Open File 20-09

Review of the Jefferson County Water Supply Policies and Analyses for Land Development in Mountain Areas

By Peter E. Barkmann, Kenneth Swift Bird
and Karen A. Berry

Colorado Geological Survey
Colorado School of Mines

For

Jefferson County Division of Planning and Zoning

Jefferson County Colorado

Through a Growing Water Smart grant from the Sonoran Institute

2020

Review of the Jefferson County Water Supply Policies and Analyses for Land Developement in Mountain Areas

By Peter E. Barkmann, Kenneth Swift Bird
and Karen A. Berry

2020

Karen A. Berry
DIRECTOR AND
STATE GEOLOGIST

Dr. Terri Hogue
DEAN
Earth Resources and
Environmental Programs

OF 20-09

DOI: https://doi.org/10.58783/cgs.of2009.ktrq4514

Table of Contents

Cover: Wellington Lake, Jefferson County (L. Scott photo)

FOREWORD

The Sonoran Institute helps "communities find a balance between their built environments and the natural world around them." The Institute helps local governments, such as Jefferson County in Colorado, to guide growth sustainably. It is no secret that the foothills area of the Front Range is an attractive place to live. Close enough to urban amenities yet far enough away to provide a quiet alternative to the hustle and bustle of city life. The quest for both space and services results in growing pressure to develop the challenging landscape for low-density housing combined with commercial centers. Development in this landscape confronts limits imposed by the natural setting, including wildland fire and limited water availability. Water is essential but limited in the semi-arid foothills of Jefferson County. Planners and elected officials must balance the needs of a growing community with protecting the primary groundwater source with every development application. The Jefferson County Planning and Zoning Department evaluates proposals using land use and zoning regulations, plans, and policies designed to balance the built and natural environments. To ensure that the county's processes fairly and equitably meet these goals, Jefferson County planners received a grant from the Sonoran Institute for an independent review of its water policies, plans, and regulations for the foothills area. This publication summarizes the results of that review. Jefferson County received the Growing Water Smart award from the Colorado Chapter of the American Planning Association for this project.

EXECUTIVE SUMMARY

At the request of Jefferson County Planning and Zoning, the Colorado Geological Survey (CGS) has reviewed documents in the Land Development Regulation (LDR), Comprehensive Master Plan (Comp Plan) and Community Plans, and Zoning Resolution (ZR) overlay districts, as they pertain to groundwater quality and quantity in mountainous areas of Jefferson County. In addition, CGS reviewed the Water Availability Analysis (WAA) process used to determine the adequacy of physical water supplies for individual proposed developments. For mountainous areas, the county implements most water-related recommendations through application of the Mountain Ground Water Overlay District (MGWOD), ZR Section 41; the related Water Supply section of the LDR Section 21; and use of the WAA. Based on our review, we summarize our comments by specific task as specified by Jefferson County:

Task 1: Comprehensive Master and Community Plans

Jefferson County's Comp Plan is a countywide document designed to guide future actions in unincorporated areas. It presents a vision for the future, with long-range goals and objectives for land-use activities. Community Plans serve the same purpose but reflect the unique qualities of individual areas. This analysis compared the Comp Plan with the Evergreen Area and Conifer/285 Community Plans. Comp and Community Plans all contain recommendations for the protection of water resources, including water quantity and quality in both surface and groundwater. Recommendations are also geared toward protecting public health, the environment, and existing and future land use. However, there are instances where this process may not be adequate to fully meet the intents Comp and Community Plan recommendations in a consistent manner.

- **Wetlands**- The Comp Plan recommends protecting recharge of wetlands, while the Evergreen Area Community Plan states that riparian zones and wetlands should be protected; impacts to wetlands and riparian areas are not addressed in the MGWOD, LDR Section 21, or the WAA.
- **Water Quantity**- Community Plans recommend that development only use groundwater that is physically on the development site and that depletion should not be allowed beyond the ability of a development area to recharge itself. These recommendations are not in the current process and the WAA looks at the water availability of a subbasin rather than the development area.
- **Water Districts**- Community Plans recommend that recharge be to the groundwater source where centralized well-water systems are used. The WAA estimates recharge but does not evaluate whether recharge is to the depth of the groundwater source. Recharge to the original groundwater source is not addressed in the MGWOD or LDR Section 21.
- **Recharge Areas**- The Comp Plan has general recommendations to encourage efforts to better define and protect recharge areas and acknowledges that recharge from wastewater treatment does not necessarily reach depths and fractures from which well water is withdrawn. It recommends that recharge from sewage treatment systems occur in the same general area from which water is withdrawn, but recharge to the original groundwater source is not addressed in the MGWOD, LDR Section 21, or the WAA.
- **Compatibility**- The Comp Plan, Evergreen Area Community Plan, and Conifer/285 Area Community Plan have recommendations that proposed land-use activities be compatible with existing surrounding uses in terms of water and sewer, and the Comp Plan recommends the scale/density of a development be consistent with groundwater that is physically found on site. Compatibility of proposed land use activities with existing water uses is not specifically listed as a requirement in the MGWOD, LDR Section 21, or the WAA. Compatibility may be addressed by planners during rezoning or special use.

Task 2: Mountain Ground Water Overlay District (MGWOD)

ZR Section 41.D specifies requirements for a four-hour well-yield test for building permits, rezoning applications, site development plans, special use, and platting applications. When the sustained yield of a well is less than 1 gallon per minute, 300 gallons of storage is required. Since a 1 gallon per minute rate produces 1,440 gallons in one day, proof of 300 gallons of storage for yields less than that provides a safety factor of storage above an expected daily use of 200 gallons per day under normal conditions. A yield less than 0.14 gallons per minute would not be sufficient for a daily use of 200 gallons, even with storage. This lower threshold is not addressed in ZR Section 41.D.

Currently in Colorado, there are no requirements for monitoring water quality of individual well-water supplies. Adding a water quality requirement to the well-yield test in ZR Section 41 would be an effective way to bring monitoring of private water supply wells for quality in line with public water supplies.

Task 3: LDR Water Supply Section

Threshold values for water requirements of 0.28 and 0.10 acre-feet per year per acre are used to establish whether an aquifer test is required for rezoning and special use, or platting and site development applications, respectively.

These threshold values are consistent with the ranges of estimated water requirements for single-family dwellings on 1-acre lots. Changing the thresholds to the same volumes (0.28 and 0.10 acre-feet per year) per 5 acres would be more consistent with the overall intent of the local Community Plans.

LDR Section 21.C.2 specifies a minimum aquifer test duration of eight hours to establish stabilization of flow and draw- down for the aquifer. For typical commercial, municipal, and industrial wells, 24-hour pump tests are considered minimum. Longer tests have a better probability of indicating boundary conditions that can ultimately limit long-term sustained well production from an aquifer. We recommend increasing the minimum requirement to 24 hours, with a condition that the duration could be reduced if a shorter test demonstrates a positive boundary condition

Task 4: WAA

The WAA is intended to provide a rough approximation of the availability of an area to meet anticipated water demands for a proposed development. It has two components:

- An estimate of water requirements by the types of use for a proposed development.
- A basic water balance for a subbasin area where the proposed development is.

The water-balance component takes an estimate of anticipated consumptive use from the development and adds that to the existing water balance of the aquifer in the hydrologic unit, or subbasin, in which the development is located. That water balance takes into consideration inflow of water to the aquifer as recharge from precipitation specific to the area of the subbasin, and outflow from uses by existing development within the subbasin. In situations where the balance is in deficit, i.e., outflow exceeds inflow, the WAA calculates declines in storage as water declines, and sustainability in terms of time to deplete groundwater in storage.

Essentially, the WAA is comprehensive and includes the necessary components to achieve its main objective. However, there are several shortcomings. First, the two components do not seem to link together. Second, the main input parameters are estimated values not necessarily directly tied to empirical data. Furthermore, the results are shown in a numerical format that suggests levels of accuracy that are not possible. Finally, the WAA spreadsheet structure is hard to follow, and input parameters are not consistently documented:

Recommendations

- Provide for consistency where possible between the Comp Plan and Community Plans.
- Add a water quality requirement to the well-yield test in ZR Section 41.
- Change the water requirement threshold values for requiring an aquifer test on the site of a proposed development from 0.28 for rezoning and special use and acre-feet per [one] acre per year for plat or site development plan to 0.28 and 0.10 acre-feet per five acres per years.
- Lengthen the duration of the aquifer test to be more consistent with accepted standards for production wells.
- For large properties, we recommend adding a condition that additional aquifer tests would be required if production wells are proposed in areas underlain by different rock types than what is at the location of the test well.
- Add specifics for content of the Well Water Supply Report including a requirement for submitting a numeric table of aquifer test data.
- Integrate results of the aquifer test into the WAA so that the results support the use of proposed supply wells.
- Provide a concise cover page for the WAA.
- Results of calculations in the WAA should be rounded to a numeric format in line with the level of accuracy and quality of input parameters; alternatively, provide a qualitative flag for the summary result of a water balance, such as “positive” when the calculations indicate that there is enough water in a subbasin, or “negative,” if there is not.
- In the WAA provide detailed documentation of sources of input parameters.
- In the WAA use the same water requirement estimates arrived at in the Water Requirement tab in the WAA tab.
- In the GIS model for the WAA reconfigure the subbasin areas to eliminate downstream subbasins that straddle the main stream.
- Develop a monitoring program to validate and calibrate the WAA.
- Adapting hydrologic parameters to the distribution of basic aquifer types within a subbasin is not justified with the availability of geologic mapping in digital format limited to a scale of 1:100,000.
- The geology of the mountainous area of the county should be mapped in digital format at a larger scale, such as 1:24,000, to provide detail more consistent with the subbasin areas.
- Refine estimates of recharge rates to the crystalline bedrock. This would involve future studies and is contingent on more detailed geologic mapping.

INTRODUCTION

Jefferson County regulates land development in unincorporated parts of the county through a set of land development regulations and zoning resolutions. While the regulations and zoning resolutions cover many aspects of land development, certain parts deal with water supply. In particular, Section 21 of the Land Development Regulation (LDR) pertains to water supply in general, and Zoning Resolution (ZR) Section 41 establishes the Mountain Ground Water Overlay District (MGWOD) for the mountainous part of the county. The latter recognizes that most of the land development in the mountainous part of the county is reliant entirely on groundwater from fractured, crystalline bedrock. Fractured, crystalline bedrock forms an aquifer that is complex and highly variable. It is often referred to as the fractured, crystalline-rock aquifer, and is very common throughout the mountainous region of Colorado. Water availability for new development from this aquifer is not assured.

In addition, Jefferson County has a Comprehensive Master Plan (Comp Plan) that is a guidance document for land development decisions. This Comp Plan includes goals and policies related to water and water supply. Local Community Plans developed as collaborative efforts within individual communities reflect unique qualities of each community and add specifics to the Comp Plan. This analysis compares the Comp Plan with the Conifer/US 285 Corridor Area and Evergreen Area Community Plans. Both the Comp Plan and Community Plans include guidance policy and goals that pertain to water supply that seek to maintain sustainability of water supply as new growth comes along.

Jefferson County asked the Colorado Geological Survey (CGS) to review and comment on the various components of the land development regulations, zoning resolutions, Comp Plan, and Community Plans that relate to water supply. The intent of the county was to have a third-party review of how well the components tie together and how well they help guide decision-making to account for sustainability of water supply in the mountainous part of the county.

SCOPE

The scope of the CGS review is divided into four primary tasks. Each task calls for a review and preparation of general comments. Task descriptions are directly from the scope of work provided by the county to CGS.

Task 1: Research and provide general comments on the Jefferson County Comprehensive Master Plan. This plan is Jefferson County's guidance document for land use recommendations.

- Review the Goals and Policies related to Water in the Jefferson County Comprehensive Master Plan (pages 48–50 & 66–68).
- Review the water supply section in the Evergreen Area Plan (pages 40–42).
- Review the Water Quantity, Quality & Sanitation section of the Conifer/285 Corridor Area Plan (pages 31–33)
- Review the water usage values in the Appendix C: Environmental Section of the Jefferson County Comprehensive Master Plan (pages 99–100).

Task 2: Research and provide general comments on the MGWOD Section in the Jefferson County Zoning Resolution (Section 41). The Zoning Resolution is Jefferson County's regulatory document which specifies allowed land uses and activities.

- Review overall language in ZR Section 41
- Review the requirements for a 4-hour well yield test (Part 41.D)
- Review if a water quality component should be added to the 4-hour well yield test as part of the building permit application.

Task 3: Research and provide general comments on the Water Supply Section in the Jefferson County Land Development (Section 21). The Land Development Regulation is Jefferson County's regulatory document that includes specific submittal requirements including details for water supply.

- Review overall language in LDR Section 21
- Review the threshold requirements for an 8-hour aquifer test (Part 21.B.2.a.(4))
- Review if an eight-hour aquifer test is sufficient for higher water requirement projects (Part 21.B.2.a.(4))
- Review the data provided by the WAA and the eight-hour aquifer test (if required) and how the data in both correlate (Part 21.C.2)

Task 4: Research and provide general comments on the Water Availability Analysis (WAA), which is a GIS-based tool Jefferson County uses to evaluate water availability for development proposals that plan to utilize a water supply well in the fractured, crystalline-rock environment. The WAA takes into account existing land uses, existing and proposed water use requirements, expected groundwater recharge from precipitation and potential impact from proposed development on a subbasin level.

- Review data presentation in WAA (4 tabs)
- Review ArcGIS model including data sources
- Review hydrogeologic inputs utilized in WAA (green boxes listed as parameters in WAA tab)

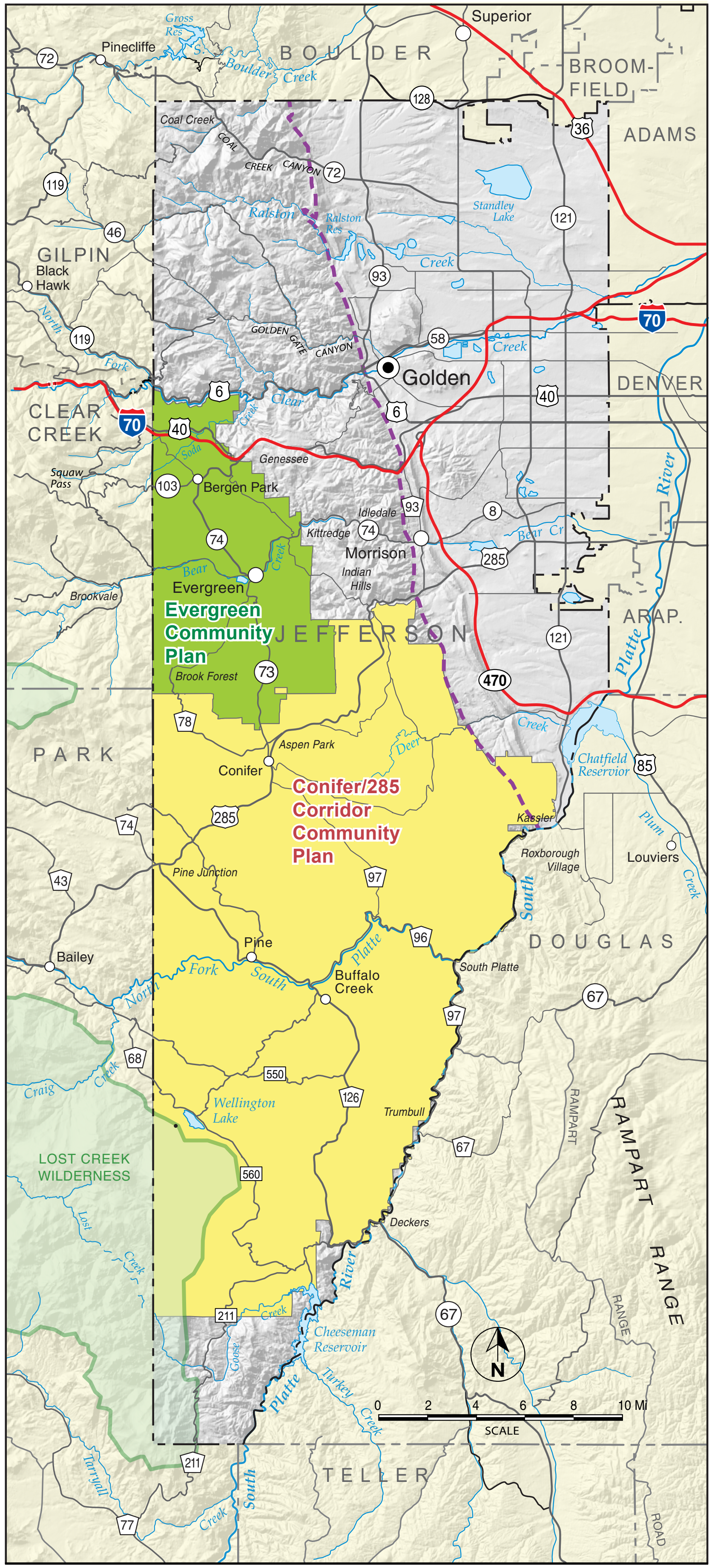
- Review Table 5a (WAA tab) including Water Budget (row 79 on WAA tab)
- Review if different Basin Aquifer Group (Table 1 on WAA) should have different hydrogeologic inputs

RESULTS AND GENERAL COMMENTS

Task 1: Review of Comprehensive Master Plan and Community Plans

Jefferson County's Comp Plan is a countywide document designed to guide future actions in unincorporated areas. It presents a vision for the future, with long-range goals and objectives for land use activities. The subarea, or Community Plans, serve the same purpose but reflect the unique qualities of each area and community. Together, the plans also allow the county to plan development in a way that protects natural resources valued by the community. It is clear that water is such a resource. Comp and Community Plans all contain recommendations for the protection of water resources, including water quantity and quality, and both surface and groundwater. Recommendations are also geared toward protecting public health, the environment, and existing and future land use.

