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Turning to Groundwater: An Engineering Perspective

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more expensive than smaller projects.

With a plan in place, the state can be more confident about their supply, but at some point of consumption, the risk of running out of water even with a plan in place becomes too much. Eric Wilkinson used as an example the historical level of water at Lake Mead, a high use reservoir, which has gone through draughts and re-fills in the past, but in the last 15-20 years has experienced a steady decline without any major re-fills. Even though the upper basin has had wet years the last six of seven years, the lower basin states' increased use has depleted most reservoirs. Therefore, all regions should be concerned with what happens when the next draught reduces runoff and water flows.

In conclusion, both speakers acknowledged that there is not a simple supply-side solution for the dramatic population increases in the region. In addition, there are future, unsolved legal issues regarding curtailment if the upper basin falls below their Compact obligations, which are vastly different depending on each compact state's interpretation. Colorado should utilize all the possible statewide supply options with agricultural transfers as a backup because variable hydrology and drier years ahead mean a decline in available runoff.

David Baker

TURNING TO GROUNDWATER: AN ENGINEERING PERSPECTIVE

Luke Harris, Daniel Niemela, and Christopher Sanchez, employees with Bishop-Brogden Associates, Inc., a water-consulting firm based out of Englewood, Colorado, discussed different classifications and legal issues concerning groundwater in the Rocky Mountain region and its effects on the residents of Colorado.

Harris started by explaining the difference in classification of groundwater between tributary and non-tributary aquifers and how both can potentially effect the doctrine of prior appropriation. He also discussed well augmentation plans and their purpose in administering tributary water wells, as well as how credits, water storage, and other measures restore future depletions. Harris then provided an informative legislative background into Colorado groundwater legislation, explaining how certain statutes helped define water rights to tributary water and established water permits. He also covered various provisions that encompassed banking, well fields, and gravel pits.

Next, Niemela discussed the basic aquifer types found in Colorado and how the geological features of these different aquifers effect the flow of groundwater. First, Niemela discussed alluvial aquifers, which consist of loose sands and gravels and run sub-parallel to streams. He also noted that, typically, the specific yield of alluvial aquifers is ten to twenty percent. Due to the large capacity of alluvial aquifers, recharge plans are effective because a large amount of surface water can be stored in alluvial aquifers. Second, Niemela talked about sedimentary

bedrock aquifers, which are comprised of sandstone and can be hundreds to thousands of feet deep. The specific yield of bedrock aquifers is typically lower than alluvial aquifers because the sands and stones in sedimentary bedrock aquifers are more compacted. A unique aspect of sedimentary bedrock aquifers is that artesian conditions are likely to be present, meaning that water in the aquifer is stored under pressure. Niemela also referred to the term "specific storage," which is the amount of water stored under pressure within an artesian aquifer. Not only do these aquifers provide access to groundwater, but they also have the ability to play a role in surface water storage.

Aquifer storage recovery is an emerging technology through which non-tributary aquifers store surface water for later uses. This can be beneficial because evaporated losses decrease in storage aquifers when compared to other storage sites, like reservoirs. Key geological factors of sedimentary bedrock aquifers are dipping beds, faults, and fractures, all of which control groundwater flow. In addition, sedimentary bedrock aquifers have different layering of rocks where the degree of layering controls the vertical flow of groundwater. Finally, Niemela spoke about hard rock bedrock aquifers that are typical tributary aquifers. The permeability is usually through fractures, which is also known as secondary permeability. With these types of aquifers, specific yield is low due to limited groundwater flow through the fractures. Thus, hard rock bedrock aquifers are unable to sustain high density well development. Niemela also talked about the kinds of processes engineers and hydro geologists use in evaluating users' groundwater resources.

Finally, Sanchez spoke about the various regulatory agencies and how they have an impact on the development of groundwater supplies. Sanchez explained that prior appropriation creates an important safeguard for existing users, but that it also has increased stress on the system. Sanchez discussed the importance of the Division of Water Resources, which administers water rights decrees, augmentation plans, and well permits for exempt, non-exempt, and headgate wells. Further, Sanchez emphasized that counties also play an important role through zoning of different residential areas and by coordinating with the state engineers' office to determine whether water supply is sufficient. Sanchez continued by discussing the positives of groundwater usage. He explained that groundwater is usually economically available, drought tolerant, and of good quality due to the natural filtration by sands and stones contained within aquifers. Some municipalities actually pump surface water into aquifers because of the filtration benefits provided by aquifers. Sanchez concluded by stating that, in the planning stage, it is important to consider the availability of groundwater, to drill and test for the presence and quality of the water, and to understand the current regulatory framework, so one knows what water rights are available.

Joseph Murphy