
**DEVELOPMENT OF COUNTY-WIDE HYDROGEOLOGICAL
AND HYDROLOGICAL GIS MAPS FOR
PITKIN COUNTY, COLORADO**

**Phase 2 of the Development of County-wide Maps for GIS-Based
Groundwater Resources Evaluation, Pitkin County, Colorado**

By:

**Paul K.M. van der Heijde
Heath Hydrology, Inc.
Boulder, Colorado
(under subcontract with Integral Consulting Inc.)**

and

**Dr. Kenneth E. Kolm
Integral Consulting Inc.
Louisville, Colorado**

for:

**Pitkin County
Health Rivers Board and
Board of County Commissioners
Colorado**

Contract No. 195-2010

July 8, 2011

Contents

1.0 Introduction.....	5
2.0 Developing a Coherent and Consistent Hydrogeological Nomenclature.....	6
3.0 Development of County-wide Hydrogeological GIS Data Bases.....	15
3.1 Digitizing Geological Maps and Creating Hydrogeological GIS Data Bases for the URF Study Area	15
3.2 Completing the Hydrogeological Mapping of Unmapped Sections between Previous Study Areas	16
3.3 Modifying the Structure of the Hydrogeological GIS Data Bases Produced in the MRF, CSC, and CRWS Studies	17
3.4 Creating County-wide GIS Layers and Data Bases for the Major Hydrogeological Units.....	18
3.5 County-wide GIS Map for Use in Conjunction with the Groundwater Resources Evaluation Procedure.....	20
4.0 References.....	21
Appendix 1. Data Sources.....	22

List of Tables

Table 1. Correlation of Geological and Hydrogeological Units in Pitkin County and their Composition and Hydrogeological Characteristics.	9
Table 2. Hydrogeological GIS Data Base Structure – Field Definitions.	17

List of Figures

Figure 1. Location of the Central Roaring Fork Tributaries (CRFT), Crystal River and West Sopris Creek (CRWS), Capitol and Snowmass Creek (CSC), Middle Roaring Fork (MRF), and Upper Roaring Fork (URF) Study Areas, Pitkin County, Colorado.	6
Figure 2. Map of Pitkin County Showing the Area Covered by Geologic 7.5-Minute Quadrangle Maps (Scale 1:24,000) published by the U.S. Geological Survey (USGS) and the Colorado Geological Survey (CGS) and the coverage by the 1°×2° Geologic Quadrangle Maps (Scale 1:200,000) Published by the USGS.	7
Figure 3. Hydrogeological Units of the Upper Roaring Fork (URF) Study Area, Pitkin County, Colorado.	16
Figure 4. Hydrogeological Units in Mapping Gaps Between Previous Studies.	17
Figure 5. County-wide GIS Layer of Quaternary Hydrogeological Units.....	18
Figure 6. County-wide GIS Layer of Bedrock Hydrogeological Units.....	19
Figure 7. County-wide GIS Layer of Hydrogeological Structures.	19
Figure 8. County-wide GIS Map showing the Watersheds and Stream Layers. (The Left Display Area is the Table of Contents (TOC) Showing All Available Layers and the Legend for Activated Layers; the Right Side of the Window Is the Map Display Area showing the Activated Layers.)	20

1.0 Introduction

Under an agreement with Pitkin County, Integral Consulting, Inc. (Integral) of Louisville, Colorado in cooperation with Heath Hydrology, Inc. (HHI) of Boulder, Colorado was tasked to complete a series of geographic information system (GIS) maps. These maps are to be used in conjunction with the earlier developed groundwater resources evaluation procedure as planning and land use management tools by Pitkin County. The project consists of two major elements: 1) conducting a Hydrologic and Environmental Systems Analysis (HESA) and preparing supporting GIS maps of the area covered by the watersheds of the streams tributary to the central Roaring Fork (CRFT) between the towns of Basalt and Aspen, Colorado, including the Fryingpan River, Maroon Creek, Castle Creek, Hunter Creek, Woody Creek, and the City of Aspen; and 2) integrating the results of the focused HESA and resulting GIS maps with the GIS maps developed in previous studies, providing county-wide coverage of the hydrogeology.

