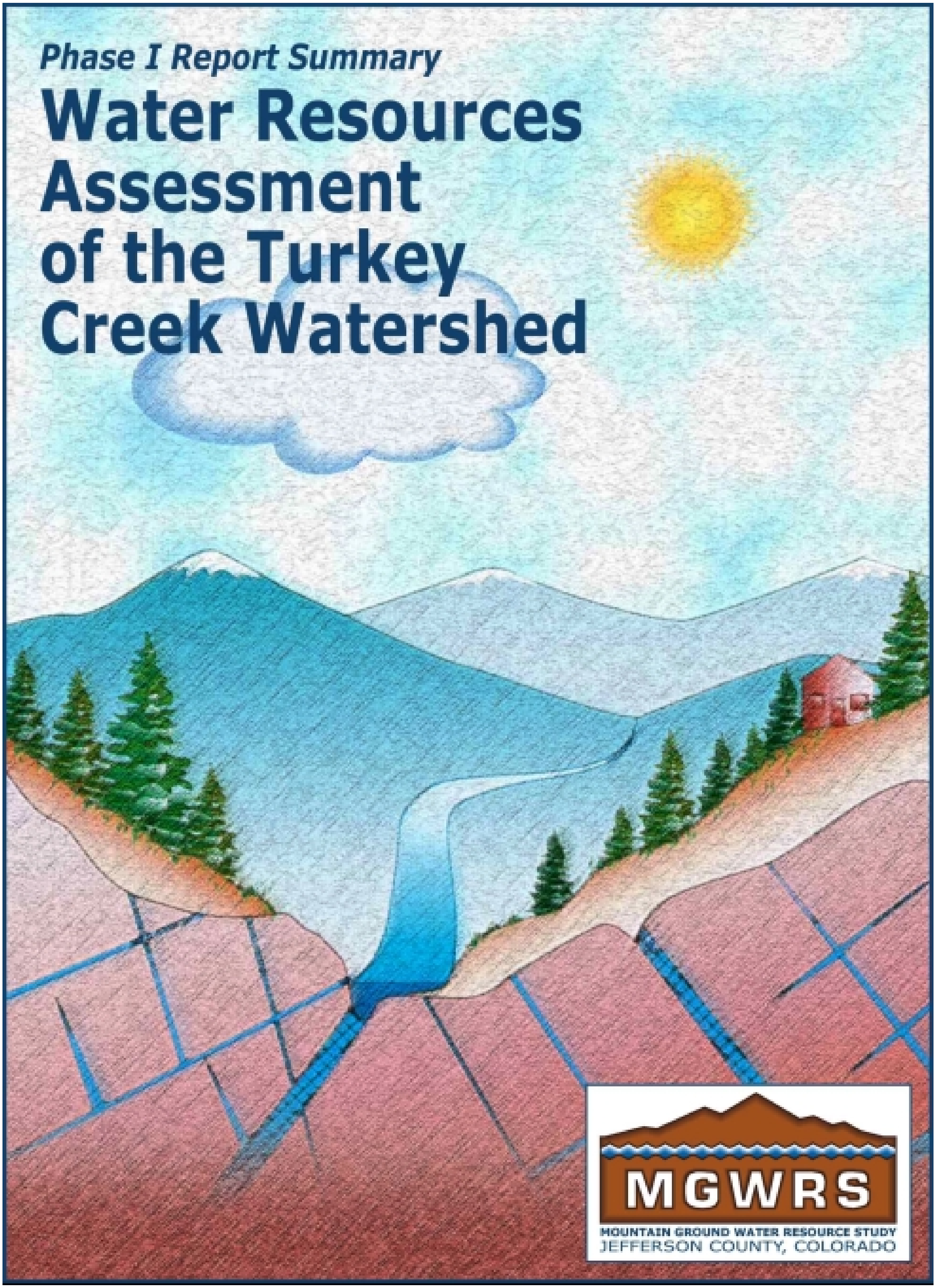
Phase I Report Summary

Water Resources Assessment of the Turkey Creek Watershed



MGWRS
MOUNTAIN GROUND WATER RESOURCE STUDY
JEFFERSON COUNTY, COLORADO

Mountain Ground Water Resource Study

Phase I Report Summary
Water Resources Assessment of the Turkey Creek Watershed
1998 to 2000

Prepared for: Jefferson County, Colorado

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Dear Reader:

The attached report, entitled: **Summary of Phase I Report: Water Resources Assessment of the Turkey Creek Watershed, Jefferson County, Colorado, 1998-2000**, provides a brief overview of Phase I of the Mountain Ground Water Resource Study (MGWRS). The use of this summary report should be limited. The reader is cautioned that the data interpretations, conclusions, and conceptual understandings presented in the Summary Report will continue to evolve as more work is completed under Phase II of the MGWRS. The interpretations and conclusions are subject to change as more data is obtained and analyzed. The United States Geological Survey (USGS) will publish a final, USGS report after Phase II of the MGWRS is completed at the end of 2001.

The MGWRS, started in 1998, is a detailed study of ground water resources in the Turkey Creek Watershed, located in the foothills of western Jefferson County. Research has been conducted by the USGS. Funding has been provided by Jefferson County, USGS and the Environmental Protection Agency. Guidance and oversight has been provided by a Steering Committee comprised of representatives of Federal, State and local governments as well as local water experts, consultants, and citizens.

The focus of the data collection and analyses is to develop a sound conceptual understanding of the ground water system within the watershed. Extensive hydrologic data have been collected to describe the occurrence, flow, quantity, and quality of ground water in the fractured rock that underlies the forty-seven square mile Turkey Creek Watershed. A variety of characterization tools and approaches have been used to evaluate and analyze the information and data including: outcrop mapping, water quality analyses, collection and analysis of evapotranspiration data, hydrograph analysis, and watershed modeling (Precipitation Runoff Modeling System).

This study is critical considering the increased demand for ground water for domestic use caused by the significant population growth in western Jefferson County. Jefferson County will consider using the findings in the final report to support and implement future water use and land management regulations and policies to ensure a sustainable ground water supply.