Recommendations found in the Comp Plan and two Community Plans reviewed (summarized in Appendix A) generally fall into the following categories: environmental (wetlands and wildlife habitat), water quantity, water districts, groundwater recharge, combined water quality and quantity, water



Map of Jefferson County Community Plan areas and Mountain Ground Water Overlay District. Over half of Jefferson County extends into the foothills of the Front Range west of the Denver metropolitan area. In this rugged area, where elevations range from 6,000 to more than 10,000 feet, water supplies are limited primarily to groundwater from the fractured, crystalline-rock aquifer. Jefferson County has created a Mountain Groundwater Overlay District, west of the purple dashed line, to better manage growth through special requirements for well and aquifer testing. Individual Community Plans address locally important issues regarding land development, including water.

conservation, and water quality. Some recommendations do not distinguish between surface and groundwater. In such cases, we reviewed items that can be reasonably applied to groundwater.

For mountainous areas, the county implements most water-related recommendations through application of the MGWOD, the related water supply section of the LDR, and use of the WAA. This process allows the county to evaluate groundwater resources through all stages of the development process, from zoning to building permitting and site planning.

However, there are instances where this process may not be adequate to fully meet the intent of Comp and Community Plan recommendations. Some key examples are discussed below as are the water usage values in Appendix C of the Comp Plan.

- **Wetlands**- The Comp Plan recommends protecting recharge of wetlands while the Evergreen Plan states that riparian zones and wetlands should be protected from degradation. Evaluation of impacts to wetlands and riparian areas is not required by or included in the MGWOD, LDR Section 21, or the WAA.
- **Water Quantity**- The Evergreen and Conifer/US 285 Corridor Area Community Plans have recommendations on the scale and density of development. While worded differently, both plans recommend that development only use groundwater that is physically on the development site. In addition, depletion, beyond the ability of a development area to recharge itself, should not be allowed. These recommendations are not in the current process. In particular, the WAA looks at the water availability of a subbasin rather than the development area. This is an important distinction. Water availability on a development area is likely less than that available in a larger subbasin.
- **Water Districts**- The Evergreen and Conifer Community Plans recommend that in areas where centralized well-water systems are used, recharge should be to the groundwater source. The Conifer Plan recommends 90% of well water should be returned to the recharge area from which it is taken. While the WAA estimates recharge, it does not evaluate whether recharge is to the depth of the groundwater source. Recharge to the original groundwater source is not addressed in the MGWOD or LDR Section 21.
- **Recharge Areas**- The Comp Plan has general recommendations to endorse efforts to better define and protect recharge areas. It also acknowledges that recharge from wastewater treatment systems, including individual on-site systems, does not necessarily reach depths and fractures from which well water is withdrawn. However, the Comp Plan differs from the two Community Plans reviewed in that it recommends the recharge from sewage treatment systems occur in the same general area from which water is withdrawn. As with similar recommendations for water districts, recharge to the original groundwater source is not addressed in the MGWOD, LDR Section 21, or the WAA.
- **Water Conservation**- The Comp Plan recommends that the county encourage development to conserve water. It is our understanding that the county is working on water-conservation policies and guidelines.
- **Water Quality**- The Comp Plan recommends that development meet or exceed national and state standards for clean water. In addition, the plan also states that water supply must meet applicable drinking water standards. State water quality standards, as they apply to individual wells and private water supplies, and associated recommendations, are discussed in greater detail below.
- **Compatibility**- The Comp Plan and two Community Plans reviewed have recommendations that proposed land use activities be compatible with existing surrounding uses in terms of water and sewer. Language in the Comp Plan differs from that in the two Community Plans in that it recommends the scale/density of a development be consistent with groundwater that is physically found on site. While county planners likely evaluate some aspect of capability with existing water uses during a rezoning process, it is not specifically listed as a requirement in the MGWOD, LDR Section 21, or the WAA.
- **Water Usage Values**- The Comp Plan has a reference table of water usage estimates by common types (Section I.f. in Appendix C, pages 99 and 100). The table does not cite references; however, the water requirement references tab in the WAA spreadsheet links to a table from the Montana Department of Natural Resources, Division of Water Resources that has the same values suggesting that this may be the original source. The values listed are within ranges generally used in other applications of estimating water use. Colorado also has a similar geographic and cultural setting to Montana in many ways so using Montana values may be representative of ranges in Jefferson County. As discussed in the Task 4 comments, units used in some of the example WAA calculations do not match those in the water usage table in the Comp Plan. In addition, water-use values are included in the Comp Plan that are not always being used. We recommend consistent use and documentation throughout the planning process.

Task 2: Review of the MGWOD

As stated in ZR Section 41, the MGWOD is "…intended to promote the public health, safety and general welfare of the citizens of Jefferson County by regulating land uses in order to maintain ground water resources. This District was established to address water resources in the fractured rock environment." Generally, the language and structure clearly describe the district with its applicability and provides requirements to help meet the intents of the district. Comments on specifics are discussed below.

- **Requirements for a Four-Hour Well-Yield Test**- ZR Section 41.D specifies requirements for a four-hour well-yield test for building permits. A four-hour well-yield test simulates a high-demand cycle for a typical household well. It provides data used in evaluating physical characteristics of the well and the aquifer immediately around the well. These characteristics influence how long water can be pumped from the well at given rates under normal operating conditions for a typical household. These requirements seem reasonable for typical household and domestic wells. When the sustained yield of a well is less than 1 gallon per minute, 300 gallons of storage is required. There are 1,440 minutes in a day and a sustained yield of 1 gallon per minute would produce 1,440 gallons of water. This volume is more than adequate for the typical needs of a household (200 to 250 gallons per day for a four-person household listed in the table in the Comp Plan). This threshold provides a safety factor of storage above expected daily use under normal conditions for requiring proof of storage. A daily use of 200 gallons would require a minimum sustained yield of 0.14 gallons per minute and this lower threshold is not addressed. If the results of the yield test fall below this threshold, the yield would not be enough to replenish natural storage in the well and a supplemental source of water would be necessary.
- **Water Quality Requirement for a Well-Yield Test**- Currently in Colorado, there are no requirements for monitoring of water quality of individual well-water supplies. There are limited requirements for potability at the time of sale of a property, but these are limited to nitrate and bacteria. Under the United States Safe Drinking Water Act (SDWA), there are requirements for monitoring public water supplies for a number of constituents, with both primary and secondary standards. Colorado has primacy under the SDWA for regulating public water supplies but does not have the authority to regulate private sources. Adding a water quality requirement to the well-yield test in ZR Section 41 would be an effective way to bring monitoring of private water supply wells for quality in line with public water supplies.

Task 3: Review of the Water Supply Section, LDR

LDR Section 21 sets standards, requirements for documentation, and guidelines for plans for development proposals. Developments can be of two types: 1) developments that tie into existing approved public water districts or companies, or 2) developments that use wells not part of a public system for water supply. Requirements for developments that use a well water supply system, as described in part B of LDR Section 21, are more extensive than for a development simply tying into an existing public water system. Most development in the mountainous area of the county fall into this second type. The requirements include proof of legal water, or that the applicant can demonstrate that it has adjudicated water rights for that water to be used by the development. Requirements for platting and site development plan applications also include submittal of a Well Water Supply Report. This report includes a requirement for an Aquifer Test under defined circumstances. LDR Section 21 also specifies that Planning and Zoning Staff will also provide a WAA of the proposed development. Specific requirements are described below.

- **Threshold Requirements for Aquifer Test**- Under LDR Section 21, an aquifer test is required for a proposal for rezoning or special use if the water requirement for the proposal is greater than 0.28 acre-feet per acre per year, as determined from the water requirements analysis in the WAA discussed in a later

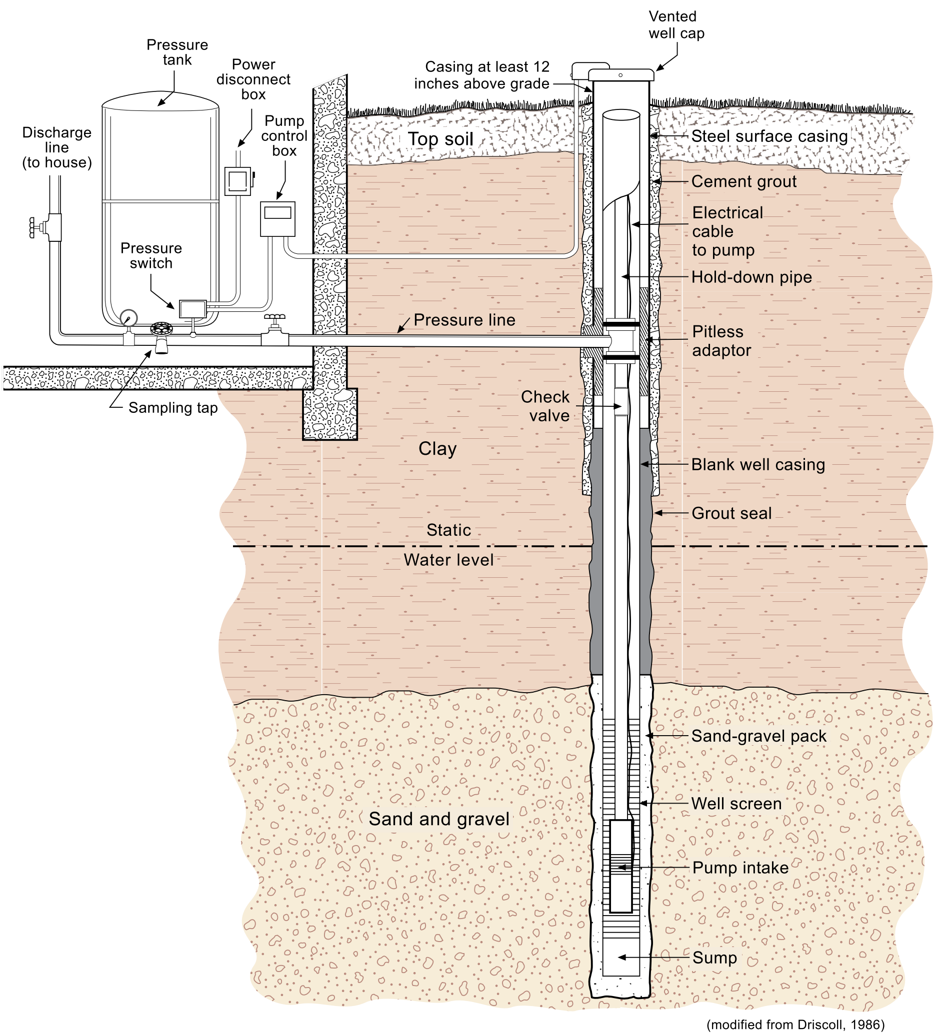
A wellhead rises about 1 foot above the ground and is capped with a sanitary seal. There also may be a conduit for wiring. Much more lies below the surface within a borehole that could extend hundreds of feet into bedrock. That borehole holds protective casing, a pump with wiring, and piping to bring water from the pump to the house.

section in this report. For a plat or site development plan, that threshold drops to 0.10 acre-feet per acre per year. These threshold values equate to 250 and 90 gallons per day per acre, respectively, which are consistent with a range of water use values expected for single-family dwellings on a one unit per acre density. A lower density of one single-family dwelling unit per 5 acres is called for in the Conifer/285 Corridor Area Plan. Areas with constraints, like steep slopes and critical wildlife habitat, may have lower densities, while areas in activity centers, with public water and sewer, may have higher densities. The plan also states: "The need for an aquifer test for a proposed development will be determined on a case-by-case basis through consultation with Jefferson County Public Health if the proposal has a water requirement greater than 0.28 acre-feet per year (the equivalent of 250 gallons per day per acre)." In the Evergreen Plan, recommended densities vary according to use areas and constraints.

The plan also specifies a threshold of 300 gallons per day per 10 acres for recommended supply by public centralized water systems for nonresidential development. Changing the thresholds for an aquifer test to 250 and 90 gallons per day per 5 acres would be more consistent with the overall intent of the Conifer/US 285 Corridor and Evergreen Area Community Plans

- **Aquifer Test Requirements**- An aquifer test is required for development proposals with water requirements above the thresholds discussed above. The objective of the aquifer test is to demonstrate the ability of the aquifer beneath the property to sustain water yields to meet the anticipated requirements of the development. The aquifer test standard in LDR Section 21.C.2 specifies at least one viable aquifer test where individual wells are proposed and that the test shall be of a duration of a minimum of eight hours.

An aquifer test differs from a well-yield test specified for in the MGWOD in that it is conducted to assess a larger area of the aquifer away from the well and to evaluate the ability of a well in the aquifer to sustain yield over an extended period of time. For this purpose, the standards call for a longer test duration of 8 hours instead of 4 for a well-yield test and monitoring of water levels in the well being tested along with any existing wells within the proposed development property. The standard also recommends monitoring water levels in off-site wells within 600 feet of the production well, if permission is obtained. Monitoring of water levels in the well being pumped and other observation wells is to continue for at least 24 hours after pumping stops. Data are to be included in the Well Water Supply Report.



A typical domestic-type water system connects a submersible pump in a water supply well to a pressure tank in the building where water is used. Aquifer types can be quite different depending on location. This diagram shows a well in a porous sand and gravel aquifer, typical for areas in the eastern plains or in large valley areas. In the foothills, the main aquifer is fractured, crystalline bedrock where water moves through and is stored in fractures in an otherwise nonporous material. The height of the static water level above the pump represents storage volume in the well and is a function of the wellbore diameter.