The project is a follow-up of previous studies performed by Hydrologic Systems Analysis, LLC in cooperation with HHI for the Crystal River and West Sopris Creek areas (CRWS; *Kolm and others, 2008*); the Middle Roaring Fork area (MRF; *Kolm and Gillson, 2004*), the Upper and Middle Roaring Fork areas (URF/MRF; *Kolm and van der Heijde, 2006*), and for the Snowmass and Capitol Creek areas (CSC; *Kolm and others, 2007*) (see Figure 1 for location).

The project consists of four phases: 1) HESA, formulating conceptual models of the groundwater systems, and developing a supporting database for the CRFT area; 2) developing a coherent and consistent county-wide hydrogeological nomenclature, updating the GIS maps of the MRF and URF study areas, and preparing county-wide maps and data bases of the major hydrogeological units; 3) creating county-wide GIS maps showing aquifer presence and characteristics and groundwater resource sustainability and vulnerability, and production of a short outreach document describing the past and current GIS-based groundwater resources evaluation studies; and 4) presenting findings to the Board of Pitkin County Commissioners and staff and to the public.

This report presents the results of phase 2 of this project (developing county-wide hydrogeological and hydrological GIS maps) and includes: 1) developing a coherent and consistent county-wide hydrogeological nomenclature; 2) updating the hydrogeological GIS layers and data bases of the MRF and URF study areas; 3) completing the hydrogeological GIS mapping of unmapped sections between previous study areas (indicated by the dark grey area in Figure 1); 4) modifying the structure of the GIS data bases of the URF/MRF, CSC, and CRWS study areas to make them compatible with the data bases for the CRFT area; and 5) preparing county-wide GIS maps and data bases of the major hydrogeological units. This report also includes a description of updated auxiliary hydrological GIS data bases for use with the groundwater resources evaluation procedure developed in previous projects (*Kolm and others, 2008*).