INTRODUCTION

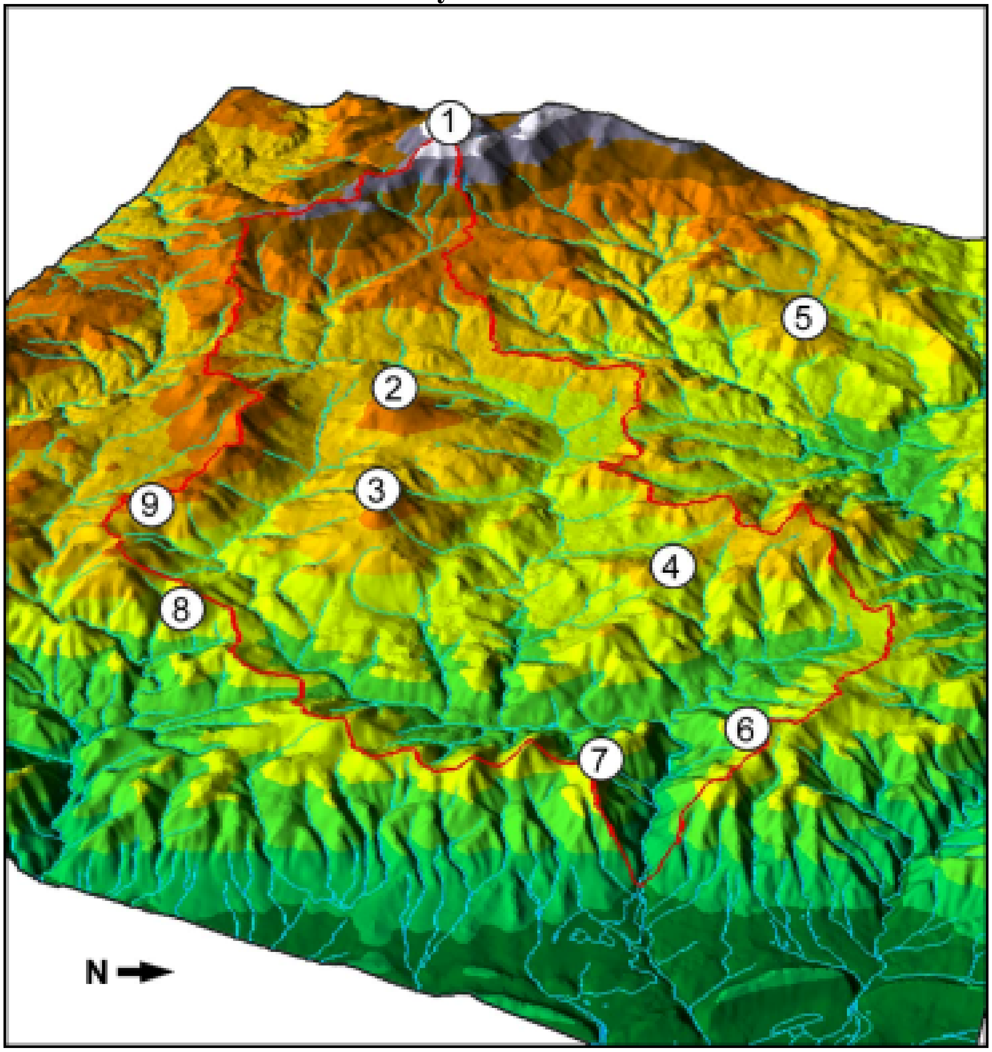
The purpose of this Summary is to describe the current (1999-2000) understanding of water resources, including surface and ground water quantity and quality, in the forty-seven square mile Turkey Creek Watershed (Figures 1 and 2). The data, information, and conceptual understandings presented in this summary are derived from the Mountain Ground Water Resource Study (MGWRS), initiated in 1998 by Jefferson County, Colorado and conducted by the U.S. Geological Survey (USGS). An understanding of the occurrence, flow, quantity and quality of ground water in the mountainous parts of Jefferson County needs to be developed as a first step in developing scientifically sound management strategies for ground water use. The Turkey Creek Watershed is a pilot study area for development of methods to assess ground water availability within different hydrologic settings, and ground water vulnerability to various land uses.

Figure 1
Location of the Turkey Creek Watershed

Phase I of the MGWRS focused on developing a method for evaluating ground water quantity in fractured bedrock aquifers using the Precipitation Runoff Modeling System (PRMS) and other modeling techniques. Hydrogeologic characteristics of the watershed are used to delineate unique areas called hydrologic response units (HRUs). An estimate of the amount of ground water in storage and the availability of ground water is calculated for the HRUs.

Refinements of this methodology in Phase II of the MGWRS are designed to provide a more complete intra-watershed understanding of water supplies available in the fractured bedrock aquifer system. The approach outlined in this study could be used to evaluate water resources in other fractured bedrock aquifers in Jefferson County or in other mountainous areas of Colorado and the Rocky Mountain West.

Figure 2
The Turkey Creek Watershed



Key: 1) Black Mountain 2) Berrian Mountain 3) Double Head Mountain 4) Lone Peak 5) Evergreen Mountain 6) Mount Falcon 7) Mount Lindo 8) Yegge Peak 9) Crow Hill

DATA COLLECTION

Water quality data describing concentrations for water quality properties and constituents in ground and surface water were collected at about quarterly intervals, for one year beginning in Fall 1998 at 113 wells and springs, and at 22 surface water sites in the study area. A stream gage (USGS station number 06710995), located at the mouth of Turkey Creek Canyon, continuously measured discharge (ft^3/sec) in Turkey Creek. Water levels were measured monthly at fifteen wells (monitoring holes 1 through 13) in and near the watershed beginning in September 1998.

Seven tipping-bucket rain gages and three weighing-bucket rain gages (rain gages 1 through 10) were installed by USGS at selected locations in the watershed in the fall of 1998. Snow tables were co-located at all tipping-bucket rain gage locations and nine other snow tables (snow tables 1 through 9) were installed. Detailed evapotranspiration (ET) data were collected at two sites within the watershed, a forested site and a grassland meadow site, utilizing two different micrometeorological methods to measure ET.

Fracture data were collected at nine natural (except for fault zone localities) outcrops representative of the dominant rock types found in the watershed. The basic fracture data collected included: position (for spacing and intensity), orientation (strike and dip), length, how the fracture tips end, widths of opening, degree and type of mineralization, shape, roughness, and geologic history.