Aquifer test data are shown as graphs of water-level measurements plotted over time for the duration of the test. The slope of the line connecting the points represents the rate of drawdown. As specified in the standard, yield of the well being tested is determined as a stabilized pumping flow rate where neither the pumping rate or the rate that drawdown increases change by more than 10%.

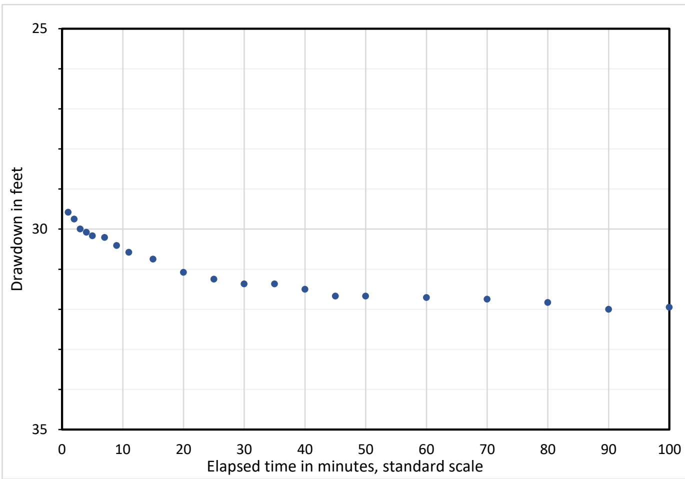
For large production wells, it is important to determine if there are limiting boundary conditions in the vicinity of a well. Boundary conditions can consist of changes in the geometry or geology of the aquifer that affect how the aquifer performs. These changes can work in two ways. First, a boundary condition may be the physical edge of the aquifer or a reduction in permeability caused by changes in geology that decrease the ability of the aquifer to continue to produce water to the well. In a fractured, crystalline-rock aquifer, this could be a closing-up or decrease in density of fractures. Such a boundary would be seen as an increase in the rate of drawdown or steepening of the drawdown curve. That change in drawdown rate could increase the rate of drawdown beyond the 10% stabilization specified in the standard during the final hour of the test. The conclusion from this would be that the rate has not stabilized as required. Alternatively, a boundary may be an increase in the ability of the aquifer to yield water. Such a boundary may be a nearby surface body of water in direct connection with the aquifer. This type of boundary would be seen as a decrease in the rate of drawdown or leveling off of the drawdown curve. In this case, the drawdown has stabilized. It is important to keep in mind that both the drawdown and flow rate need to stabilize within 10%. Drawdown can be forced to stabilize by purposefully decreasing the rate during an aquifer test, but this is contrary to the requirement that both drawdown rate and pumping rate cannot change by more than 10%.

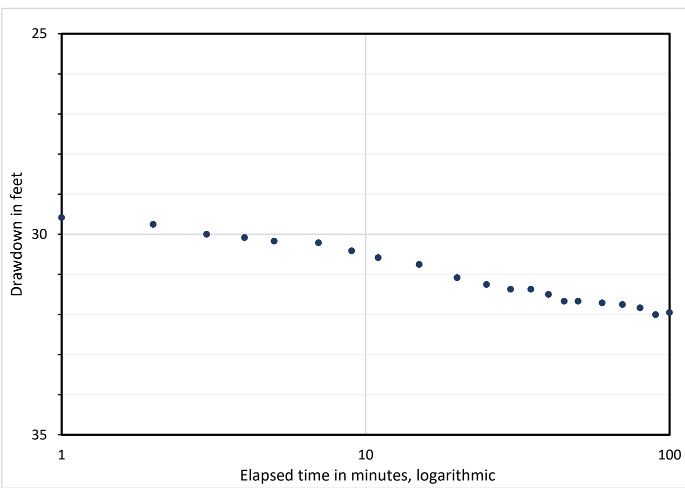
Fractured, crystalline bedrock, which is mostly massive granitic rock or banded gneiss, makes up the primary aquifer in the foothills. The rock itself has no significant pore space between crystal grains to hold water; instead, water moves through open fractures. In this photo, a borehole drilled for blasting to widen a roadway cuts through granitic rock, illustrating what a well would look like viewed from underground. In this example, the borehole hole intersects several fractures that could carry water.

In a granular aquifer, the influence of well pumping expands radially over time from the well. The mathematics behind this geometry of flow means that the effect of the well moves outward from the well at an ever-slowing rate. A short-term test provides information about the area close to the well, while a longer-term test provides more information for a larger area. It may be argued that the radius of influence of an aquifer test in a fractured, crystalline-rock aquifer setting will not expand as one would in a granular aquifer. For example, when a well produces from a single open fracture, the influence of pumping may expand away from the well in a more linear and rapid fashion so that boundary conditions may be seen in a shorter time. This hypothetical condition is dependent on the geometry and density of fractures, information that simply may not be available for specific wells. It is conservative to assume that in a typical fractured, crystalline-rock aquifer the well will respond in a similar fashion to a granular aquifer.

For production wells designed to serve municipal, commercial, or industrial needs, well tests performed to assess an aquifer are typically run for a minimum of 24 hours. An eight-hour test as specified in LDR Section 21 is really not of sufficient duration to test an aquifer for a production well. We recommend lengthening the duration of the aquifer test to be more consistent with accepted standards for production wells. Because of the exponential nature of expansion of the area of influence, the time period for demonstrating stabilization should be increased from one hour to three at the end of the test. Under special circumstances, a recharge boundary might be identified in a shorter time period and there could be language to account for this possible scenario.

A single aquifer test seems adequate for small development sites where there may not be changes in rock type beneath the proposed development site. For developments on large parcels, particularly on parcels where there are changes in rock type and where wells are proposed in areas of differing rock types, a single aquifer test may not be sufficient. The Turkey Creek Watershed study by Bossong and others (2003) grouped rock types into four major classifications because of possible differences in hydrologic properties: intrusive, metamorphic, fault zone, and Pikes Peak granite. For large properties, we recommend considering adding a condition that additional aquifer tests would be required if production wells are proposed in areas underlain by different rock types based on this classification.





Drawdown plots from a well in western Kansas tested at a rate of 449 gallons per minute illustrate the concept of stabilization of drawdown during a test. Points on the graph mark depth to the water in the well as time elapses since the start of pumping. The upper plot is a standard plot that shows the parabolic shape of the curve becoming nearly flat later in the test. A parabolic shape reflects the radial nature of the flow of water toward the pumped well. The lower plot is the same data but with the time scale in a logarithmic format that shows a straight line continuing at about the same slope. The test is considered stabilized when the amount of increased drawdown does not exceed a prescribed amount in a specified increment of time. The current aquifer test requirements call for 10% change in drawdown during the last hour of an eight-hour test, where flow rate does not change by more than 10%.

The standard for the aquifer test, LDR Section 21.C.2., calls for documentation of aquifer hydraulic properties with a narrative describing the adequacy of the water supply in the Well Water Supply Report. This requirement seems too general for what is expected from this type of test. There should be minimum requirements for the content of this documentation and narrative. Furthermore, this standard should require that the water-level and flow-rate data over time from the test be included as a numeric table.

- **Integration of Aquifer Test Results with WAA-** Results of the aquifer test should be integrated in the WAA in a manner that the aquifer test demonstrates that the aquifer, and proposed wells, are sufficient to the anticipated water requirements. The WAA further seeks to demonstrate that the water is physically available within the sub-basin that the proposed development is in from a water balance perspective. As discussed below, the WAA does include a place to list results of the aquifer test to facilitate that integration. It is unclear how an analysis of the data is presented for easy comprehension in the context of the WAA.

Task 4: Review of the WAA

General Comments

The WAA generalizes conditions in a complex and highly heterogeneous hydrologic system to identify whether there is sufficient physical water available to meet the demands of a proposed development. A WAA is completed for each development during the rezoning application process. Jefferson County Planning and Zone staff perform the WAAs, but applicants can also prepare their own for consideration as part of the negotiation process. The WAA process has a two-fold approach for a hydrologic unit, or geographic subbasin area, where a proposed development is located. In this process a WAA calculates:

(1) A water balance of water inflow and outflow to the sub basin, and

(2) Available water in storage in the aquifer beneath the subbasin.

The WAA formulates the water balance from existing uses, adds the impact of the proposed development, and evaluates sustainability over time by factoring an estimate of the available water in storage in the aquifer. While the WAA incorporates many parameters in its analysis, it essentially relies on only three components:

(1) Inflow from recharge,

(2) Outflow by wells, and

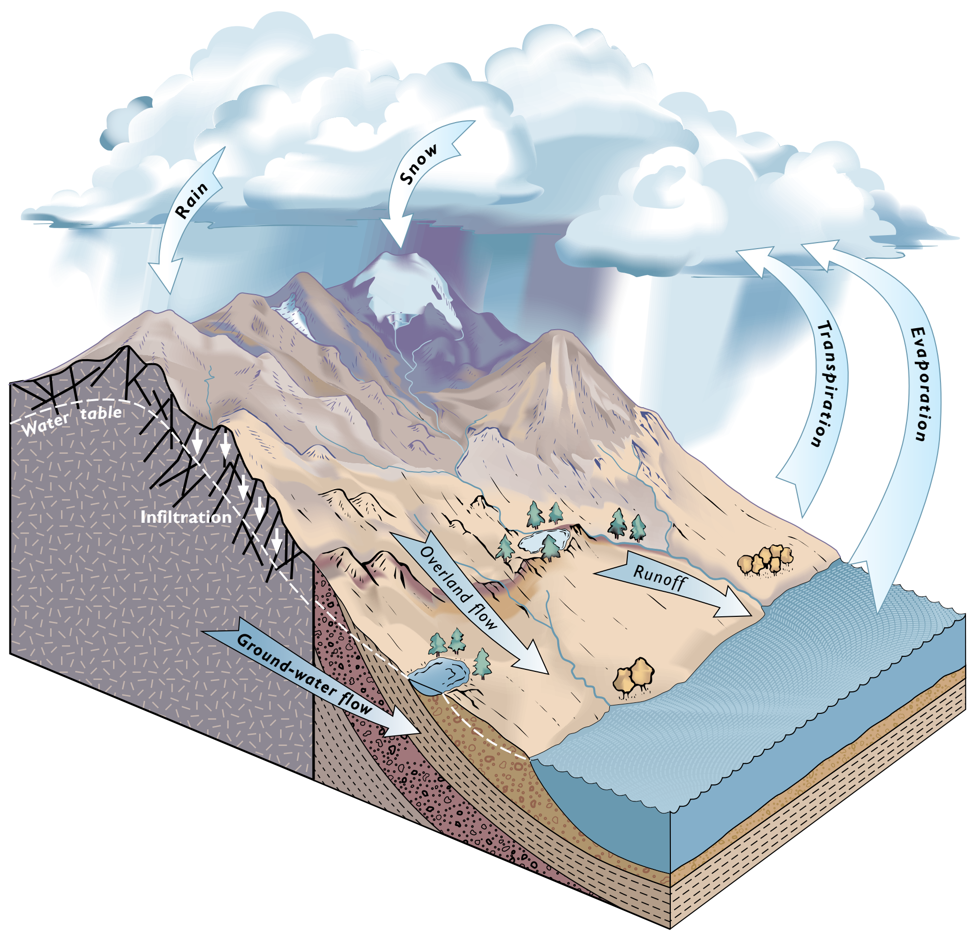
(3) volume of storage in open fractures in the crystal line-rock aquifer.

Reliable empirical data are not available for these three components and each estimate in the analysis is made using indirect methods. It is important to keep expectations of what the WAA can do in line with these limitations. It should also be emphasized that the WAA process addresses the physical availability of water for the proposal but does not address water quality.

Parameters and Hydrologic Inputs

Appendix B provides a detailed discussion of the WAA structure and the many parameters used in the process. Thirty-nine parameters enter into the analysis: Many are inputs of physical characteristics of the subbasin; many are details from the proposed development; and many are results from previous calculations in the WAA. As already pointed out, the essential components in the WAA are estimates, rather than empirical data. These are:

- **Water inflow from recharge-** natural recharge from precipitation over the footprint of the subbasin or recharge of water pumped from wells. Both estimates in the water balance are arrived at indirectly using estimated percentages from the literature. The estimate for recharge from precipitation takes into consideration the portions lost to direct evaporation and transpiration by vegetation, or evapotranspiration, and runoff. The estimate for recharge from wells is that water that is not consumed by use and is therefore assumed to return to the aquifer after treatment, typically through leachfields.
- **Water outflow from well use-** the total of well production from existing wells plus new wells for the proposed development. For most wells within the subbasins, production is estimated by well type using a value less than the maximum annual volume allowed by the permit. Commercial and municipal wells may have meter data, but these are the exception. Commercial and municipal wells also have maximum production and/or flow rates specified in their water rights decrees. These values can also be used; however, these values are not as reliable as actual meter data.
- **Available water in storage in the sub-basin aquifer-** an estimate using saturated thickness of the aquifer. This estimate is based on an average depth of all existing wells in the subbasin, porosity of the fractured, crystalline-rock aquifer, and an estimate of the ability of fractures to yield water to wells. The porosity estimates are of a physical property that may be quite variable, and values used are from the literature. While using the average depth of existing wells in the basin defines the saturated thickness by existing usage, the actual depth of the fracture network could go much deeper.



A water balance is integral to the greater hydrologic cycle. Water moves continuously, with evaporation sourcing water in the atmosphere. Atmospheric water eventually falls as precipitation, which in turn provides a source of surface flow and groundwater flow that take the water back to the source for evaporation. Some water is held in storage either in surface water bodies or in the ground as groundwater. Volumes of water, evaporating, falling as precipitation, and moving as surface flow or groundwater flow must always be accounted for in a water balance.

ArcGIS Model

The WAA pulls in hydrologic data by subbasin in ArcGIS. Delineation of the subbasins used in this process is detailed in the discussion of WAA input parameters in Appendix B as Parameter A - Basin Area. The use of subbasin areas to gather inflow and outflow parameters by discrete hydrologic areas is an efficient way to compile data from multiple sources. However, water availability is dependent on the size and extents of the subbasin. And as discussed previously, Community Plans recommend considering water availability limited to the specific development footprint area rather than the subbasin it is in.

The concept of subbasin used in the WAA process is consistent with delineating hydrologic units of watersheds as done in typical hydrologic studies. Subbasins can include both headwater subbasins at the top of a watershed and downstream subbasins. The WAA analysis does not require an estimate of inflow from upstream subbasins since the water balance simply looks at inflow and outflow from the footprint of the subbasin where the proposed development is located. It is important to note, however, that inflow from upstream subbasins can affect the water balance and ultimately impact the sustainability of a subbasin.

WAA Structure

Each WAA has two sections:

(1) a ***Water Requirements*** tab, and

(2) a ***WAA*** tab.

Cells in the *Water Requirements tab* calculate the anticipated water use by the proposed development and determines if an aquifer test is required under LDR Section 21.B.2. This analysis further computes consumptive use from that total water usage. It also provides a place to document the results of any aquifer tests performed.

Cells in the *WAA* tab calculate the water balance of the subbasin and estimate the water in storage in the aquifer beneath the subbasin where the proposed development is located. Additional functions estimate how quickly storage will be depleted and predict how quickly water levels will fall if the water balance shows a deficit. There is a complex progression of calculations with many elements that tie together to lead to indications of water sustainability.

Table 5a of the *WAA* tab provides a critical summary for the subbasin where a proposed development is located. It estimates the balance of inflow from recharge and outflow from consumptive use. The consumptive use includes existing uses in the subbasin and the addition of those from the proposed development. It is a simple mathematical subtraction of consumptive use from groundwater recharge. If the result is positive, there should be enough water in the balance of the subbasin to sustain existing uses and the proposed new use. A negative value suggests that the groundwater resource is not sustainable even without adding the proposed new use. This is a very simple and clean analysis of the water balance for a subbasin that is based entirely on the footprint of the subbasin.