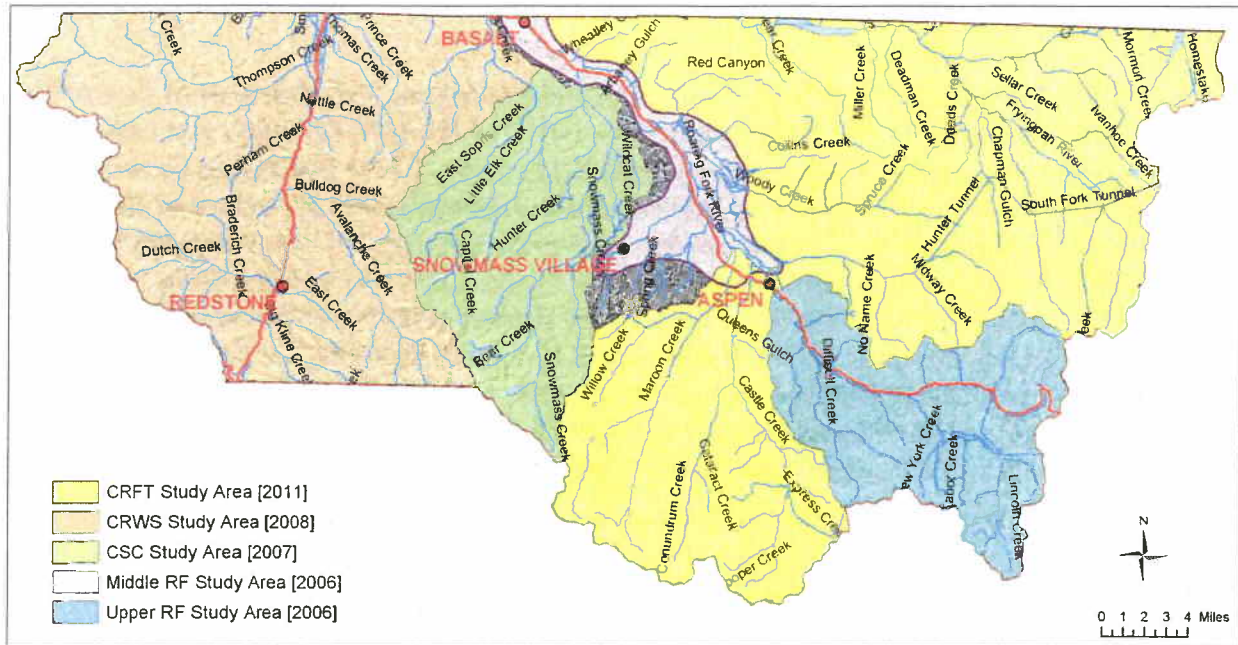


Figure 1. Location of the Central Roaring Fork Tributaries (CRFT), Crystal River and West Sopris Creek (CRWS), Capitol and Snowmass Creek (CSC), Middle Roaring Fork (MRF), and Upper Roaring Fork (URF) Study Areas, Pitkin County, Colorado.

2.0 Developing a Coherent and Consistent Hydrogeological Nomenclature

The complex hydrogeological framework present in Pitkin County has been described in previous reports (*Kolm and Gillson, 2004; Kolm and Van der Heijde, 2006; Kolm and others, 2007; Kolm and others, 2008; Kolm and Van der Heijde, 2011*). The hydrological systems in Pitkin County have multiple, distinct hydrogeological and hydrostructural units, including unconsolidated units consisting of various tertiary- and quaternary-aged highly permeable deposits, multiple water-bearing and confining bedrock units, and highly transmissive fault and fracture zones. To determine the relevant hydrogeological and hydrostructural units in Pitkin County, HESA is applied to various parts of the County, integrating elements of climate, topography, geomorphology, groundwater and surface water hydrology, and geology (among others) (*Kolm and Van der Heijde, 2006; Kolm and others, 2007; Kolm and others, 2008; Kolm and Van der Heijde, 2011*). An integral part of these HESAs and the subsequent mapping of hydrogeological units is the evaluation of the geology as represented by various geologic maps. These maps have different authors, are developed by different agencies, and are published at different times, resulting in inconsistent geological insights and terminology. Therefore, additional evaluation and interpretation, guided by HESA, was required to incorporate these geological maps into the development of the current hydrogeological GIS maps.

Identification of the geological units present in Pitkin County is primarily based on geological maps published by the U.S. Geological Survey and the Colorado Geological Survey on scales 1:24,000 and 1:250,000 (*Bryant, 1969 [Maroon Bells], 1970 [Hayden Peak], 1971 [Aspen], 1972a [Highland Peak]; Freeman, 1972a [Ruedi Reservoir], 1972b [Woody Creek]; Gaskill and others, 1991 [Gothic]; Gaskill and Godwin, 1966 [Marble]; Godwin, 1968 [Chair Mountain]; Mutschler, 1970 [Snowmass Mountain]; Streufert and others, 1998 [Basalt]; Streufert, 1999 [Mount Sopris]; and Tweto and others, 1976 [Montrose 1°×2°]*),

1978 [Leadville 1°×2°]). The coverage provided by these geological maps is shown in Figure 2. The geological units present in these maps are grouped together based on their hydrogeological characteristics using the HESA process. Each group is assigned a hydrogeological name that is related to the most common geological unit in that group. In addition, an alphanumeric symbol is assigned to each of these hydrogeological units for the purpose of GIS mapping. The results of this procedure are presented in Table 1 which also includes a short description of the composition and hydrogeological characteristics of the hydrogeological units.