GEOLOGIC FRAMEWORK

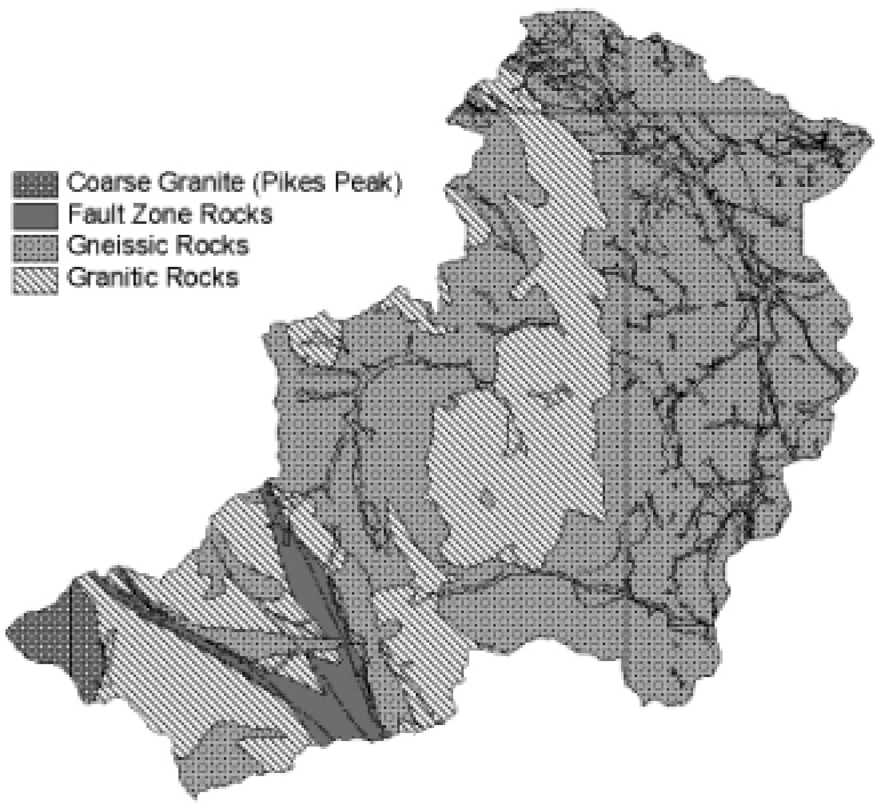
The geology of the Turkey Creek Watershed is complex. Because of this, the major rock types are combined into four major groups that may exhibit unique geologic and hydrogeological properties that include fracture characteristics, storage capacity, and permeability (Figure 3).

The major rock groups include:

1) Gneissic Rocks (gneiss and schist),
2) Granitic Rocks (intrusive quartz monzonites and other granitic rocks),
3) Fault Zones (major fault zones in both the metamorphic and igneous rock groups), and
4) Coarse Granitic Rocks (Pikes Peak Granite that outcrops only in the SW portion of the watershed).

Surficial alluvial deposits do not provide a sustainable water supply in the Turkey Creek watershed, but they may play a role in recharge and shallow seasonal ground water flow.

Figure 3
Rock Groups in the Turkey Creek Basin



WATER-QUALITY

The quality of ground and surface water in the Turkey Creek watershed is generally good. However, when compared to water quality data collected in the 1970s and 1980s there appears to be a trend of decreasing water quality, as demonstrated by increasing concentrations of nitrate plus nitrite, and chloride (Table 1). About 3 percent of the samples exceed the National Primary Drinking Water Standards (U. S. Environmental Protection Agency, 1999) or National Secondary Drinking Water Standards (U.S. Environmental Protection Agency, 1991) in ground water, or Colorado In-Stream Standards (Colorado Department of Public Health and Environment, 2000) for surface water.

Ground water in the Turkey Creek Watershed is classified as calcium bicarbonate, which is typical for shallow ground water along the Front Range. All surface water samples exhibit elevated chloride concentrations that are probably caused by individual septic disposal systems (ISDS), the application of road salt, or both. Elevated nitrate concentrations in some ground water samples also may indicate an ISDS origin.

Table 1:
Comparison of concentrations of selected water quality constituents in historic (1970s and 1980s) and current ground water samples in the Turkey Creek Watershed, Jefferson County, Colorado.

Variable		Ground-water				Surface-water			
		Avg	Max	Min	N	Avg	Max	Min	N
Specific Conductance µS/cm	historic	278	950	32.7	316	149	266	47.5	24
	current	330	1090	22.0	363	403	840	106	78
Hardness, total, mg/L	historic	110	380	22.0	65	56.0	110	22.0	24
	current	137	550	0.16	270	134	320	25.0	56
Calcium, total, mg/L	historic	31.1	130	6.60	65	15.8	31.0	6.60	24
	current	39.8	77.4	3.48	22	37.9	84.6	7.10	53
Magnesium, total, mg/L	historic	7.85	24.0	1.00	65	4.03	8.00	1.00	24
	current	9.61	15.9	0.85	22	10.1	24.0	1.91	53
Sodium, total, mg/L	historic	19.5	120	2.90	65	7.99	15.0	2.90	24
	current	15.2	50.4	5.87	22	26.1	49.8	6.07	53
Potassium, total, mg/L	historic	2.03	25.0	0.20	284	1.66	8.50	0.50	24
	current	2.91	4.64	2.18	22	3.21	5.70	0.50	50
Alkalinity, total, mg/L	historic	112	425	13.0	65	53.6	107	13.0	24
	current	118	270	7.12	273	95.0	209	24.8	58
Sulfate, mg/L	historic	13.4	90.0	1.20	65	8.41	16.0	3.00	24
	current	22.0	2500	1.00	272	11.8	26.3	2.50	58
Chloride, mg/L	historic	9.26	64.0	0.40	313	8.77	27.0	1.00	24
	current	25.0	230	0.50	269	59.6	153	5.41	58
Fluoride, mg/L	historic	0.66	2.90	0.10	65	0.52	1.10	0.20	24
	current	0.88	4.70	0.15	242	0.50	2.70	0.22	55
Nitrate plus Nitrite, as N, mg/L	historic	0.12	2.10	0.01	28	0.21	0.78	0.01	24
	current	2.26	18.5	0.05	309	0.45	1.47	0.05	47
Phosphorous, total, mg/L	historic	0.04	1.30	0.01	109	na	na	na	na
	current	0.10	0.71	0.02	64	0.04	0.15	0.02	33

