower flow systems, the signals may be attenuated so much that they cannot be discerned at downstream streamgages. Fonley and others (2015) used idealized stream networks and simplified flow equations to demonstrate how stream network topology and geomorphological dispersion (Rinaldo and others, 1991) can explain the observed behavior in daily ET signals. For Michigan downstream accounting, intermittent streamflow depletions are expected to have complicated patterns in upstream headwaters and the degree to which these local withdrawals will combine to propagate peak depletion rates downstream is unknown. Simple models such as those used by Fonley and others (2015), or other similar approaches, will be applied to investigate idealized networks designed to be like networks in different parts of Michigan. These networks will be tested with baseflow ranges representative of those observed in the state. **Results of this testing will illustrate how in-stream processes may affect the propagation of peak streamflow depletion rates.**

The effects of exchange with groundwater (hypothesis 2) can be tested by applying groundwater models with stream boundaries that will simulate changes in stream stage in response to changes in baseflow. Active exchange of groundwater and surface water has been well documented in the literature (for example, Covino and others, 2011), and applying simple models will allow testing of combinations of stream and aquifer characteristics to determine which combinations might lead to the most attenuation of streamflow depletion signals resulting from the exchange of water with near-stream storage. **The initial testing will explore different combinations of aquifer and streambed characteristics representative of systems in Michigan.** Idealized models can be used to show how far downstream signals might propagate under different conditions and isolate the important features of the system. **If accessing near-stream aquifer storage is determined to be a feasible mechanism through these simple models, coupled groundwater/surface-water models from areas in Wisconsin can be used to illustrate the effects using more realistic models calibrated with extensive field data** (Hunt and others, 2013; Hunt and others, 2016).

Timeline

The project is envisioned to require 2-2.5 years depending on the start date of the project. Those working on the project will be required to meet regularly with the Michigan Water-Use Advisory Council Modeling Subcommittee, or a subset of the committee, to keep the Modeling Committee appraised of progress and solicit input on test cases of interest.

Research Team

If the recommendation is accepted, then a research team will be assembled. The proposed budget is designed to support a junior staff member or graduate student working under the direction of a senior scientist. In addition to working with the Michigan Water-Use Advisory Council Modeling Subcommittee, the project team will be expected to coordinate with researchers focused on streamflow and climate records analysis, which is a separate recommendation from the model subcommittee, to exchange ideas and identify priority questions to study.

Budget Summary

The estimated budget, including indirect costs, is $235,000.

References

Covino, Tim; McGlynn, Brian; and Mallard, John, 2011, Stream-groundwater exchange and hydrologic turnover at the network scale: Water Resources Research, v. 47, no. 12, W12521, doi:10.1029/2011WR010942.

Fonley, Morgan; Mantilla, Ricardo; Small, S. J.; and Curtu, Rodica, 2016, On the propagation of diel signals in river networks using analytic solutions of flow equations: Hydrology and Earth System Sciences, v. 20, no. 7, pg. 2899-2912. doi:10.5194/hess-20-2899-2016.

Hunt, R.J., Walker, J.F., Selbig, W.R., Westenbroek, S.M., and Regan, R.S., 2013, Simulation of climate-change effects on streamflow, lake water budgets, and stream temperature using GSFLOW and SNTEMP, Trout Lake Watershed, Wisconsin: U.S. Geological Survey Scientific Investigations Report 2013–5159, 118 p., http://pubs.usgs.gov/sir/2013/5159/.

Hunt, R.J., Westenbroek, S.M., Walker, J.F., Selbig, W.R., Regan, R.S., Leaf, A.T., and Saad, D.A., 2016, Simulation of climate change effects on streamflow, groundwater, and stream temperature using GSFLOW and SNTEMP in the Black Earth Creek Watershed, Wisconsin: U.S. Geological Survey Scientific Investigations Report 2016–5091, 117 p., http://dx.doi.org/10.3133/sir20165091.

Rinaldo, Andrea; Marani, Alessandro; and Rigon, Riccardo, 1991, Geomorphological dispersion: Water Resources Research, v. 27, no. 4, pg. 513-525, https://doi.org/10.1029/90WR02501.

Wondzell, S. M., Gooseff, M. N., and McGlynn, B. L., 2007, Flow Velocity and the Hydrologic Behavior of Streams during Baseflow: Geophysical Research Letters, vol. 34, no. 24, 2007 doi:10.1029/2007GL031256.