Even though the WAA process may address the intended purpose of estimating physical water availability, the spreadsheet layout and documentation fall short of presenting the progression in a clear and concise manner. As structured, the WAA spreadsheets are hard to follow and understand. It would be helpful for there to be better introductory discussions of the intent and progression of each component. Documentation of data sources should also be detailed.

A clearly labeled cover summary tab that brings the main output parameters together would facilitate comprehension of the results of the WAA and thereby allow comparison of elements against each other and standards in the land development regulations. Integration of the *Water Requirements* tab with the *WAA* tab seems to be lacking, with the two appearing to serve separate purposes when they could, and should, link. In particular, the *Water Requirements* tab calculates consumptive use by anticipated development use-type while the *WAA* tab applies a value for consumptive use for the proposed development estimated based on well type for the development in its estimation of recharge. The first estimate should be considered more representative of the development's potential impact. The second estimate should show that the proposed well supply meets the anticipated demand.

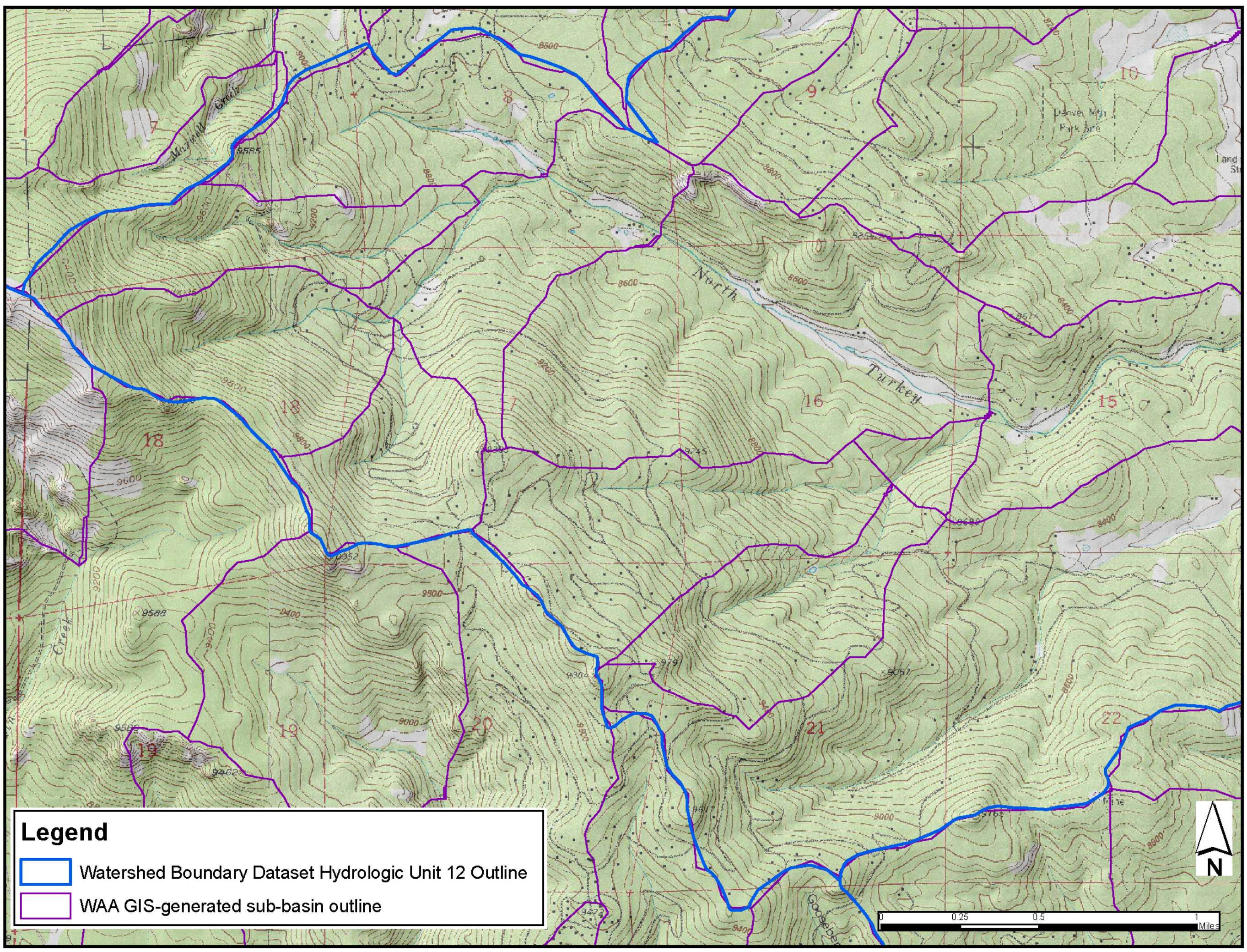
Basin Aquifer Groups

Although the current WAA lists different rock types for the basin aquifer groups, the distribution by type is not used in the analysis. The relative distribution of rock types across a sub-basin could affect the porosity value in estimating available water in storage. Infiltration rate and groundwater recharge may also differ by major rock type, but these differences are not well characterized.

Existing geologic mapping across the mountain area is not consistent in style, detail and scope. Our understanding is that the GIS digital geologic map data used for the WAA is from the 1:100,000 scale mapping available from the United States Geological Survey (USGS). These maps include the Denver West 30' X 60' quadrangle map by Kellogg and others (2008) and the Bailey 1 30' X 60' quadrangle map by Ruleman and others (2011). Both of these maps are compilations of other geologic maps, many of which are 1:24,000 scale quadrangle maps. Of these maps, many were provisional maps never published as final map products. These source maps also represent mapping efforts over several decades of time by many different authors. With such diversity these maps were often generated with different geologic mapping styles and objectives. By necessity preparing a smaller scale compilation such as the two GIS source maps used in the WAA requires some generalization and a loss of detail.

Detail of the 1:100,000 geologic compilations may be oversimplified for the scale of the subbasin hydrologic units used in the WAA. A quick review of aerial photography of the area around one proposal from the Marshdale area indicates that the extent of the Quaternary surficial deposits may be greater than the generalized map indicates. Thick Quaternary cover can include alluvium, colluvium, or sheetwash deposits, all of which may have much higher porosity and permeability than the underlying bedrock units. Furthermore, very linear trends of drainage patterns are apparent that may indicate the presence of faults that are not shown on the map. They may also be areas where the bedrock is highly fractured. Because of poor exposure, areas where bedrock is more fractured are often not shown on geologic maps. The possibility of both greater extent of Quaternary deposits and undocumented faulted and fractured areas can change how to consider infiltration rates and storage in a water balance.

The WAA uses an estimated 2% value for porosity universally in the estimation of available water in storage. This value is within the range expected for fractured, crystalline rocks typical of the mountain area of Jefferson County (Lane and others, 1995; Schild and others, 2001). At a subbasin scale, existing detailed and consistent geologic data in GIS format for the entire county's mountainous areas are currently not available. Given the intent of the WAA and the complexity of the area, this estimated value seems reasonable.



The WAA computes a water balance over a subbasin area. Subbasin outlines, shown as thicker purple lines, are generated by a GIS tool using a digital elevation model (DEM) of the area's topography. Subbasins in the WAA resemble larger formal hydrologic units, such as the USGS National Hydrologic Dataset WBDHU12 unit for the Turkey Creek watershed, shown with the thinner blue outline.

RECOMMENDATIONS

Based on our review of the Comp Plan and land development regulations that pertain to water supply, we make the following recommendations:

Comp Plan and Community Plans

- We recommend that there be consistency where possible between the Comp Plan and Community Plans.

MGWOD

- We recommend adding a water quality requirement to the well-yield test in ZR Section 41.

Water Supply Section of the LDR

- We recommend changing the water requirement threshold values for requiring an aquifer test on the site of a proposed development from 0.28 for rezoning and special use and acre-feet per [one] acre per year for plat or site development plan to 0.28 and 0.10 acre-feet per five acres per years.
- We recommend lengthening the duration of the aquifer test to be more consistent with accepted standards for production wells
- For large properties, we recommend adding a condition that additional aquifer tests would be required if production wells are proposed in areas underlain by different rock types than what is at the location of the test well.
- We recommend adding specifics for content of the Well Water Supply Report including a requirement for submitting a numeric table of aquifer test data.
- We recommend integration of results of the aquifer test into the WAA so that the results support the use of proposed supply wells.

WAA Process

- We recommend a restructured WAA worksheet designed to better explain the review process. This should include a cover sheet that brings forward the results vital to decision-making and clearly explains in a logical order the input and calculation process. For example, results from the Water Requirements tab calculations of total demand could be shown next to total estimated capacity of proposed wells based on the aquifer tests. This would allow a reviewer to quickly see if the proposed supply is adequate to meet the anticipated demand.
- We recommend rounding the numeric results of calculations. Since the WAA is a very simple analytical tool that uses general estimates as the primary inputs, it is important to clearly portray the level of accuracy that the inputs allow. In the summary sheet, it would be best to round values to a significant digit that more closely reflects the type of input data. The examples provided listed the results to two or three significant digits, which suggests some level of confidence than is greater that the confidence in the input data. A summary sheet could simply show the balance as either positive or negative.
- We recommend more thorough documentation of sources of input parameters.
- We recommend using the consumptive use result value from the Water Requirements tab for the consumptive use input for impact of the proposed development on the subbasin water balance in the WAA tab; it does not make sense to work with two different values for consumptive use arrived at by different methods.
- We recommend delineating subbasins in a manner that avoids downstream subbasins that straddle the watershed axis. This would facilitate validation of the WAA water-balance results using water level monitoring data. A negative result in Table 5a of the WAA indicates that water would be removed from storage over time. This should result in water levels dropping in the subbasin as estimated in Table 5b. However, in downstream subbasins as delineated, inflow from upstream would replace water lost and water levels might not drop as anticipated.
- We recommend systematic monitoring of water levels in the mountainous area. Model results from the WAA could be improved via validation and calibration with transient water-level data across Jefferson County. Developing an effective monitoring program would ensure that model outputs from the WAA reflect real world conditions, and a monitoring program could also delineate areas in Jefferson County with highly impacted groundwater resources (i.e., "hot spots") that are susceptible with further development. Groundwater monitoring can be conducted via automated, noninvasive methods, and developing a groundwater monitoring network in Jefferson County would greatly improve the accuracy of the WAA to ensure that groundwater resources are being used sustainably. Monitoring in watershed subbasins instead of downstream subbasins would provide better validation of the WAA process because there should not be an inflow component from upstream areas.
- We recommend further refinement of recharge estimates by rock type, elevation, slope, and aspect. Recharge rates from precipitation are one of the driving factors of the WAA and are currently estimated from a water balance completed by Bossong and others (2003). Those rates were further used to develop regression equations for recharge rates in the major aquifer types found in Jefferson County (CDM, 2011). Results of these regression analyses

were not always consistent with expected behavior by rock type. In particular, in the regression analyses recharge rates in fault zones were predicted to be lower than those in areas underlain by metamorphic and igneous rocks. We would expect the opposite since fault zones can be more fractured. This suggests that there are assumptions that are not correct in how the data are being applied in the water balance and regression analyses, particularly for recharge by different rock types. It may also reflect the lack of detail in geologic mapping at a scale that fits the application of the models. It may also indicate that other factors such as elevation, slope and aspect may contribute to recharge rates.

- We recommend refined geologic mapping at a scale larger than 1:100,000 to better characterize distribution of aquifer types. New technologies are also available that could increase geospatial characterization of geologic features important to hydrologic conditions. Fracture density is a critical factor in determining and permeability in fractured, crystalline rock. Distribution of unconsolidated surficial deposits can impact near surface groundwater storage and potentially recharge rates. Lidar is a new technology that can be used to analyze surface conditions even in heavily vegetated areas.

REFERENCES

Bolay-Koenig, N.V., 2001, Phanerozoic Deformation in the Southern Rocky Mountains, U.S.A. – A Kinematic Analysis of Minor Faults in North Central New Mexico and Regional GIS Analyses: Fort Collins, Colorado, Colorado State University, M.S. Thesis, 159 p.

Kellogg, K.S., 1997, Geologic Map of the Dillon Quadrangle, Summit and Grand Counties, Colorado: U.S. Geological Survey, OF 97-738, scale 1:24,000.

Kellogg, K.S., Bartos, P.J., and Williams, C.L., 2002, Geologic Map of the Frisco Quadrangle, Summit County, Colorado: U.S. Geological Survey, MF-2340, scale 1:24,000.

Kellogg, K.S., Bryant, B., and Redsteer, M.H., 2003, Geologic Map of the Vail East Quadrangle, Eagle County, Colorado: U.S. Geological Survey, MF-2375, scale 1:24,000.

Kellogg, K.S., Shroba, R.R., Bryant, B., and Premo, W.R., 2008, Geologic Map of the Denver West 30' x 60' Quadrangle, North-Central Colorado: U.S. Geological Survey, Scientific Investigations Map SIM-3000, scale 1:100,000.

Kellogg, K.S., Shroba, R.R., Premo, W.R., and Bryant, B., 2011, Geologic Map of the Eastern Half of the Vail 30' x 60' Quadrangle, Eagle, Summit, and Grand Counties, Colorado: U.S. Geological Survey, SIM-3170, scale 1:100,000.

Lindsey, K., 2018a, Landslide Inventory and Susceptibility of Douglas County, Colorado: Colorado Geological Survey, OF 18-07.

Lindsey, K., 2018b, Landslide Inventory and Susceptibility of Jefferson County, Colorado: Colorado Geological Survey, OF 18-06.

Lovering, T.S., 1935, Geology and Ore Deposits of the Montezuma Quadrangle, Colorado: U.S. Geological Survey Professional Paper 178, scale 1:62,500.

Morgan, M.L., 2003, Published Faults of the Colorado Front Range: Colorado Geological Survey, OF 03-04.

Ruleman, C.A., Bohannon, R.G., Bryant, B., Shroba, R.R., and Premo, W.R., 2011, Geologic Map of the Bailey 30' x 60' Quadrangle, North-Central Colorado: U.S. Geological Survey, SIM-3156, scale 1:100,000.

Tweto, O., 1979, Geologic Map of Colorado: Colorado Geological Survey, MI-16, scale 1:500,000.

Wallace, C., Keller, J., McCalpin J., Bartos, P., Route, E., Jones, N., Gutierrez, F., Williams, C., and Morgan, M.L., 2005, Geologic Map of the Breckenridge Quadrangle, Summit and Park Counties, Colorado: Colorado Geological Survey, OF 02-07, scale 1:24,000.

Widmann, B.L., Bartos, P.J., McCalpin, J.P., and Jackson, J., 2004, Geologic Map of the Copper Mountain Quadrangle, Summit, Eagle, Lake, and Park Counties, Colorado: Colorado Geological Survey, OF 03-20, scale 1:24,000.

Widmann, B.L., Morgan, M.L., Bartos, P.J., Shaver, K.C., Gutierrez, F., and Lochman, A., 2003, Geologic Map of the Keystone Quadrangle, Summit County, Colorado: Colorado Geological Survey, OF 02-03, scale 1:24,000.

APPENDIX A

Comprhensive Plan Water Recomendations Summary Table

Comprehensive Plan Water Recommendations Summary

Plan recommendations that may not be fully implemented are highlighted in yellow.