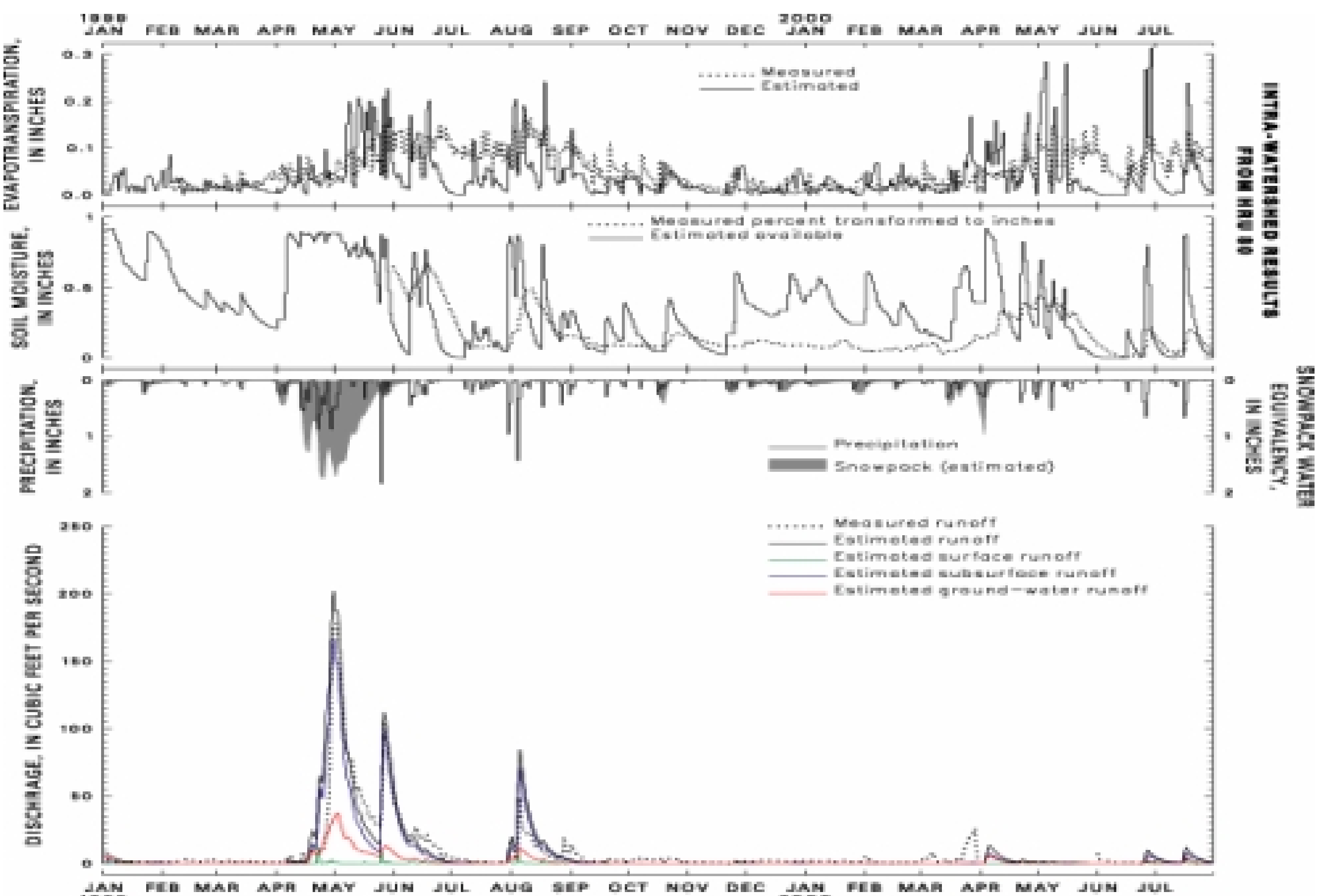
Key: ***Avg=average, Max=maximum, Min=minimum, N=number of samples, na=not analyzed, µS/cm=microsiemens/cm at 25°C***

SURFACE WATER

Runoff hydrographs from the Turkey Creek Watershed (Figure 4) are characterized by peaks that occur in the Spring in direct response to spring snowmelt. The Turkey Creek Watershed also experiences direct runoff as a result of local summer thunderstorms. Thunderstorm hydrographs have the same asymmetrical shape as snowmelt hydrographs, however, their duration is much shorter and their peaks are generally lower than snowmelt peaks (tens of ft^3/sec).

Between periods of direct runoff, streamflow in the Turkey Creek Watershed is characterized by steady flows that slowly recede in a linear fashion. This sustained streamflow is a result of baseflow, or ground water discharge to Turkey Creek. Ground water flow is the steady base flow seen in streamflow that does not occur in direct response to precipitation or snowmelt. Ground water flow velocities are much less than surface streamflow and direct runoff velocities.

Figure 4
Graphs illustrating measured and PRMS-estimated values for: evapotranspiration, soil moisture, precipitation, and surface-water discharge in the Turkey Creek Watershed, Jefferson County, Colorado, 1999-2000.



