APPENDIX 2

Net Inflow

The water balance in an aquifer can be represented by

Water volume change in aquifer = Inflows – Outflows

Prior to groundwater development, variations in groundwater levels will naturally occur during extended dry and wet periods as the inflows and outflows change in response to those conditions. However, the average inflows and outflows will balance over longer time periods, so the right-hand side of the equation will be zero and the system will be considered to be at a dynamic steady state.

In this dynamic steady state condition, inflows to an aquifer include

- Precipitation recharge, i.e., water falling on the earth's surface that is able to infiltrate past the zones of evaporation of soil moisture and uptake by plant roots to reach the water table. This includes water running off the surface into and then seeping below playas and ephemeral stream channels and into perennial streams where the water can enter stream banks or seep into the subsurface when flooding occurs.
- Lateral groundwater flow into the area.
- Vertical groundwater flow from underlying geologic units (such as the Dakota aquifer).

Outflows in this condition include

- Discharge of groundwater into streams
- Lateral groundwater flow out of the area
- Vertical groundwater flow into underlying geologic units
- Extraction of groundwater from the water table or capillary fringe just above the water table by plants (plants called phreatophytes such as cottonwood, willow, salt cedar) where the water table is very shallow, such as in the floodplain of a stream

When pumping from an aquifer occurs, water tables decline and the water balance has to readjust to accommodate the extraction of the groundwater. This can cause the following changes to inflows:

- Irrigation return flow, i.e., the amount of irrigation water applied to crops that is able to infiltrate below the zones of evaporation of soil moisture and plant root uptake
- Enhanced precipitation recharge over irrigated fields due to increased soil moisture allowing more rainfall to infiltrate past the zones of soil evaporation and plant root uptake
- Increased precipitation recharge along stream channels that became narrower or dried up due to the lowering of the water table
- Delayed drainage of water from smaller pores of the aquifer that were formerly saturated before water levels dropped in response to pumping
- Increased lateral flow into the area if the pumping lowered groundwater levels relative to neighboring areas of the aquifer
- Increased vertical flow into the aquifer from underlying units caused by the decreased hydraulic head in the aquifer resulting from water-table declines

Changes to outflows include

- Decreased discharge of groundwater to streams
- Decreased lateral flow out of the area if the pumping lowered groundwater levels relative to neighboring areas of the aquifer
- Decreased extraction of groundwater by plants unable to extend their roots to the lower water table

In effect, pumping of water from an aquifer for irrigation captures some precipitation that would have left the system through evapotranspiration, groundwater discharge to streams, lateral and vertical groundwater flow, and phreatophyte water use. In addition, the declining water table results in the slow drainage of recently dewatered sediments.

The term "net inflow" can be used to indicate all aquifer inflows and outflows except pumping (Butler et al., 2016) during groundwater development; the above equation thus changes to

Water volume change in aquifer = Net inflow – Pumping

If the goal is to have the water volume change in an aquifer equal to zero (i.e., stable water levels), pumping must equal the net inflow. In general, the capture of many inflows and outflows is rapid enough (over a span of a few years to decades) that a relatively constant net inflow value can be obtained from a plot of water-level change versus water use. Over most of the High Plains aquifer in Kansas, the net inflow has been near constant for the last quarter of a century or more (Butler et al., 2018).

Pumping reductions will eventually produce changes in net inflow as the various inflows and outflows will respond to those reductions. For example, all of the changed inflows listed above would be expected to decrease, albeit at different rates. In addition, the outflow to neighboring areas could increase. The timing of these changes in net inflow in response to pumping reductions has yet to be determined. Eventually, however, the net inflow will decrease, producing increased water-level declines for the same volume of pumping. Thus, further pumping reductions will be required to maintain the conditions experienced after the first round of reductions. Clarifying the timing of the reductions in net inflow and the impact of future pumping reductions is the focus of ongoing research (Butler et al., 2020a).

Determination of the role and timing of the individual components that comprise net inflow is difficult. For example, in GMD3, the estimated net inflow is 2.9 in./yr for 2005–2022 when averaged over the entire GMD3 area. Upward flow from the underlying Dakota aquifer in parts of GMD3 induced by substantial water-level declines could contribute some to the inflow in this GMD. However, completion of many irrigation wells in the Dakota aquifer in addition to the HPA in some areas of GMD3 would decrease upward flow so the volume of inflow to the HPA is unclear. Recharge from the Arkansas River infiltrating to the subsurface along the channel and in ditch-irrigated areas in GMD3 adds to inflow along the river corridor but is equivalent to less than 0.2 in. over the entire district area during 2005–2022. Unfortunately, this inflow is contaminating the HPA in the Arkansas River corridor with saline water high in uranium concentration (Whittemore et al., 2023). Recharge from the Cimarron River entering Kansas would be much smaller (substantially less than 0.1 in. over the entire GMD3 area). Thus, the vast majority of the net inflow is likely produced by the irrigation-induced inflows, the capture of outflows, and the slow drainage of previously dewatered material. The KGS is developing and refining a groundwater model of the High Plains aquifer in GMD3 that should shed needed light on net inflow and its components.