Issue	County-wide Plan	Evergreen Plan	Conifer Plan
Water Quality and Quantity	Meet or exceed national and state standards for clean air, water, and land. pg 16	Ensure that new retail, office, industrial and community use activities are compatible with existing surrounding uses in terms of traffic, water and sewer, noise, visual amenities, and air quality, and comply with all sections of this Plan. pg 10. Does LDR and WAA look at compatibility with existing uses. How is capability defined? Is it similar uses, density and impacts? Similar water uses?	3. Ensure that new retail, office, industrial and community use activities are compatible with existing surrounding uses in terms of traffic, water and sewer, noise, visual amenities, and air quality, and comply with this Plan, Design Guidelines and Architectural Standards. pg 7
Water Quantity	New non-agricultural Development in the mountains should avoid uses generally associated with high-water consumption rates. pg 20	1. Development or expansion of development should not be allowed to deplete any existing ground water supply beyond the ability of the development area to recharge itself. pg 41	Slopes are a constraint on development because as slope increases, impacts increase, such as: Water: Generally there is less water available at the top of drainage basins. pg 5
Mining related Water Quality and Quantity	Proposals for extraction should be reviewed to evaluate for impacts on nearby wells and local Ground Water resources. Existing wells and Ground Water resources should be protected from contam-ination and decreased yields or lowered static water levels caused by extraction. pg 28		
Wetlands	New Development should not adversely affect the Recharge of nearby Wetlands. pg 35	3. To protect water quality and quantity, riparian zones and wetland areas should be protected from degradation. pg 41	
Quality	Ensure New Development protects existing wells and Ground Water resources from contamination. pg 49	There is concern about health-endangering amounts of radiation in ground water and soil resulting from natural radioactive deposits and other sources, e.g., mine tailings. 1. If an air test shows presence of radon, mitigation measures should be taken by the property owner. Furthermore, well tests for measurement of radioactive isotopes should be conducted to determine if mitigation is required. pg 29	1. Water used for human consumption should not exceed safe levels of radioactive isotopes. Owners of private wells are encouraged to conduct tests and apply remediation measures to achieve the same standards as public water supplies. pg 17
Quantity	1. Applications for New Development should demonstrate that water is adequate and available for the use proposed, <u>including any watering for outside uses such as landscaping or livestock</u>. pg 49 Adequate Water Supplies A water supply that meets applicable drinking water stan-dards, meets minimum supply quantity, and is sustainable both physically and legally. pg 107	Automobile-dependent development has increased impervious area in the ground water recharge zone. Traditionally, runoff from roads has been collected and conveyed very much like sanitary sewage. This method of stormwater management increases runoff and decreases ground water recharge, and should be discouraged. 1. Infiltration plans that naturally filter and recharge ground water should be used, rather than plans that collect and convey stormwater down stream. pg 38	Housing Densities Inside Activity Centers Where a centralized water and/or sewer system is not available, 1 dwelling unit per 5 acres should be the maximum density allowed. pg 9
Recharge	3. Ground Water Recharge from sewage treatment systems should occur in the same general area from where water is withdrawn.		
Quantity	1. Ensure that development is at a scale/density consistent with Locally Available Water Resources. Pg 50 Locally Available Water Resources The surface or ground water that is physically on the site of the development, not including water brought in from an outside source, such as truck, pipeline, or other means pg 118		8. The need for an <u>aquifer test for a proposed development will be deter-mined on a case-by-case basis through consultation with Jefferson County Public Health if the proposal has a water requirement greater than 0.28 acre feet per year (the equivalent of 250 gallons per day per acre). pg 32</u>

Comprehensive Plan Water Recommendations Summary con't

Issue	County-wide Plan	Evergreen Plan	Conifer Plan
Quality	3. Require advance treatment OWTS in areas of known Ground Water quality problems. pg 50	2. To protect water quality, the Jefferson County Public Health should continue to carefully review each application for an exemption from the required 200-foot map distance separation between a well and an OWTS, including wells and OWTS on adjacent lots, to ensure the systems meet the appropriate standards. pg 42	Related to reservoirs: Sewage treatment for commercial, residential, and recreational development attracted to the area will be required. The proliferation of package treatment plants for sewage disposal should be avoided to reduce surface and ground water contamination. An activity center approach should be taken to serve commercial development to achieve a common solution to sewage treatment and disposal, and to provide controls for later development. pg 26
Water Districts	5. Surface water is the preferred water source for Centralized Water Systems. Centralized Water Systems utilizing Ground Water as the primary water source should demonstrate hydrologic evidence that an adequate and dependable water supply exists. pg 52	1. Public centralized water and sanitation districts or systems, approved by the appropriate authorities, should be provided for all new non-residential development that requires water in excess of the equivalent of 1 dwelling unit per 10 acres or 300 gallons/day/10 acres. (Note: this means 300 gallons pumped per day, not consumptive use.) pg 41	
Water Districts	2. New water and/or sanitation districts should not be formed for the sole purpose of developing existing Platted lots that do not qualify for a well and septic system based upon the size of the lot(s). pg 52	a. The ability of the district to provide adequate legal and physical water quality and quantity to meet all health and safety standards in the areas to be served. c. When ground water is the primary source of water, there should be hydrogeologic evidence that neighboring water wells will not be adversely affected, and hydrogeologic evidence of adequate recharge to the source ground water. This hydrogeologic study should be done by a professional geologist, hydrologist, hydrogeologist, or a professional engineer specializing in hydrogeology and water resources in a granitic fractured-rock environment. This study should be reviewed by an independent panel of specialists appointed by the county and paid by the county from fees collected from the applicant. Any property served by public sewer should also be provided with public water so that water is not depleted from the ground water and then recharged to another area or stream. The only exception should be if required by the county to mitigate a threat to public health. pg 42	If a centralized water system and/or centralized sewer system is available or proposed to serve the development, housing density greater than 1 dwelling unit per 5 acres, not to exceed 1 dwelling unit per 1 acre, may be considered. The following criteria should be used to determine the appropriateness of the density. a. The source of the renewable water supply is designated at the time of zoning. The water source is a renewable water source, i.e., there should be a balance between water consumption and its natural replenishment to the area from which it is withdrawn. The preferred water source for centralized water systems is a free-ßowing stream or spring that is both physically and legally available. Well water use may supplement the preferred renewable water source. If well water is to be used, it should be in-house use only, not to exceed the 298 gallons of water per day that is allowed for 1 single family home based on the average gross density of the parcel. Wells should not be allowed as the sole or primary source of water for centralized water and/or sewer systems unless hydrologic evidence is presented that shows an adequate and dependable water supply can be provided. If wells are the primary source, 90% of the water should be returned to the recharge area from which it was taken. pg 4 b. If wells are the primary source of water for a new centralized water and/or sewer district, the Ground Water Recharge from sewage treatment systems, including OWTS, should occur in the same general area from where the water is withdrawn. d. Hydrologic evidence should be presented that neighboring water users will not be adversely affected and that there is evidence of recharge to the source ground water (a professional geologist, hydrologist or hydrogeologist specializing in hydrogeology, or a professional engineer specializing in water resources or other related specialty, should provide this report); pg 32
Water Districts	1. The formation of water and sanitation districts in the Mountain Ground Water Overlay District (M-G) should either facilitate Activity Center recommendations or address existing water quality or quantity concerns. pg 52		
Density	1. Plan for higher Intensity development where public water, sanitation, Þre protection, law enforcement pg 55	1. Uses designated within each Activity Center should be allowed only when water and sanitation from a public district is available to the property. (This Policy does not apply to the Marshdale Neighborhood Center where 1. New rezonings should allow only those uses that require little water, because the water supply is limited to wells and sewage disposal is inadequate. pg 23) pg 13. Multifamily housing, including apartments, condominiums, and townhomes should be allowed only within Activity Centers or Neighborhood Centers. and only served by public water and sewer. pg 14	
Conservation	12. Encourage development to conserve water resources. pg 55		
Wildlife	1. Protect Wildlife's access to forage areas, water, and cover. pg 65		

Comprehensive Plan Water Recommendations Summary con't

Issue	County-wide Plan	Evergreen Plan	Conifer Plan
Quality	1. When an area has been identified by the County or Colorado Department of Public Health and Environment as having a Ground Water quality problem, proper Mitigation of the problem should be implemented before zoning, health variances or changes are approved that would aggravate the problem. pg 67		
Recharge	1. Endorse efforts to better define and protect Ground Water Recharge areas. pg 67 Recharge The replenishing of ground water occurs by infiltration of precipitation, in the form of rain or snow. Return flow from On-Site Wastewater Treatment Systems may provide small amounts of infiltration. Note: Recharge area is not necessarily at the site where water is being withdrawn from the fractured rock aquifer system. Precipitation and return flow from an On-Site Wastewater Treatment System on a site does not necessarily reach those fractures that provide water to the producing interval in the well. Also, the ability to recharge an aquifer in a specific area can vary over time, and will be affected by local weather patterns, by disruption of infiltration areas, and other factors. pg 122		
Water Quality and Quantity	2. Encourage collection and analysis of data to evaluate the extent, availability, and quality of Ground Water resources in the Mountain Ground Water Overlay District. pg 67	1. The Colorado Division of Water Resources, Jefferson County Public Health, R-1 School District, property owners, and others, should conduct a needs assessment that identifies water quality and quantity problems in the **Marshdale Neighborhood Center** and recommends possible solutions. pg 24	Overall Goal: There should be a balance between the availability of water and its uses to insure that water resources are not depleted. Water quantity, quality and sanitation are critical elements that should be considered when development is proposed for the area. pg 31
Quality	1. Identify existing water contamination sources and mitigate or eliminate them. pg 67		
Conservation	5. Support gray-water reuse, when not in conflict with local, state and district rules. pg 68		
Recharge	Open Space Aquisition: Consider the preservation of property with the following attributes: surface waters 72 Prudent to add recharge areas to criteria for acquisition of open space		
Quality	4. All Centralized Water Systems should be overseen by an Operational Agency, inspected annually and have their water quality checked for Potability, regardless of the number of structures served. pg 75. Not required in LDR for water well system. Definition of Centralized Water System: A system for collection, treatment, and distribution of potable water to at least 15 service connections, or that regularly services at least 25 individuals daily at least 60 days of the year. The system must be designed as a public water system and subject to regulation by the Colorado Department of Public Health and Environment. Depending on its classification, this system may also be subject to routine inspections by Jefferson County Public Health. pg 109		
Quality	5. Encourage homeowners to regularly test their well water for Potability. pg 80		

Comprehensive Plan Water Recommendations Summary con't

Issue	County-wide Plan	Evergreen Plan	Conifer Plan
Quantity	6. Encourage well owners to regularly measure the static water level in their well to establish a baseline level. pg 80 Balance		Balance the availability of ground and surface water, water use, and ground waterrecharge with current and future development, to ensure that water resources are not over-allocated. 2. New or existing development should not be allowed to deplete the existing ground water supply beyond the ability of the local area to recharge itself. pg 31 Is local area defined as sub-basin?
Geologic Hazard		2. Water-intensive landscaping and septic systems should not be permitted in high geologic hazard areas. pg 27	
Water Quality and Quantity		Balance water use with the physical supply of surface and ground water, water use, and ground water recharge, so that water resources are protected from long term depletion pg 40 How is long-term depletion defined?	
Water Quality and Quantity		Site Design Guidelines: Maintain hydrologic features in a way that does not adversely affect water quality or quantity. pg 45	
Quantity			7. New lots under the 1 dwelling unit per 5 acres density should be served by a centralized water and/or sewer system. If a lot already containing a home or business needs to rezone or request a special use, these uses could continue on lots smaller than 5 acres, without being served by a centralized water and/or sewer system, as long as water use is not increased beyond what is permitted by the existing well. pg 32
Quantity			16. The County should encourage, and as resources allow, coordinate with the State Division of Water Resources to collect well and water data for individual properties. This information should include well depths, static water levels, reported flow rates (with a clear caveat about the unreliability of these rates), the number of wells drilled on a property, and documentation of any replacement, deepening or hydrofracturing of existing wells. The county should maintain the data in a computerized data-base for staff referral when evaluating claims of adequate physical water supply. This data-base should be accessible to the public. pg 33
Quantity			Livestock Watering: Livestock watering on farm, ranch, range or pasture on parcels of 35 acres or more. The daily use is about 1190 gallons of water per day. Is this the number used in WAA ? pg 55

APPENDIX B

Detailed WAA Review

Table of Contents

List of Figures

List of Tables

APPENDIX B

WAA Description

As stated in Land Development Regulation (LDR) Section 21.C.3: "The Water Availability Analysis [WAA] will be completed by Planning and Zoning and used to determine if there is a sufficient water supply in terms of quantity and dependability for the proposed uses." A WAA is completed for each zoning application specific to the proposed development in the application. It consists of two parts in an Excel spreadsheet that uses pre-set formulas to perform calculations: one estimates the water requirements for a proposed development and the second calculates a water balance of water inflow and water outflow for the hydrologic unit within which the proposed development lies.

Water requirements by a proposed development is an estimate of water use by volume within the development once built up. A *water balance* is a mathematical equation of inflow and outflow that starts with natural inflow from precipitation over the footprint of the hydrologic unit. That inflow is offset by outflow through evaporation and transpiration by vegetation ("evapotranspiration"), surface runoff, and recharge to the aquifer beneath the hydrologic unit footprint. The balance also considers consumptive use by existing land development within the hydrologic unit before adding impact from proposed development. It includes a term for storage of water within the aquifer beneath the hydrologic unit.

A hydrologic unit is a geographic subdivision of a watershed delineated for managing hydrologic data. The hydrologic units used in the WAA are called *subbasins*. In the WAA, subbasins can be at the headwaters of watersheds, where the only inflow is direct precipitation from above, or they can be downstream in a watershed where they can also receive flow-through from subbasins upstream. Flow-through is not considered in the water balance of the WAA.

Approach

Water Balance in Fractured Crystalline Bedrock

Estimating water availability in fractured, crystalline bedrock, otherwise known as a fractured, crystalline-rock aquifer, broadly depends on five major factors: precipitation (P), surface runoff (R), groundwater pumping (Q), evapotranspiration (ET), and storage (S), where changes in storage (ΔS) generally drive water availability as shown below:

$$\Delta S = P - R - Q - ET$$

These processes combine to form a water balance, where incoming precipitation partitions into outgoing runoff, evapotranspiration, or groundwater pumping, and any residual water influences bedrock storage. **Figure B1** shows a conceptual aquifer system in fractured, crystalline bedrock where groundwater is stored in fractures below the water table and well yields are controlled by fracture intensity and connectivity.

Quantifying groundwater storage is critical to ensuring that groundwater resources are being used sustainably in areas that rely on aquifers for domestic and commercial uses. However, geologic heterogeneity; fracture permeability; climate variability; and slope and aspect all impact water balance calculations in fractured, crystalline bedrock, making storage a difficult parameter to estimate. Water balance terms and components for the mountainous areas of Jefferson County, described by Bossong and others (2003) and CDM (2011), are summarized below:

Major Water Balance Terms

Precipitation is the movement of water from the atmosphere to the land surface, typically falling as rain, snow, or sleet. It is the major incoming water source in a water balance, making it a critical parameter in water balance applications. Quantifying precipitation is generally done through monitoring of weather stations or using remote sensing. The National Weather Service has an extensive network of weather stations, so precipitation measurements generally have a high degree of confidence. Precipitation is a parameter entered into the WAA calculation.

Runoff is the drainage from precipitation that flows into surface water bodies either via surface runoff, baseflow, or shallow infiltration that percolates into streams, reservoirs, and lakes. This term generally depends on slope, rainfall intensity, soil properties, and vegetative cover. Runoff is generally measured at the basin scale through the use of several empirical relationships or detailed analysis of stream hydrographs, making it fairly well constrained in water balance applications. Measurement of runoff is not used as a direct parameter in the WAA.