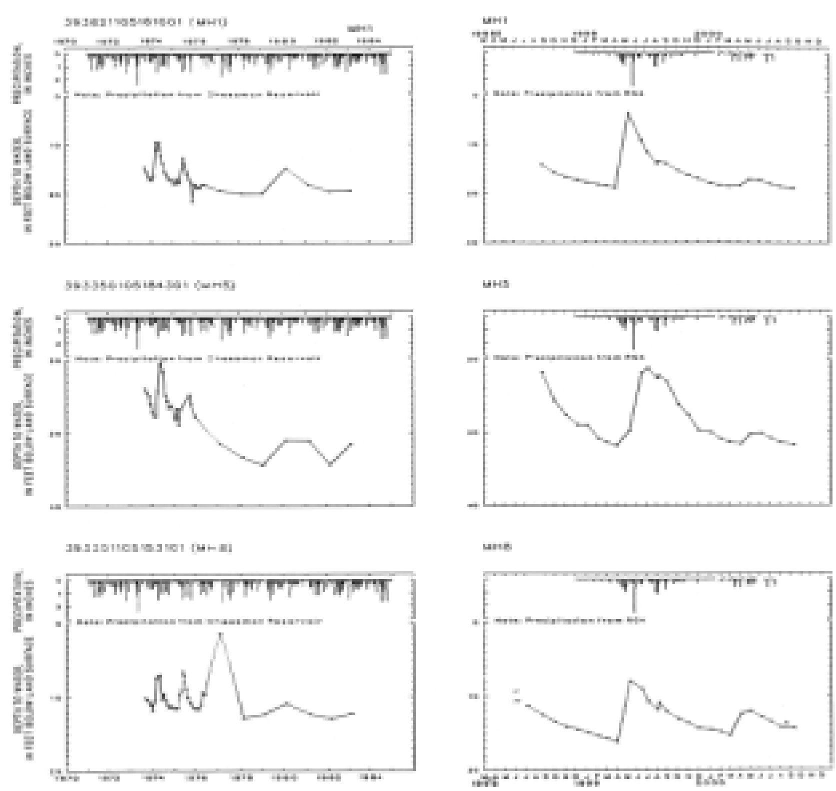
EVAPOTRANSPIRATION

Observed evapotranspiration (ET) values from the two measuring points are greatest in late spring and early summer, and are lower the rest of the year, as recorded during both 1999 and 2000 (Figure 3). Precipitation was 41 percent greater in 1999 than in 2000 (25.1 inches and 17.8 inches, respectively), but, ET did not vary as much as precipitation (18.7 inches in 1999 and 17.3 inches in 2000). ET was 74.5 percent of precipitation in 1999 and 97.2 percent of precipitation in 2000.

GROUND-WATER LEVELS

Ground water levels fluctuate seasonally in the monitoring wells and high water levels relate to precipitation events and spring snowmelt. This relation is shown in Figure 5 where the maximum accumulation of precipitation from April through May 1999 corresponds to the highest recorded water levels in almost all of the monitoring holes. Periods of extended drought in the study area may result in lower ground water levels in the Watershed. Static ground water levels from State Engineer’s Office (SEO) records for about 1,100 wells were used to calculate water table elevations.

Figure 5
Graphs illustrating historic and current water level in selected monitoring wells in the Turkey Creek Watershed, Jefferson County, Colorado.



WELL STATISTICS

Statistics computed using well construction and well yield information from the SEO indicate an average reported yield of 5.57 gallons per minute (Table 2). Average total well depth is 340 feet. Current information indicates that some new wells are being drilled to depths greater than 1000 feet. Other information on Table 2 indicates that although average well yield by rock group is highest for fault zone rocks, the variability is also highest for these rocks. Variability in well yields is fairly constant between the other rock groups. There were more than twice as many wells completed in gneissic rock than in granitic rock, and the minimum yield was much lower in the gneissic rocks (0.06 gpm versus 0.40 gpm). The number of wells completed per year is increasing, and more wells were completed during the time interval 1991 to 1998 compared to other ten year intervals (beginning in 1951), but these statistics may be indicative of better record keeping practices after the mid-1970s in addition to increased well drilling. It is also clear that reported well yields have increased in time.

Table 2
Summary statistics for well construction characteristics and reported well yields

Variable	Avg	Median	Stdev	Q1	Q3	Min	Max	N
Yield	5.57	4.00	5.37	2.00	7.00	0.06	50.0	1109
Total depth	340	305	164	225	425	6.00	902	1116
Depth to water	89.1	70.0	75.6	40.0	108	1.00	519	1075
Perforated length	154	100	107	100	200	4.00	663	631
Top of perforated length	220	195	147	105	300	9.00	820	631
Bottom of perforated length	374	350	165	260	477	55.0	900	631
Well Yield by Rock Group								
Granite	5.39	4.00	27.9	na	na	0.40	50.0	309
Gneiss	5.52	4.00	26.1	na	na	0.06	50.0	677
Fault zone	7.33	4.00	83.9	na	na	0.75	50.0	43
Coarse granite	6.91	5.00	21.9	na	na	1.00	15.0	15
Well Yield for all rock groups combined, by time period								
1951 - 1960	2.00	2.00	----	na	na	2.00	2.00	1
1961 - 1970	2.80	2.00	3.70	na	na	1.00	6.00	5
1971 - 1980	5.49	3.45	24.3	na	na	0.25	30.0	192
1981 - 1990	7.03	5.00	51.8	na	na	0.06	50.0	133
1991 - 1998	5.98	4.00	36.3	na	na	0.25	50.0	296

Key: yield=reported yield in gallons per minute; all depths in feet below land surface, avg=average, stdev=standard deviation, Q1=25th percentile, Q3=75th percentile, Min= minimum, Max=maximum, N=number of cases, na=not applicable

ESTIMATES OF POTENTIAL POROSITY

Estimates of potential porosity were modeled using statistical techniques for three of the rock groups (granitic, gneissic, and fault zone). There were no fracture measurements made in the coarse granitic rocks. Potential porosity is defined as an estimate of the volume of ground water that could be stored in fractures. The estimates of potential porosity are based on computer models which utilize the geometric characteristics of the fracture networks measured in each of the nine outcrops. Although the estimates are rough, they do provide some information about how much water could potentially be stored in the upper few tens of meters in the different rock groups. The estimates for each rock group are given in Table 3.

Table 3
Estimated fracture porosity (in percent) for 100 micron-wide fractures in the Turkey Creek watershed, Jefferson County, Colorado, 1998-2000

Potential Porosity	Granitic Rocks	Gneissic Rocks	Fault Zones
Average	0.0227	0.0338	0.2748
Maximum	0.0246	0.0452	0.2778
Minimum	0.0201	0.0161	0.2717

The granitic and fault zone rock groups show little variation in potential porosity, whereas the gneissic rock group shows some variation. The estimated porosities in the fault zone rock group are about ten times greater than the estimated porosities in the granitic and gneissic rock groups.

ESTIMATES OF POTENTIAL GROUND-WATER AVAILABILITY

Potential ground water availability is defined as the time it would take to withdraw all the water stored in the simulated rock groups at typical rates of use for the Turkey Creek Watershed. The estimates of potential availability are based on the modeled potential porosities and the following assumptions:

1) a hypothetical aquifer one kilometer square and 100 meters thick,
2) 300 gallons per day ($0.3m^3$) of water are used by each of 40 households,
3) the aquifer is 100 percent saturated (this may never actually happen as aquifer storage fluctuates with time),
4) ground water only exists in fracture networks (there is no matrix porosity),
5) there is no recharge,
6) there is no discharge other than wells,
7) all fractures are of uniform width, and
8) all of the water can be removed from the fractures (completely interconnected).

As an example, using reasonable fracture widths of 100 microns (or about the width of one human hair), ground water in the non-fault zone rock groups would potentially last from 1.4 to 2.0 years (Table 4). Using the same fracture widths, ground water in the fault zone rock group would potentially last for about 15 years (Table 4). Although the actual widths of all fractures in a representative block of the aquifer cannot be measured, the values in Table 4 give a reasonable range of potential ground-water availability. These estimates are conservative because they are based on the assumption of no recharge.