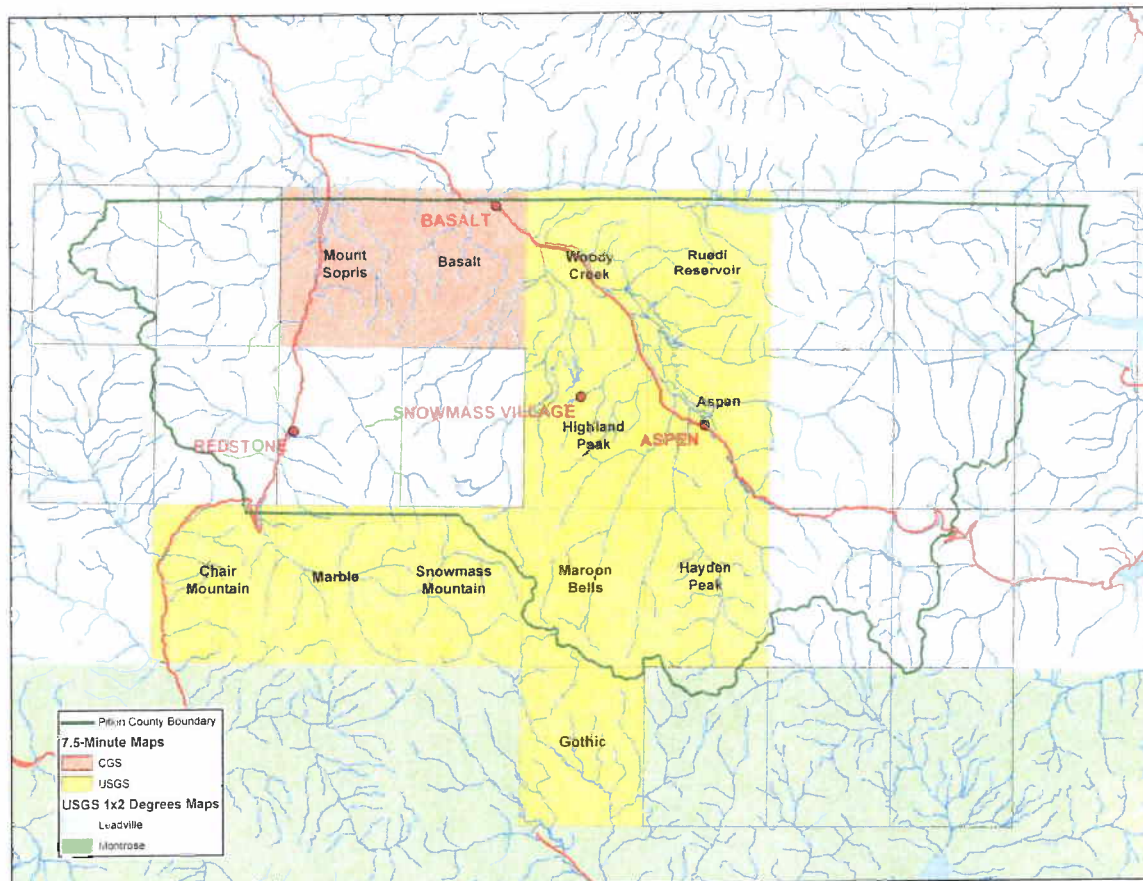


Figure 2. Map of Pitkin County Showing the Area Covered by Geologic 7.5-Minute Quadrangle Maps (Scale 1:24,000) published by U.S. Geological Survey (USGS) or Colorado Geological Survey and the coverage by the 1°×2° Geologic Quadrangle Maps (Scale 1:200,000); published by USGS.