Groundwater Pumping is the withdrawal of water from aquifer storage, typically to support domestic needs and commercial development. Groundwater withdrawal estimates are commonly derived from well permit applications, which may not reflect actual groundwater usage. Groundwater pumping is a parameter used in the WAA with values from multiple sources. In most cases, groundwater pumping values are assumed based on well type since metered values are uncommon. Verification of groundwater pumping and usage rates should be completed when possible by comparing permitted (i.e., assumed) water withdrawals to metered (i.e., actual) water usage to ensure there are no major discrepancies.

Evapotranspiration is the collective term for water that moves from the land surface to the atmosphere as a result of evaporation and transpiration from plants. This flux

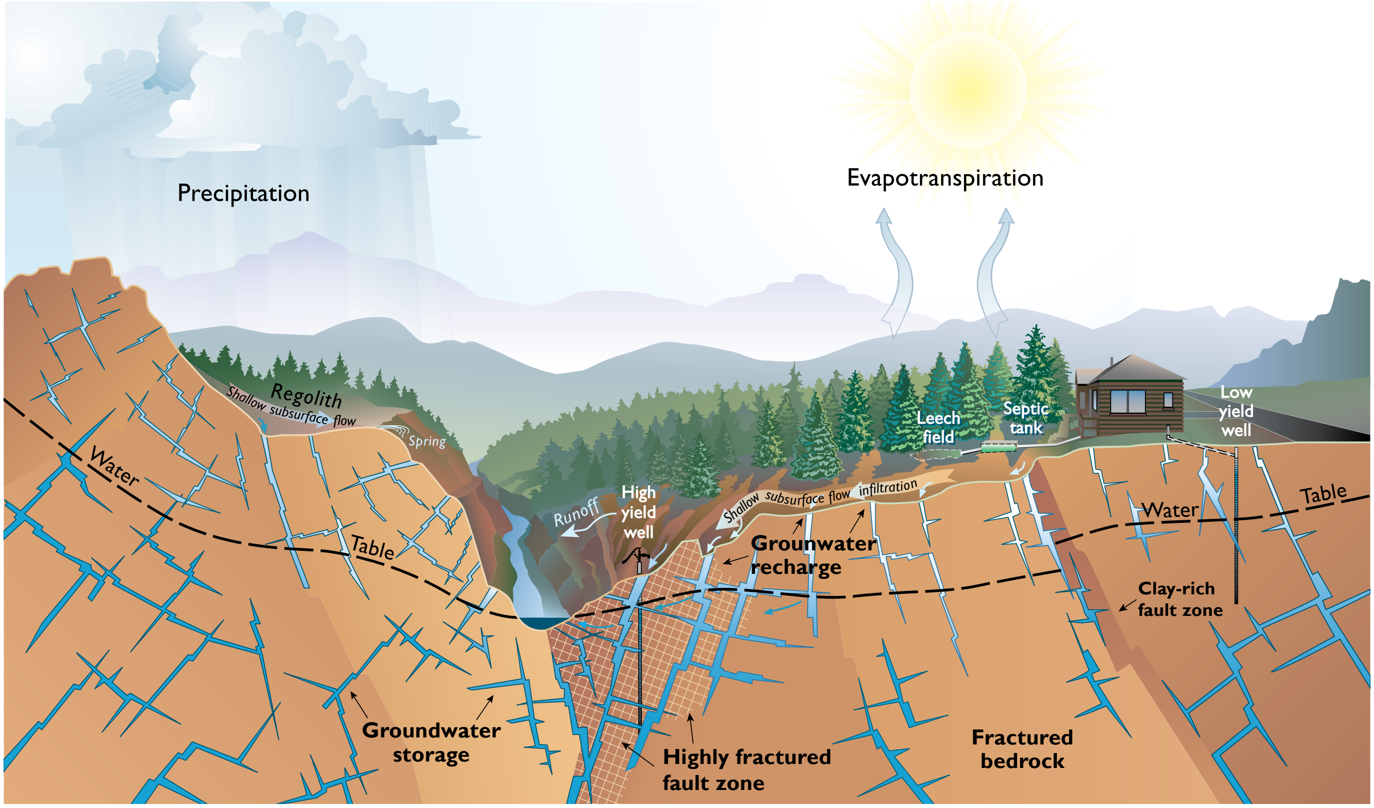


Figure B1: The water cycle in the mountain foothills is complex. Water in the atmosphere is sourced from local or distant evaporation. Under the right conditions, it falls as precipitation, either snow or rain. Precipitation either runs off through streams or soaks into the ground. Some is lost to direct evaporation and transpiration through vegetation root systems in near-surface soils, collectively called evapotranspiration. That which is not lost to evapotranspiration flows deeper through porous weathered bedrock, where a portion may flow downslope as shallow subsurface flow. The remainder continues into the deeper bedrock aquifer, where it passes through and is stored within open fractures. Eventually, most of the groundwater flows though the fractures toward streams, where it is carried off. This deeper groundwater is available to wells. Wells completed in the fractured rock capture some of the groundwater for use within homes or businesses. What is not completely consumed is treated and then released back to groundwater through a leach field.

removes water from the subsurface, and is generally controlled by temperature, soil properties, vegetative cover, and water availability. Evapotranspiration is highly transient depending on annual climate (i.e., wet year vs. dry year) or land cover (e.g., forested, meadowland, developed land, etc.). Direct measurements of evapotranspiration are difficult, making this parameter relatively uncertain in water balance calculations. As with runoff, evapotranspiration is not a direct parameter in the WAA since recharge is based on a percent of precipitation.

Groundwater Recharge occurs when deep infiltration reaches the regolith-bedrock boundary and continues percolating into bedrock storage reservoirs. Regolith is a layer of unconsolidated rocky material at the top of bedrock that is made up mostly of fragments of weathered bedrock. Recharge is the major mechanism that replenishes groundwater storage and can occur naturally by infiltration of precipitation, as well as artificially by pumping water into an aquifer (i.e., aquifer storage) or through human-made infiltration systems. In natural systems, recharge is typically the residual of precipitation that is not captured by runoff or evapotranspiration in a water budget. In crystalline bedrock, other factors controlling recharge are hydraulic conductivity of fractures; regolith weathering; slope and aspect; and vegetative cover. Given that recharge is a residual factor of other processes, it is often difficult to constrain in water budgets. Recharge is a critical input in the WAA that is estimated from precipitation values and return flows of water from well pumping, adjusted for consumptive use.

Groundwater Storage capacity in crystalline bedrock is the result of secondary porosity generated by fracturing and weathering processes, as the matrix of crystalline rocks is generally impermeable and provides little to no primary porosity. Higher infiltration and recharge rates increase bedrock storage, while increased evapotranspiration, runoff, and groundwater pumping rates decrease water storage. Thus, groundwater storage in a given area is dependent on hydraulic properties of underlying bedrock; slope and aspect; vegetation; and climate, with many of these factors being interrelated. Deriving accurate groundwater storage estimates in fractured, crystalline bedrock requires detailed geologic mapping, evaluation of bedrock hydrogeologic characteristics such as porosity and water levels, and long-term climate monitoring.

Groundwater storage in crystalline bedrock can be described in three distinct areas in watershed modeling (Bossong and others, 2003; CDM, 2011). A portion of water in the near-surface regolith may discharge relatively rapidly to surface water in what is called the *interflow reservoir*. Water that continues deeper into bedrock enters what is called the *base flow reservoir*, which eventually flows to streams to support baseflow. A deeper reservoir exists below the stream base level that is termed the *deep groundwater reservoir*, which ultimately discharges to regional streams. The base flow and deep groundwater reservoirs are considered the reservoirs that support development. In the WAA, groundwater storage is used to evaluate sustainability of water use in an area when the balance is negative, with outflow exceeding inflow. The WAA only looks at a single value of groundwater storage without any distinction of reservoirs.

WAA Examples

Jefferson County provided CGS four completed WAA spreadsheets as examples for this review. These examples are from previous cases that have been through stages of the review process and represent diverse settings and development types. They are listed below by zoning case number and name:

- **16-103864RZ 27826 Alabraska Lane:** A proposal for residential, conference center, office and preschool uses on an 11.38-acre parcel near Marshdale in a headwaters subbasin. The proposal called for water supply from one commercial well. In the WAA, the balance showed the subbasin to already be in deficit without adding impact from the proposed development.
- **18-107113RZ Conifer Heights:** A proposal for high-density multiple-housing units on 25 acres at a location straddling two subbasins in the Conifer-Aspen Park activity center, one a headwaters subbasin and the second a downstream subbasin. This proposal calls for a water supply from eight commercial wells with wastewater treatment through an adjacent municipal system.
- **19-106332RZ Eudaimonia:** A proposal for a church, wellness center, three single-family dwellings, a cabin, and a bathhouse on 11.35 acres in Parmalee Gulch and a headwaters subbasin. It calls for a water supply from one commercial well.
- **19-102754RZ Red Wing Park:** A proposal for mixed commercial uses on a 1.14-acre parcel in the Conifer-Aspen Park activity center and a headwater subbasin. It calls for water supply from six commercial wells and water treatment through an adjoining municipal system.

WAA Structure

Each WAA consists of a Microsoft Excel spreadsheet with four tabs. Each tab serves a specific purpose for either analysis or reference and documentation. **Table B-I** lists the tabs and their functions.

Water Requirements V3 tab

This tab contains information about the proposed development in addition to five elements that either provide analysis or documentation. Basic information includes case number, property address, official development plan or subdivision name, status of location within the Mountain Groundwater Overlay District (MGWOD), and compliance with the MGWOD. There may be a map insert. It includes tables with preset cell calculations and rows with documentation:

1) "Calculate Water Withdrawal and Consumptive Water Use of Proposed Development – Table 1: Proposed Uses" calculates anticipated consumptive water use for a development based on proposed uses of the developed space specified in the application. Use-type entries are specific to the proposal, and there can be many types depending on the application. For each use, there is the type, a per-unit total water use, and a proposed number of units. Units can include surface area of use, such as square feet of retail or office use, or numbers, such as housing units. Total use by type is the product of per-use need and number of units. This total use is further adjusted to consumptive use by type. Values for daily withdrawal are determined from references and may be accepted typical values or values based on documented and relevant similar-known uses. Percent consumptive use is a subjective value and can vary by use and type of wastewater disposal. For example, residential consumptive use has a lower value than irrigation. Values applied are determined from references.

   This calculation is tied directly to the proposed uses of the development, and values for the parameters can come from documented sources. It can be considered the best estimation for the given proposal.

2) "Calculate water requirement in terms of acre-feet per acre per year. (based on table 1 above)" is a simple conversion of the average daily water withdrawal for

Table B-I
WAA Spreadsheet Tab Structure

Tab Name	Functions
Water Requirements V3	1) Calculate water requirements specific to proposed development by uses included in the application 2) Determine in an aquifer test is required.
Water Requirements References	Background information for input parameters for the water requirements tab calculations. Can include specific data from outside sources, such as meter data for facilities similar to what is proposed.
WAA	1) Calculate the existing water balance for a specified watershed basin that the proposed development is in and estimate the impact the development would have on the water balance. 2) Estimate sustainability of the basin watershed under different scenarios. 3) Estimate the lifetime of the water resource if the water balance indicates unsustainable depletion.
WAA References	Reference material for input parameters to the calculations in the WAA tab.

the whole proposed development in gallons per day to acre-feet per acre per year using the footprint of the proposed development in acres.

3) "Based on water requirements and Section 21 of the LDR, is an Aquifer Test required?" This row uses results of the previous calculations to determine the need for an aquifer test based on LDR Section 21.B.2.4. Per LDR Section 21.B.2.4, an aquifer test is required for a rezoning application when the value of 2) above for the proposed development site exceeds 0.28 acre-feet per acre per year and 0.10 acre-feet per year for a plat or site development plan.
4) "Aquifer Test Data" documents aquifer test results when an aquifer test is required per 3) above.
5) "Comments" serves as a space to include documentation of specifics about an application and different variables or scenarios used in the calculations.

Water Requirement References tab

This tab is simply a place to list references or show additional data used to customize the inputs to the Water Requirements tab. It includes links to outside sources of data.

WAA tab

This tab places the development and its anticipated water consumption in the context of its hydrologic subbasin. The purpose is to analyze a water balance based on existing inflow and outflow and then add the estimated consumption for the proposed development to determine impacts from the added development. As such, it considers sustainability of the subbasin purely on physical water available from inflow minus outflow. Inflow and outflow are limited to the footprint of the hydrologic subbasin without factoring in inflow from upstream sources or outflow downstream. The tab includes a map showing the location of the proposed development within the subbasin and six analytical tables; two of the analytical tables have subtables:

Table 1: "Estimate of Available Groundwater Resources in the Basin," calculates groundwater in storage within the sub-basin that the proposed development is located in. It is a simple volumetric calculation using the sub-basin surface area; saturated thickness of the aquifer, based on existing well depths; and an estimated porosity for the rock type. The result is reported as total acre feet and acre feet per foot for the basin.

Table 2: , **"Analysis of Groundwater Withdrawal, Recharge, and Consumptive Use from Existing Wells in Basin,"** estimates total current water consumption by existing wells in the basin. Numbers and types of wells are based on Colorado Division of Water Resources

(DWR) permitted well data. Withdrawal volumes are based on permit type that are multiplied by total number of well by type. Consumptive use is estimated by adjusting the total withdrawn by a value for recharge returned to the aquifer, which is also a value assigned by well type. The estimate of water returned as recharge varies by well-use-type and the values are taken from references.

Table 3: "Estimate of Annual Groundwater Recharge to the Basin from Precipitation," calculates the inflow of water to the subbasin aquifer from natural recharge. It is a simple volumetric calculation using the surface area of the subbasin, average annual precipitation from existing records for the region, and an estimate of the percent of precipitation that is available to recharge the aquifer. The value for percent of precipitation available to recharge the aquifer is a value obtained from references.

Table 4: "Ground Water Resource Impact of Proposed Development," calculates the anticipated additional consumptive use of groundwater by the development using proposed wells and type of use by those proposed wells. This calculation is consistent with the estimate of existing groundwater depletions by existing well types in the basin. However, it differs in approach to the calculation of water requirements in the Water Requirements tab, which estimates consumptive use based on proposed use of space in the development.

Table 5 is a set of three subtables that addresses sustainability of the groundwater resource in the subbasin by estimating a total water balance with the proposed development added to existing uses.

Table 5a: "Water Availability Analysis on the Basin Based on Existing and Proposed Development," is the water-balance calculation using water inflow to the aquifer from natural recharge adjusted by water outflow from consumptive use by existing uses plus consumptive use by the proposed development. If the adjusted value is positive, the water supply should be adequate for the new development; if negative, there is not sufficient water available. This analysis specifically limits water inflow to that from precipitation directly to the subbasin alone and does not account for inflow of surface or groundwater from upstream subbasins. It does not draw from water in storage calculated in Table 1.

Table 5b: "Impact on the Basin Based on Existing and Proposed Development With No Recharge From Precipitation," addresses longevity of water in storage calculated in Table 1. It calculates the loss in storage from the proposed development alone in Table 4 without inflow from recharge from precipitation and portrays that loss in storage as a decline in basinwide water level in feet per year. It also estimates the time to deplete the groundwater in storage in years from the estimated saturated thickness from combined depletions by existing uses plus the proposed development.

Table 5c: "Impact on the Basin Based on Existing and Proposed Development Including Estimated Recharge From Precipitation," is the same calculation as the second part of Table 5b, but adds in recharge from precipitation. It provides an estimate of longevity of the resource in the basin based on consumption by existing and the proposed development but factors in natural recharge.

Table 6: is a set of three subtables that mimic the Table 5 subtables while acknowledging that platted lots within the basin eventually may be built on. These already-platted lots are treated as additional depletions to the groundwater resource.