Table 4
Average estimated water volumes and potential availabilities for hypothetical aquifers in the Turkey Creek watershed, Jefferson County, Colorado

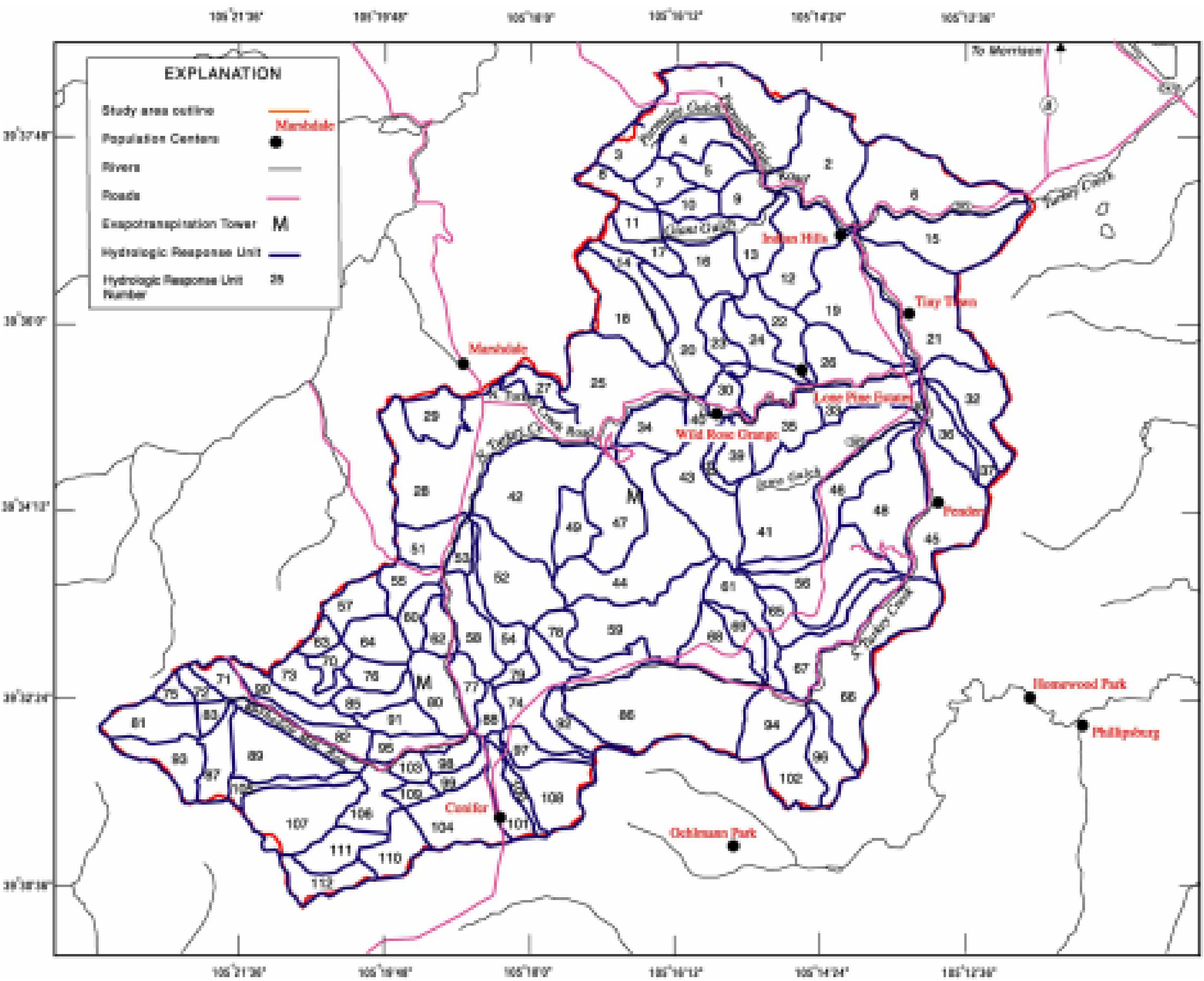
	Granitic Rocks		**Gneissic Rocks**		**Fault Zone Rocks**	
Fracture width	Total water volume (gallons)	Water available (years)	Total water volume (gallons)	Water available (years)	Total water volume (gallons)	Water available (years)
10 microns	602,000	0.14	894,000	0.20	6,700,000	1.53
100 microns	6,020,000	1.37	8,940,000	2.04	67,000,000	15.3
1 millimeter	60,200,000	13.7	89,400,000	20.4	670,000,000	153

Key: ***the following assumptions: 1) aquifer volume is 1 km square and 100 m thick, 2) water use is 300 gallons per day per each of 40 households, 3) the aquifer is 100 % saturated, 4) ground water only exists in the fractures, 5) there is no recharge, 6) there is no discharge other than wells, 7) all fractures are of uniform width, and 8) all fractures are completely interconnected and all water can be removed***

PRECIPITATION RUNOFF MODELING SYSTEM

Runoff modeling was used to evaluate the amount of precipitation received by the Turkey Creek Watershed that is potentially available for ground water storage. The Precipitation Runoff Modeling System (PRMS) distributes the measured water inputs throughout the entire Watershed relative to known or estimated physical characteristics. Typically, areas within the Watershed are defined by unique physical characteristics and hydrologic response; referred to individually as a hydrologic response unit (HRU). HRUs are defined on the basis of unique mappable combinations of slope, aspect, soil characteristics, vegetation types, and precipitation distributions. The 112 HRUs delineated for the study area are shown in Figure 6.

Figure 6
Map of Hydrologic Response Units (HRUs) in the Turkey Creek Watershed delineated using PRMS



The PRMS system variables are illustrated in Figure 7. The watershed system is represented as a series of reservoirs. System inputs consist of daily sums of precipitation and temperature extremes. System outputs consist of values for all variables for each HRU. The most important output variables for this study are the three components of runoff (surface runoff, subsurface flow, and ground water flow), evapotranspiration, and the storage of subsurface and ground water reservoirs.