Geological Unit <i>(from USGS and CGS quads and Leadville 1x2° map) *</i>	Hydrogeological Unit	Hydrogeological Unit Symbol	Composition	Hydrogeological Characteristics
Alluvium (Qa); Stream channel, floodplain and low terrace deposits (Qa); Younger alluvial deposits (Qy); Alluvium (Qal); Older alluvium (Qalo)	Modern alluvium	Qal	Poorly sorted riverine gravel, sand, and silt deposited mainly in stream channels and floodplains in major stream valley bottoms; moderately to well-bedded deposits	Generally good local phreatic aquifer with matrix-based permeability; limited variations in groundwater levels; often sustained by local and sub-regional discharge to adjacent stream or directly by stream.
High level alluvium (QTa); Gravels (Qg, Qga, Qgb, Qgc, Qgd); (Older) alluvial fan deposits (Qf, Qof, Qfi, Qfo, Qfa, Qfb); Terrace gravel deposits (Qte, Qty, Qtm, Qto, Qtg); Local origin gravels (Qgl)	Quaternary gravels, fans and terraces	Qgf	Poorly sorted sands and gravels; pebbles and cobbles in sand to silt matrix; forms terraces above current Roaring Fork River level	Potentially good, spatially continuous phreatic aquifer with high matrix-based permeability and small water table gradients; sustainability depends on local natural and/or anthropogenic recharge mechanisms; may be supported by underlying bedrock; may be prone to significant (seasonal) water table fluctuations.
Glacial drift, till (Qd, Qdo, Qti); Glaciofluvial deposits (Qga, Qgb, Qgc, Qgd); Moraine deposits (Qm); Glacial deposits (Qma, Qmb, Qmbc, Qmc, Qmd, Qme); (Old) rock glacier (Qr, Qor, Qrg); Quaternary deposits undifferentiated (Qu)	Quaternary glacial deposits	Qm	Heterogeneous, poorly sorted deposits of boulders, gravel, sand, silt, and clay	Potentially good local phreatic aquifer with variable matrix-based permeability and high water table gradients; sustainability depends on local natural and/or anthropogenic recharge mechanisms; may be prone to significant water table fluctuations.
Talus (Qt); Landslide deposits (Ql, Qls); Colluvium (Qc, Qco); Hillslope sheetwash deposits (Qh, Qsw); Debris flows (Qdf); Solifluction deposits (Qs)	Quaternary colluvium and landslide deposits	Qls	Loose gravels and rock debris with mixed matrix composition (sand-clay) on valley sides, valley floors and hillslopes; deposited by gravitational processes	Potentially good, highly localized phreatic aquifer with high matrix-based permeability and high water table gradients; sustainability depends on local natural and/or anthropogenic recharge mechanisms and may be dependent on underlying bedrock characteristics; may be prone to significant (seasonal) water table fluctuations.

Table 1. Correlation of Geological and Hydrogeological Units in Pitkin County and their Composition and Hydrogeological Characteristics.