Table 6a: "Water Availability Analysis on the Basin Based Existing, on Build out of Platted Lots and Proposed Development," mimics Table 5a but adds in depletions from other lots already platted for development that have not been built on. The number of platted lots is taken from county plat records and a value for depletion is based on the type of use for which the lots are platted using well values by use (see Table 4).

Table 6b: "Impact on the Basin Based on Build out of Platted Lots and Proposed Development Including No Recharge From Precipitation," mimics Table 5b and addresses longevity of the aquifer in the basin without the inflow of water from recharge, including already-platted lots.

Table 6c: "Impact on the Basin Based on Build out of Platted Lots and Proposed Development Including Estimated Recharge From Precipitation," mimics Table 5c and addresses longevity of the aquifer in the basin but adds in the inflow of water from recharge, including already-platted lots.

WAA References tab

This tab is simply a place to list references or show additional data used to customize the inputs to the WAA tab and links to outside sources. It is pre-populated with sources of template data that are already built in to the WAA.

WAA Input Parameters

Many parameters go into the spreadsheet analyses in the WAA. **Table B-IIa** lists the parameters in the *Water Requirements tab* and **Table B-IIb** lists the parameters in the *WAA tab*. These parameters fall into five basic classifications based on source.

1) Reference parameters (Rf in Tables IIa and IIb) are

those where values are taken from published sources, or other empirical data sets.

2) Calculated parameters (Clc in Tables B-IIa and B-IIb)) are calculated elsewhere in the spreadsheet from other input parameters to the analysis. Many of these calculated parameters become inputs to other calculations in the tables. Others are the final outputs.
3) Application-specific parameters (Ap in Table B-IIa) are those parameters specified in the development application. These are variables such as numbers of housing units, types of use within the development, etc.
4) GIS parameters (GIS in Table B-IIb) are public-domain geospatial data or generated from public-domain geospatial data.
5) Division of Water Resources data (DWR in Table B-IIb) are public-domain data maintained by the Colorado Division of Water Resources in their permitted water well database, or defined limits for wells by type.

Discussion of WAA Input Parameters

The analyses in the WAA spreadsheet use a number of input parameters. Many are estimated from previous work in the Front Range mountain area by Bossong and others (2003) and CDM (2011). Input parameters in the WAA can be classified by subjectivity. Many input parameters are based on fixed values or simple and indisputable calculations. Other input parameters can be very subjective for a number of reasons, which will be discussed in the following section. Values for some parameters have considerable variability in the reference materials which leads to uncertainty in how the result applies to the specific setting of a proposed development. In addition, some calculations are subjective in how they use different inputs. These subjective parameters are listed in **Table B-III** in the order of the parameters in Tables B-IIa and B-IIb.

All parameters are assigned a degree of confidence as either Low, Moderate, or High for our view of accuracy or adequacy of use in the analyses. They are also assigned a degree of variability, also Low, Moderate, or High. Low variability indicates that values used are likely to vary by less than a factor of two times. Moderate variability indicates that the value could vary by up to one order of magnitude. High variability indicates that the values could vary by several orders of magnitude.

Parameter a, "Daily Withdrawal Per Unit" is used to estimate the total water consumed by the proposed development in the *Water Requirements tab* and is based on the description of proposed use types in the application. This input is per unit and is subsequently adjusted by the proposed number of units for the specific type (parameter d in Table BIIa) to arrive at the total for the development. The Jefferson County Comprehensive Master Plan (Comp Plan) lists water use by type (Appendix C, p. 99), which should be consistent with those used in this analysis unless there are adjustments based on circumstances specific to the development. Any adjustments should be well documented in the Water Requirement References tab. In each example there are links to a guideline published by the Montana Department of Natural Resources.(http://dnrc.mt.gov/divisions/water/water-rights/docs/forms/615.pdf) and the Jefferson County Comprehensive Master Plan of November 2017 (https://www.jeffco.us/DocumentCenter/View/12324). Values and units used in the four WAA

Table B-IIa: Input and output parameters in WAA spreadsheet, Water Requirements V3 tab

Parameter[1]	Description	Unit[2]	Source[3]
a	Daily withdrawal per unit (in proposed develoment by developed space type)	gpd	Rf
b	Annual withdrawal per unit (in proposed development by developed space type)	af/y	Clc
c	Percent consumptive use	%	Rf
d	Number of units (in proposed development by developed space type)		Ap
e	Total annual withdrawal (for proposed development)	af/y	Clc
g	Average water withdrawal (for proposed development)	gpd	Clc

1 Letter identification is not used in WAA spreadsheet, but is added here for reference, bold indicates final output
2 gpd = gallons per day, af/y = acre-feet per year, % = percent, # = number
3 Rf = value taken from reference, Clc = calculated, Ap = from rezoning application

	Table B-IIb **Parameters in Water Availability Spreadsheets, WAA Tab**			
Para-meter [1]	**Description** [2]	**Unit** [3]	**Table**	**Source** [4]
A	Basin area	ac	1,3	GIS
B	Average depth to GW in the basin	ft	1	DWR
C	Average depth of wells in the basin	ft	1	DWR
D	Saturated thickness of the aquifer exposed to wells	ft	1,5b,5c,6b,6c	Clc
E	Estimated average porosity of aquifer	%	1	Rf
F	Estimated amount of GW in storage	af	1	Clc
G	Effective yield of groundwater to wells	%	1	Rf
H	Estimate of GW in storage available to wells	af	1,5b	Clc
I	Estimated GW stored per saturated foot	af/f	1,5b,5c,6b,6c	Clc
J	Number of wells by type	#	2,4,6a	DWR or Ap
K	Estimated amount of GW withdrawal per well	af/y	2,4,6a	DWR
L	Total estimated amount of GW withdrawn	af/y	2,4	Clc
M	Estimated percent returned to recharge GW	%	2,4,6a	Rf
N	Estimated amount of GW recharged by well type	af/y	2,4	Clc
O_e	Estimated CU of GW from existing wells	af/y	2,5a	Clc
O_p	Estimated CU of GW for the proposed development	af/y	4,5a	Clc
O_t	Total estimated CU of GW for the PrD and existing combined	af/y	2,5b,6b	Clc
P	Mean annual precipitation	in	3	GIS
Q	Average annual precipitation over basin	af	3	Clc
R	Estimated percentage of precipitation that is recharge	%	3	Rf
S	Estimate of annual recharge from precipitation	af	3,5a	Clc
T	GW budget: recharge minus total consumptive use	af/y	5a,5c,6c	Clc
U	Estimated percent of aquifer depletion based on CU of PrD	%	5b	Clc
V	Annual average basin wide drop in water level due to CU of PrD with 0 recharge from precipitation	af/y	5b	Clc
W	Time to drain saturated aquifer by the CU of existing and PrD with 0 recharge from precipitation	yrs	5b	Clc
X	Time to drain saturated aquifer by the CU of existing and PrD with recharge from precipitation	yrs	5c	Clc
Y	Number of lots in basin	#	6a	GIS
Z	Number of vacant lots in basin	#	6a	GIS
AA	CU impact of build out of vacant lots	af/y	6a,6b	Clc
AB	Annual average basin wide drop in water level due to CU at full build out based on platted lots and PrD with 0 recharge from precipitation	ft/y	6b	Clc
AC	Time it would take to drain the saturated thickness of the basin by the CU at full build out based on platted lots, existing, and PrD with 0 recharge from precipitation	yrs	6b	Clc
AD	Time it would take to drain the saturated thickness of the basin by the CU at full build out based on platted lots, existing, and PrD with estimated precipitation recharge	yrs	6c	Clc

1) Letter identification as used in WAA spreadsheet, bold indicates final output
2) GW= groundwater, PrD= proposed development, CU=consumptive use
3) gpd = gallons per day, af/y = acre—feet per year, % = percent, # = number
4) GIS = from geospatial data, DWR = Division of Water Resources permit files or well type ...... definitions, Rf = value taken from reference, Clc = calculated, Ap = from rezoning application

examples reviewed do not seem to be from the cited references and it is unclear where the values for per-unit use have been derived. However, the values are reasonable. In two of the example WAAs (Eudaimonia and Red Wing) the reference tabs are not populated and the source of the values are not documented. The Conifer Heights example (18-107113RZ) does provide comparable data from the Evergreen Metro District with analyses of metered data. Generally, values used for each use type are not likely to vary significantly from what is in the examples. We assign

Table B-III
Parameters in the WAA Process Considered Subjective

Para-meter[1]	Description[2]	Unit[3]	Table	Confidence	Variability
a	Daily GW withdrawal per unit in PrD (by developed space type)	gpd	[4]	Moderate	Low
c	Percent CU	%	[4]	Moderate	Low
A	Basin area	ac	1,3	Moderate	Low
D	Saturated thickness of the aquifer exposed to wells	ft	1,5b,5c ,6b,6c	Moderate	Low
E	Estimated average porosity of aquifer	%	1	Low	High
G	Effective yield of groundwater to wells	%	1	Moderate	Moderate
I	Estimated GW stored per saturated foot	af/f	1	Low	Moderate
K	Estimated amount of GW withdrawal per well	af/y	2,4,6a	High	Low
M	Estimated percent returned to recharge GW	%	2,4,6a	Moderate	Low
O_p	Estimated CU of GW for the proposed development	af/y	4,5a	Low	Low
P	Mean annual precipitation	in	3	High	Moderate
R	Estimated percentage of precipitation that is recharge	%	3	Low	Moderate

1) Letters in Tables IIa and IIb
2) GW= groundwater, PrD= proposed development, CU=consumptive use
3) gpd = gallons per day, af/y = acre—feet per year, % = percent, # = number
4) Water Requirements table 1

Moderate Confidence and **Low Variability** for values used for this input.

Parameter c, "Percent consumptive use" is used in the Water Requirements tab to adjust total water withdrawal to total consumptive use to account for the portion of water returning to the aquifer as recharge after use. In this tab, the percent is applied in the context of type of use as proposed in the development application, with an assumption on how the wastewater is treated and returned to the aquifer. Uses proposed by the development can be quite variable and include such things as retail space, office space, housing units, and so forth.

For the four examples reviewed, only four values of consumptive use were listed: 10%, 16%, 90%, and 95%. The source of these values is not documented in the examples. The 10% has been applied to most office and commercial uses, many of which use municipal wastewater-treatment facilities. The 16% is applied to residential and some commercial uses and seems to reflect the use of on-site wastewater-treatment systems (OWTS), 90% has been used for irrigation, and 95% is used for special circumstances such as small cabins. Consumptive use of water in homes is an important consideration in water-balance calculations, as many rural homes utilize leach fields for wastewater treatment, which returns much of the groundwater pumped for domestic needs back to the subsurface. Several studies have investigated consumptive use of water in homes in rural settings within Jefferson County, and a study at a residence in the Turkey Creek watershed by Paul and others (2007) indicated that approximately 84% of groundwater pumped for domestic needs returns to bedrock aquifers as recharge based on. More recent and comprehensive work at the same residence suggests that about 80% of pumped domestic water is returned as recharge, with 19% directly lost by consumptive use (Stannard and others, 2010). We assign a **Moderate Confidence** with **Low Variability** to this parameter. Incorporating results from the more recent work into the WAA would improve model accuracy and would raise this to a **High Confidence** with **Low Variability**.

Parameter A, "basin area" in the WAA tab is delineated in ArcGIS using a USGS Digital Elevation Model (DEM) with ten meter resolution, and produces sub-basins with a minimum area of five acres. These sub-basins are currently delineated to ensure the WAA is sensitive to localized groundwater usage, as well as impacts from proposed development. These subbasins are currently delineated to ensure the WAA is sensitive to localized groundwater usage as well as impacts from proposed development. These subbasins are hydrologic units consistent with standard use for watershed analyses. The USGS releases standardized, citable hydrologic unit boundaries at various scales known as Hydrologic Unit Codes (HUCs). Application of the WAA to a geographic site is at a smaller scale than any of the readily available USGS data products, which currently offer a 12-digit HUC as their smallest-scale watershed division. ESRI's ArcGIS software contains tools for creating hydrologic units from digital elevation models, which is how Jefferson County created the subbasins that are smaller than the published HUCs. If 14-digit or 16-digit HUCs ever become digitally available, the WAA process should consider utilizing these similar-scale data products from the USGS to define watershed boundaries using a citable methodology.

Hydrologic units can be either at the headwaters of watersheds or they can be downstream where they may straddle both sides of the watershed valley. This is the case with both hydrologic units provided by the USGS and the subbasins generated in ArcGIS by Jefferson County for the WAA process. Using hydrologic units with this duality of configuration may be useful for many watershed hydrologic analyses. However, it is difficult to account for inflow to a downstream subbasin from upstream sources. The WAA structure does not need to account for a flow-through component, so this condition does not impact the analysis as set up. It does, however, limit the ability to check if the WAA is accurate by monitoring water levels in a subbasin. In a watershed subbasin, a deficit in the water balance should result in a general decline in water levels. This may not be the case in a downstream subbasin where an inflow from upstream would offset the deficit in the subbasin.

The concept of using subbasins is sound and reflects standard hydrologic analytical methods for surface water. However, it does assume that groundwater mimics surface water and that flow systems stay within surface watershed boundaries. In a fractured, crystalline-rock aquifer setting, this may not always be true, particularly if the aquifer is under stress by pumping.

There is the potential for some subbasins to have groundwater wells near basin boundaries. Groundwater pumping in these wells would influence the underlying aquifer beyond the basin boundaries defined in the WAA process. A buffer could be added to a subbasin that extends the area of influence to account for groundwater pumping in wells proximal to a subbasin boundary. A sufficient estimate for this buffer could be arrived at by calculating the radius of influence around a pumping groundwater well. That radius of influence is highly dependent on fracture connectivity in fractured, crystalline bedrock and can be quite variable in size and orientation. The radius of influence can be easily calculated from values obtained during aquifer tests (http://www.aqtesolv.com/forum/roi1.asp), and results from aquifer testing in fractured, crystalline bedrock indicate that a radius of influence of 100 feet may be a reasonable assumed value (Jeffers and Wittig, 2004). Adding a buffer zone may improve model accuracy, particularly in areas with high well density near basin boundaries.

Subbasin size is also a consideration. In a WAA changing subbasin area and extent impacts both inflow and outflow factors in a water-balance analysis. A larger basin brings in more inflow from precipitation over a larger area, but also may bring in more outflow from existing uses. The ratio of increase in inflow over outflow is specific to each basin. Enlargement of one basin may bring in many more existing wells at the lower edge than an adjoining basin.

An alternate approach is to limit the hydrologic unit of the analysis to the property under consideration. The Evergreen Plan includes a clause (page 41) that states: "Development or expansion of development should not be allowed to deplete any existing groundwater supply beyond the ability of the development area to recharge itself." This approach may make the most sense from a perspective of basic sustainability. However, this would likely preclude allowing almost all density development and we consider this a policy decision.

Lastly, the GIS polygon shapefile of subbasins used in the WAA process provided to CGS is not a "clean" polygon file. There are many small polyline "fragments" throughout the coverage. These may be small isolated and irregular polygons within subbasins, or they may be small appendages off of the main subbasin boundaries. These irregularities are likely artifacts of the process that the tool in the program uses. Typically, shapefiles like this should go through a quality check after the process is performed and any irregularities are removed. The irregularities may also indictate that a parameter in the process should be adjusted.

Overall, we consider the basin area approach in the WAA as applied sufficient to quantify localized groundwater impacts, and it has a **Moderate Confidence** with **Low Variability**.