Figure 7
Schematic Diagram Illustrating the Conceptual Watershed System Inputs for PRMS

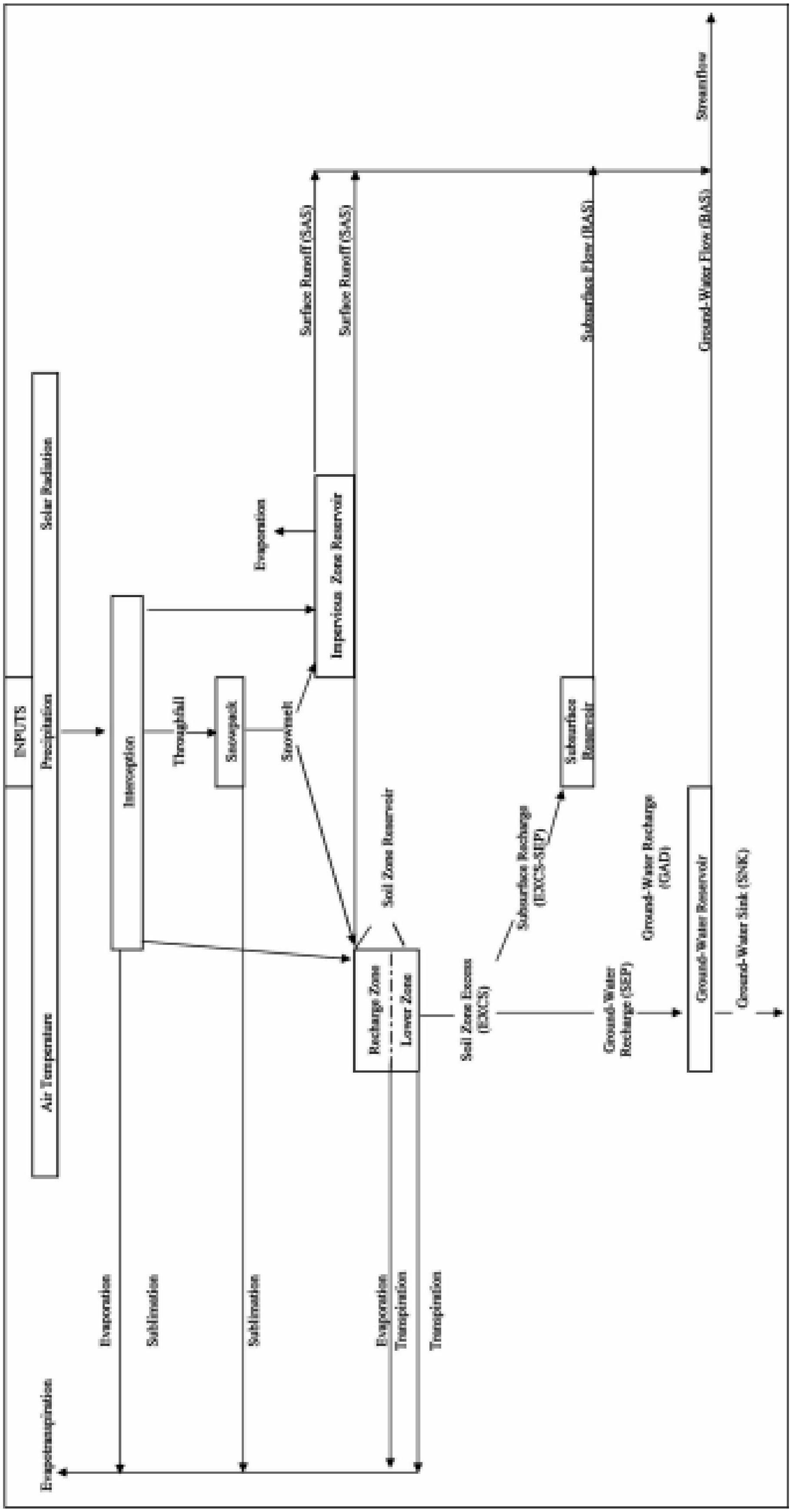


Figure 8
Conceptual Model of the Hydrology of the Turkey Creek Watershed

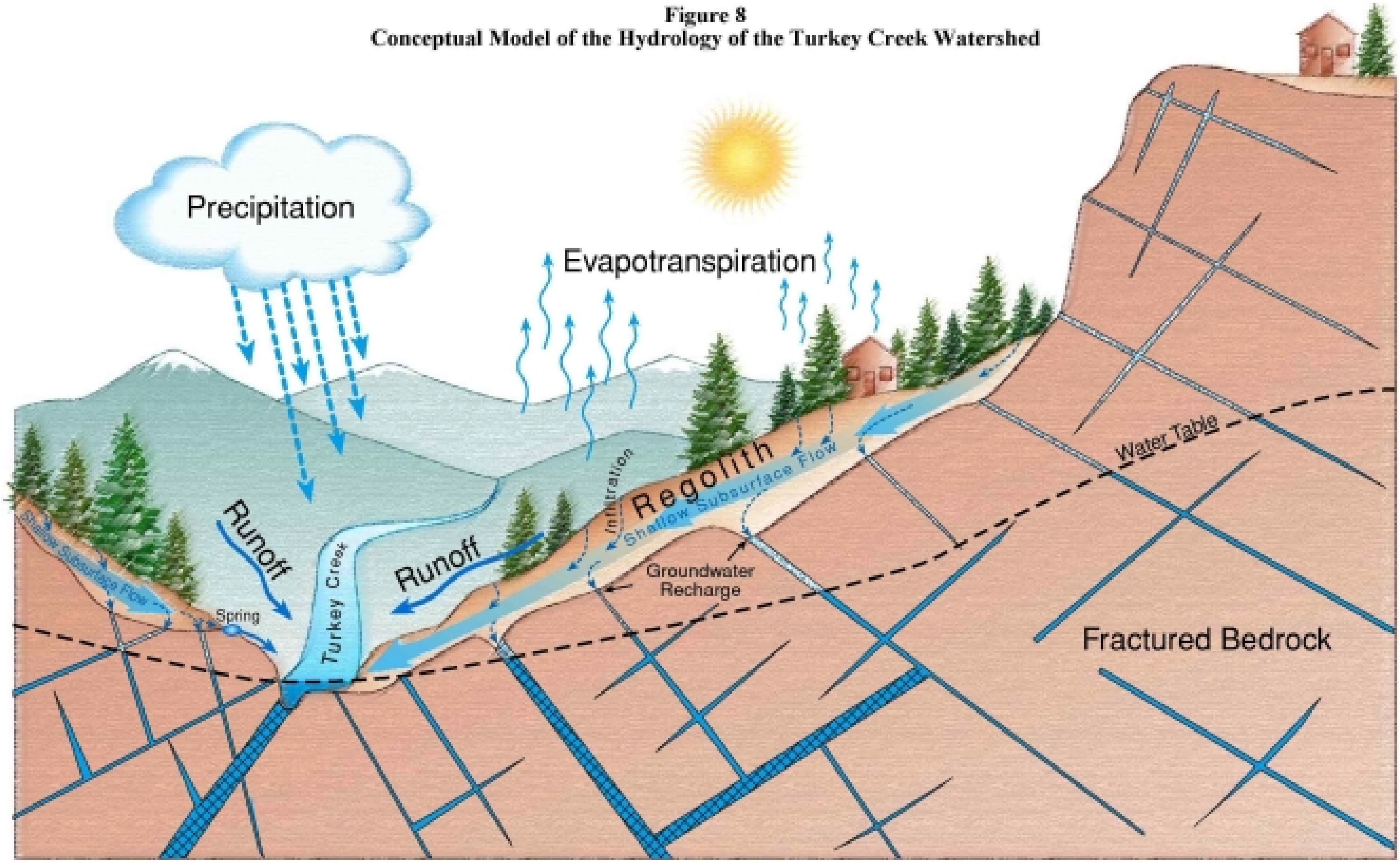


Figure 8 provides a simple conceptual model to illustrate how water enters and exits the Turkey Creek Watershed. Most of the water enters in the form of precipitation (rain and snow). Most of the water exits the Watershed through evaporation and transpiration (evapotranspiration), surface water flow in Turkey Creek, or subsurface ground water flow in the regolith or fractured bedrock.

The regolith is the entire layer of loose, incoherent, or unconsolidated rock and soil material that nearly everywhere forms the surface of the land and overlies or covers the more coherent fractured bedrock. The regolith includes rock debris of all kinds, such as volcanic ash, glacial drift, alluvium, colluvium, wind-blown sand deposits, organic materials, and soils.

PRMS RESULTS

The annual results based on water years (October 1 through September 30) for long-term simulations using PRMS (1950 through 2000), a period that includes many different climatic conditions, indicate that a large percentage, 77 percent of precipitation is returned to the atmosphere by evapotranspiration. The remaining 23 percent of the precipitation either leaves the watershed through surface runoff and subsurface flow, or becomes part of the long-term ground water storage system.

The 3 components to runoff; surface runoff, subsurface flow, and ground water flow, collectively account for about 7 percent of precipitation, or 23 percent of precipitation and evapotranspiration. Surface runoff and ground water flow are relatively small compared to subsurface flow that accounts for about 70 percent of the three runoff components. Subsurface flow emanates from a shallow zone along a preferential flow path defined by hydraulic contrasts between the regolith and crystalline rock and discharges into the surface water system.

It appears that the amount of water that enters long-term storage (approximately 1.8 inches) is nearly equal to the amount of water that is withdrawn form long-term storage on an annual basis. Ground water in long-term storage is water that cannot drain to streams through gravity.

CONCEPTUAL MODEL FOR THE TURKEY CREEK WATERSHED

The current (2001) estimate for the number of occupied households in the Turkey Creek Watershed is about 4900 and the amount of water used by each household per day is 300 gallons, or about 1,650 acre feet. In addition, about 240 acre feet of water is withdrawn by collective residential systems. The total amount of ground water withdrawn is about 1900 acre feet, which is equivalent to a depth of about 0.75 inches over the entire Watershed (47 square miles). Much of this water is withdrawn from wells that are completed almost exclusively in the crystalline rock, relatively deep in the aquifer. Most of the water that is withdrawn is not consumed. It is returned to the shallow subsurface where it may or may not return to the ground water.

However, the withdrawal of ground water from a relatively deep part of the system and return to a shallow part of the system is a deviation from the natural flow system. Most water in the regolith, or shallow subsurface zone, exits the system as subsurface flow. The relatively high chloride concentrations in surface water that have been measured as part of this Study suggests that more water from ISDS is exiting the system via subsurface flow than is percolating to the deeper aquifer, where chloride concentrations are about 50 percent of those in surface water samples.

Most runoff in the Turkey Creek Watershed occurs as shallow subsurface flow. Conceptually, subsurface flow originates from a zone in which water can move quickly. Intuitively, such a zone corresponds to the regolith, or weathered bedrock and soil, where intergranular porosity has hydraulic characteristics more capable of supporting the rapid movement of water, than in the crystalline bedrock where the absence of intergranular porosity inhibits the rapid movement of water. The interface between regolith and crystalline rock may also provide a preferential ground water flow path that may divert local reinfiltration of water.

Results of simulations using PRMS indicate that ground water flow in the Turkey Creek Watershed sustains streamflow during rainless periods. The sustaining nature of ground water flow indicates that baseflow results from discharge from the aquifer and not from shallow seasonal subsurface flow.

The absence of intergranular porosity and the relatively low values for estimated fracture porosity in the crystalline rocks limits the amount of ground water that can be stored because there is simply not enough space for large amounts of water to be stored. In fact, PRMS results indicate that the amount of water potentially entering ground water flow and the ground water storage zone is a only small fraction of precipitation (less than 10 percent).

Because fracture porosity in the crystalline rocks limits the amount of water that can be stored, the physical characteristics of the fractures are important. If there are small numbers of fractures with small openings, then it will be difficult for water to enter. However, if there are large numbers of fractures with large openings then it will be easier for water to enter. Therefore, the intensity and width of fractures are very important to the storage characteristics of the crystalline rock as well as the degree of connection between fractures. Poorly interconnected fractures will have a tendency to store, but not transmit water.

In addition to fracture intensity, width, and interconnection, movement of water through the vadose zone and into ground water storage is affected by any lateral component to water movement. As the component of lateral flow increases, the likelihood of water entering fractures decreases. The magnitude of lateral flow is a function of the degree of saturation in the vadose zone.

FUTURE DIRECTIONS

The conceptual understanding regarding ground water recharge, flow, and storage that have been defined in Phase I provide a framework for estimating the water supply in the Turkey Creek Watershed based on geology and measurements of precipitation, evapotranspiration, water use, runoff, and recharge. Intra-basin measurements made in Phase II of this study will aid in understanding how ground water may be moving in the fractured crystalline bedrock aquifers of the Turkey Creek Watershed. These measurements will also be incorporated into PRMS simulations of the water budget and refinement of the hydrogeologic settings delineated in Phase I.

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