Parameter D, "Saturated thickness of aquifer exposed to wells," in the WAA tab is estimated by taking the difference between the mean depth of wells and the mean depth to groundwater in a given basin. Depth to groundwater and total well depth were averaged in each basin from the Colorado Division of Water Resources well dataset. This calculation is used to estimate the total water in storage available to wells within a basin in Table 1. This parameter is also applied in conjunction with parameter G, "Effective yield of groundwater to wells," in estimating how much water is available in storage in a subbasin for use. The "effective yield" term acts as a factor of safety that enhances sustainability by protecting existing well users and acknowledges that not all fractures in crystalline bedrock are water-bearing. While these estimates of saturated thickness and effective yield may not be citable, they are beneficial for existing users who have shallow wells and promote conservative and sustainable use of groundwater resources in Jefferson County. Research from groundwater wells in fractured, crystalline bedrock in New England found that 2.5% of fractures encountered in 17 well boreholes were water-bearing (Boutt and others, 2010). Their findings also suggest that fracture intensity sharply decreases at 550 feet below the surface, and fractures were not present below 1,000 feet (Boutt and others, 2010). Values based on average depths may be less than 550 to 1,000 feet, suggesting that, in reality, saturated thickness could be greater than current estimates in the WAA examples. However, it is important to keep in mind that the WAA process considers existing users within the subbasin, many of which have shallow wells. Overall, the existing WAA estimates for saturated thickness have **Moderate Confidence** with **Low Variability**.

Parameter E, "Estimated average porosity of aquifer," in WAA tab is used to calculate the volume of water in storage in Table 1. Porosity is a significant driver in water-budget calculations, as it largely controls groundwater storage in the sustainability evaluation. A value of 2.0% is used for porosity in the four example WAAs reviewed but the source of that value is not cited.

Porosity can vary by aquifer type and Table 1 of the WAA tab lists relative abundances of aquifer rock type as percentages. In the four examples reviewed, the relative percentage of rock types within the basin were not used to adjust the average porosity within the basins. Porosity estimates could be improved by using the aquifer type distribution listed in Table 1 of the WAA tab if site-specific data are available. Porosity estimates for the major bedrock types commonly found in Jefferson County were estimated by modeling fracture opening size, or aperture, and density (Bossong and others, 2003). The estimates showed that values could range over several orders of magnitude for each rock type. **Table B-IV** compares the current 2% value applied in the WAA examples with other values from the literature and includes recommended representative values that could be used in the WAA process. However, adjusting the porosity values by distribution of aquifer type requires detailed geologic mapping data for the sub basin. Currently the only GIS-based geologic mapping available for the county is at a scale of 1:100,000, which is a small scale with respect to the subbasin sizes. In most cases the geologic mapping of rock type, and hence aquifer type, is not adequate to refine the porosity value for a given subbasin. We assign **Low Confidence** with the potential for **High Variability** for porosity values.

Parameter G, "Estimated average porosity of aquifer," in the WAA tab is used to adjust the total water estimated in storage based on the porosity and saturated thickness in Table 1. It is not a variable easily measured, nor are there values in the literature. It is similar in concept to specific yield of an aquifer, which represents the percentage of water that will drain by gravity from an aquifer. In most materials, the specific yield is lower than the porosity because not all water will drain by gravity. Capillary forces retain a small portion of water on the surfaces of grains where pore space is small. Capillary forces may indeed retain water within the fractures of the crystalline bedrock aquifer, but the relative amount can vary considerably, depending on fracture aperture. A value of 50% is used in the WAA process and it enters the calculations after the volume is adjusted for porosity, so it effectively cuts the porosity in half. A value of 50% serves as a factor of safety that enhances sustainability by protecting existing well users and acknowledges that not all fractures in crystalline bedrock are water-bearing. This parameter has a **Moderate Confidence** with **Moderate Variability**.

Parameter I, "Estimate of groundwater stored in the basin aquifer per foot of saturated thickness," in the WAA tab is a value used later on in assessing the sustainability of the aquifer (Tables 5b, 5c, 6b, and 6c). The value

Table B-IV
Porosity ranges and representative values for the major bedrock units that make up aquifers in Jefferson County

Aquifer Composition	Current Model	Porosity Range[1)]	Recommended Representative Porosity
Basin Wide	2%	N/A	N/A
Metamorphic	N/A	0 - 10%	2.5%[2]
Intrusive	N/A	0 - 5%	0.5%[3]
Fault Zone	N/A	0 - 10%	5%[2]
Pike's Peak Granite	N/A	0 - 5%	0.5%[3]
Alluvium	N/A	20 - 35%	25%

1 Freeze and Cherry (1979) 2 Lane and others (1995) 3 Schild and others (2001)

is calculated by multiplying the basin area by the average porosity of the aquifer. This is not an intuitive calculation and does not reflect the title of the parameter. A better calculation, which reflects the parameter title and intent of the use in later calculations, is to divide the volume in the saturated thickness by the saturated thickness. This change in calculation increases the estimated drop in water level (parameter V in Table 5b) and decreases the time to deplete the aquifer (parameter W in Table 5b). As currently calculated, we assign **Low Confidence** with **Moderate Variability**.

Parameter K, "Estimated amount of groundwater withdrawal," in the WAA tab is used to calculate the total withdrawal by existing wells in the basin in Table 2 and then again in Table 4. Table 4 estimates the total withdrawal by wells in the proposed development. For exempt wells, primarily household and domestic, the values are 0.3 and 1 acre-feet per year, respectively. Since these wells are not metered, this value is reasonable to use and is what is typically applied when estimating water use by these types of wells. The Upper Mountain Communities study (CDM, 2011) uses 0.6 acre-feet per year for domestic, 0.25 for household, and 0.33 acre-feet per year for all other types. A domestic permit allows up to about 3 acre-feet per year. In many cases, the values may be high; in others, they may underrepresent actual usage. For administered wells, such as municipal and commercial, reported use data are available from the Colorado Department of Water Resources. We assign this value **High Confidence** with **Low Variability**.

Parameter M, "Estimated returned to recharge groundwater," in the WAA tab is an estimate of direct recharge to the aquifer after a portion of the pumped water is consumed. Conceptually it is essentially the same as parameter c in the Water Requirements tab. Both parameter c and M are based on estimates of total consumptive use. Parameter M in the WAA tab is reported as the percent returned to the aquifer in contrast to percent consumed for c in the Water Requirements tab; hence c=1-M. Parameters c and M also differ in how the values are derived; and this is a significant distinction. Parameter M in the WAA tab is based on the source-well type, whereas parameter c in the Water Requirements tab is based on the use of developed space and how the water is treated and returned to the aquifer proposed for the development. Uses proposed by the development vary and include such things as retail space, office space, housing units, and so forth. Estimating consumptive use, and hence recharge to the aquifer, by proposed use of space and use of the water should be considered a more realistic estimate. In the four examples, there is consistency in values used. We assign this parameter **Moderate Confidence** with **Low Variability**.

Parameter Op, "Estimated returned to recharge groundwater," in the WAA tab is used to assess the impact of the proposed development in Table 5a. This value should be similar to the estimated total consumptive use, parameter f, in the Water Requirements tab. Any difference between the two would reflect that a variable is not correct in one of the analyses. If parameter Op is higher than parameter f, either the estimated use by developed space is underestimated or the amount of water available to be consumed by the proposed wells is too high. Conversely, if parameter Op is lower than parameter f, either the estimated use by developed space is overestimated or the amount of water available from the proposed wells is too low. The latter condition would be a flag that the proposed wells may not be physically or legally adequate to meet the anticipated demands. As currently calculated, we assign **Low Confidence** with **Low Variability.**

Parameter P, "Mean annual precipitation based on NWS RFS data," is used in Table 3 to estimate water available from the water balance. The value is calculated based on National Weather Service River Forecast Centers, which utilize both raingage and radar data on a 4-kilometer by 4-kilometer grid system. Annual precipitation measurements from 2005–2013 were collated from 145 stations across Jefferson County and were interpolated to provide precipitation estimates across the county. These stations are well distributed across Jefferson County with a sufficiently high spatial resolution to provide an accurate estimation of precipitation inflows across the county. The current time range investigated (2005–2013) should be sufficient to capture climate variability, but periodically updating the precipitation dataset will ensure that precipitation inflows remain accurate in the model. The value does not take into consideration possible climate change. Overall, precipitation is characterized well by the existing WAA with a **High Confidence** and **Moderate Variability** in the current model.

Parameter R, "Mean annual precipitation based on NWS RFS data," is used in Table 3 to arrive at a value of direct inflow of water to the aquifer from natural recharge. It represents the natural inflow of water to the subbasin area of the proposed development. Other sources of water inflow may exist, including recharge from human activities, such as infiltration from on-site leach fields and ponding of water in disturbed areas. For downstream subbasins there can be an inflow from groundwater underflow or seepage from the stream into the aquifer under favorable conditions. Recharge from precipitation is a major driver of incoming water in the current WAA process, and recharge from precipitation is listed at 3.5% for all of the basins in Jefferson County. Recharge is an important consideration in water-balance applications because it is the major source to replenish groundwater in storage.

A complete water balance was modeled for Turkey Creek in Jefferson County (Bossong and others, 2003; CDM, 2011), which estimated that evapotranspiration is a sink for 86.5% of incoming precipitation; 5.1% of incoming precipitation is lost to surface runoff; 6.1% of incoming precipitation runs off into surface water via the shallow interflow reservoir; and 2% of incoming precipitation partitions into deep bedrock reservoir recharge. CDM (2011) performed regression analyses of baseflow against precipitation by major rock type and the results are listed **Table B-V**. There were not sufficient data available from alluvium to develop a regression equation, so CDM assumed recharge in alluvium is comparable to that in Pikes Peak granite, which has the highest recharge rates out of all of the geologic classes.

Recharge rates derived from the regression analysis did not match expected relationships, with recharge rates in Pike's Peak Granite and other intrusive rocks being higher than fault zone areas and metamorphic bedrock, which should have a higher intensity of fracturing. This may reflect weathering processes in the Pike's Peak Granite, which has a thick regolith layer that could support greater recharge rates than non-weathered intrusive rocks. The unexpected results for the fault zone may be an artifact of application of the regression analysis against a watershed model simulation where fault zones represent discrete and limited features. It may also reflect the scale of geologic mapping available in digital GIS format. Geometry and extents of various geologic units in the watersheds may be much more complex than the 1:100,000 digital maps indicate and the regression analysis may not account for actual geologic conditions. Further work should be done to collect field measurements of infiltration rates in major bedrock classes present in Jefferson County, which would better quantify hydraulic conductivity of these major classes and generate physical estimates of recharge processes. We assign **Low Confidence** with **Moderate Variability** for this parameter.

Recommended Parameter Revisions

Based on our evaluation we recommend considering revisions to the values of parameters listed in **Table B-VI**. These values are based on a review of current available literature relevant to the foothills area of Jefferson County.

Other Considerations

Slope and aspect: Slope and aspect could also be important factors to consider for water balance calculations in the WAA. Weathering processes are significantly different on north facing slopes compared to south facing slopes. Steepness also affects weathering and regolith characteristics, as well as runoff of precipitation. Recent studies completed by the Colorado School of Mines suggests that slope weathering profiles are significantly more intense on north facing slopes (Bandler, 2016). These effects could greatly impact hydrogeologic properties of north facing slopes, as intensely weathered regolith could significantly enhance both recharge rates and storage from porosity. Results from this study suggest that on north facing slopes, groundwater flow can approximate matrix dominated conditions in fractured bedrock, while on south facing slopes groundwater flow is controlled by fractures (Bandler, 2016). Thus, recharge rates are likely to be significantly greater on north facing slopes, which could greatly impact water balance calculations.

Changes in land cover from development: In some development sites large areas of land can be modified. Once forested areas may be cleared, large areas may be graded exposing deeper parts of the regolith or unweathered bedrock. Other areas may be covered with impervious surfaces. All of these modifications may change runoff patterns, evapotranspiration rates, and ultimately recharge rates that can impact the water balance. There may not be a practical way to factor this into a WAA at the sub-basin level, but these changes may be an important factor in the overall water balance in areas of heavy development.

Table B-V
Percent of precipitation that recharges groundwater storage.

Geologic Bedrock Class	% Recharge from Precipitation[1]
Metamorphic	7.5%
Intrusive	10.0%
Fault Zone	5.40%
Pike's Peak Granite	19.2%
Alluvium	19.2%

1 CDM (2011)

Table B-VI
Summary table for JeffCo WAA parameters that could be updated to improve model accuracy

Parameters Dependent on Bedrock Type:	Porosity		Recharge from Precipitation	
Aquifer Composition	Current Model	Recommended Representative Porosity	Current Model	Recommended Representative Recharge
Basin Wide	2%	N/A	3.5%	N/A
Metamorphic	N/A	2.5%	N/A	1.88%
Intrusive	N/A	0.5%	N/A	2.5%
Fault Zone	N/A	5%	N/A	1.35%
Pike's Peak Granite	N/A	0.5%	N/A	4.8%
Alluvium	N/A	25%	N/A	4.8%
Other Parameters:	Current Model Value		Recommended Value	
Percent Consumptive Use of Domestic Wells	84.4%		80.4%	
Water Demands	Table 4 WAA Tab		Table 1 Water Requirements Tab	

REFERENCES

Bandler, A., 2016, Geophysical constraints on critical zone architecture and subsurface hydrology of opposing montane hillslopes: Colorado School of Mines Masters Thesis, 48 p.

Bossong, C.R., Caine, J.S., Stannard, D.I., Flynn, J.L., Stevens, M.R., and Heiny-Dash, J.S., 2003, Hydrologic conditions and assessment of water resources in the Turkey Creek watershed, Jefferson County, Colorado, 1998-2001: Water-Resources Investigations Report 2003–4034, accessed at http://pubs.er.usgs.gov/publication/wri034034.

Boutt, D.F., Diggins, P., and Mabee, S., 2010, A field study (Massachusetts, USA) of factors controlling the depth of groundwater flow systems in crystalline fractured-rock terrain: Hydrogeology Journal, v. 18, p. 1839–1854.

Camp Dresser & McKee (CDM), 2011, Upper Mountain Communities Aquifer Sustainability Project-Final Report:

Driscoll, F.G., 1986, Groundwater and wells (2nd ed.): St. Paul, Minn., Johnson Division, 1,089 p.

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Prentice-Hall, Inc., 624 p.

Jeffers, P., and Wittig, V., 2004, Fractured bedrock aquifer hydrogeologic characterization for a bioaugmentation pilot study: Conference Proceedings, p. 148–157.

Kellogg, K.S., Shroba, R.R., Bryant, B., and Premo, W.R., 2008, Geologic map of the Denver West 30' x 60' quadrangle, north-central Colorado: Scientific Investigations Map 3000, accessed at http://pubs.er.usgs.gov/publication/sim3000.

Lane, J.W., Haeni, F.P., and Watson, W.M., 1995, Use of a square-array direct-current resistivity method to detect fractures in crystalline bedrock in New Hampshire: Ground Water, v. 33, no. 3, p. 476–485.

Ruleman, C.A., Bohannon, R.G., Bryant, B., Shroba, R.R., and Premo, W.R., 2011, Geologic map of the Bailey 30' x 60' quadrangle, North-Central Colorado: Scientific Investigations Map 3156, i–38 p., accessed at http://pubs.er.usgs.gov/publication/sim3156.

Schild, M., Seigesmund, S., Vollbrecht, A., and Mazurek, M., 2001, Characterization of granite matrix porosity and pore-space geometry by in situ and laboratory methods: Geophysics Journal International, v. 146, p. 111–125.

Topper, R., Spray, K.L., Bellis, W.H., Hamilton, J.L., and Barkmann, P.E. Ground water atlas of Colorado: Special Publication, Colorado Geological Survey.