Geological Unit (from USGS and CGS quads and Leadville 1x2° map) *	Hydrogeological Unit	Hydrogeological Unit Symbol	Composition	Hydrogeological Characteristics
Old/Older gravels (Qog, Qgo); Tertiary (unconsolidated) sediments on ridges and higher elevations of slopes (Ts) – also see Ts for basin fill	Older ridge top sands and gravels	Qog	Poorly sorted sands and gravels; pebbles and cobbles in sand to silt matrix	Although having high matrix-based permeability, location in topography precludes any significant groundwater presence.
Sedimentary deposits (Ts) in basins	Tertiary sedimentary basin fill deposits	Ts	Weakly indurated to unconsolidated fluvial deposits (pebbles and cobbles in a matrix of silty sand) filling the Carbonate Collapse subsidence feature and present in some adjacent areas	In the basins and valleys near the north-central boundary of county it is a good continuous, very thick aquifer with high matrix-based permeability; regionally sustained by direct recharge and recharge through adjacent bedrock; significant subregional flow exiting Pitkin County to the North.
Ash-flow tuffs (Taf, Tsf); Basalt (Qb, Tb)	Tertiary ash-flow tuffs and basalts	Taf	Massive, fractured, bedded, well-cemented, non-welded ash-flow tuffs; some thick, vesicular, locally dense basalt	Potentially good local bedrock aquifer with fracture-based permeability; sustainability depends on elevation and local recharge mechanisms.
Intrusive rocks (Tmi, TKi); Mount Sopris Granodiorite (Tgs), (Hornblende) Granodiorite (Tg), and Phorphyritic Granodiorite (Tgp); also TKd, TKq, TKa, TKap	Tertiary intrusive rocks	Tmi	Granodiorite and quartz monzonite; may occur as dikes and sills	Fractured crystalline system with very low matrix permeability; not a (sub-)regional aquifer; may produce locally water in concentrated fracture zones and support adjacent Quaternary aquifers. These characteristics may extend into adjacent rocks metamorphosed during the Tertiary intrusion.
Wasatch and Ohio Creek formations (Two)	Wasatch and Ohio Creek formations	Two	Channel sandstones and overbank siltstones and shales; conglomerate; carbonaceous shales and lignite near base	Overbank sandstones form a good aquifer system with moderate to good matrix- and fracture-based permeability; may be a locally good water producer; siltstones and shales are confining layers; aquifers are sustainable at moderate elevations in western part of county; outcrops are recharge areas for a regional flow to the west across county border.

Table 1 continued. Correlation of Geological and Hydrogeological Units in Pitkin County and their Composition and Hydrogeological Characteristics.

Geological Unit <i>(from USGS and CGS quads and Leadville 1x2° map) *</i>	Hydrogeological Unit	Hydrogeological Unit Symbol	Composition	Hydrogeological Characteristics
Mesa Verde Group or Formation (Kmv, Kmvu, KmvI)	Mesa Verde Group	Kmv	Interbedded sandstones and siltstones, shales and carbonaceous shales, and coals	Good regional bedrock aquifer system; sandstones and coals have both moderate matrix- and fracture-based permeability; may locally be a good water producer; shales are confining layers; regionally sustainable aquifer at moderate elevations in western part of county; outcrops are recharge areas for regional flow to the west across county border.
Mancos Shale (Km, Kmu)	Mancos Shale (undivided)	Km	Silty to sandy shale with bentonites with minor limestone and sandstone beds; when undivided, lower section includes Ft Hays limestone (see separate section below)	Mostly aquitard with very low permeability serving as a confining layer for underlying or embedded aquifers; however, locally moderate aquifer conditions when highly fractured or in areas with sand lenses and sandy beds; sustainability highly dependent on local recharge mechanisms.
Upper and Lower Sandstone Members of Mancos Shale (Kms, KmsI)	Mancos Shale - Sandstone members	Kms	Outcrops of local or discontinuous sandstone beds in Upper Mancos Shale unit	Locally moderate aquifer conditions; sustainability highly dependent on local recharge mechanisms.
Fort Hays Limestone Member of Mancos Shale (Kmf)	Mancos Shale - Fort Hays Limestone member	Kmf	Thick-bedded coarse-grained limestone	Good local or regional fractured-flow aquifer; however, generally covered by many hundreds of feet of shale except near outcrops; outcrops are recharge areas for a regional flow to the west across county border; (sub-)regionally sustainable aquifer.
Lower Mancos Shale, including Frontier Sandstone and Mowry Shale members (Kml)	Mancos Shale - Lower Shale unit	Kml	Silty shale with sandstone beds	Mostly very low permeability aquitard; however, locally moderate aquifer conditions when highly fractured or in areas with sand lenses and sandy beds; sustainability highly dependent on local recharge mechanisms.

Table 1 continued. Correlation of Geological and Hydrogeological Units in Pitkin County and their Composition and Hydrogeological Characteristics.

Geological Unit (from USGS and CGS quads and Leadville 1x2° map) *	Hydrogeological Unit	Hydrogeological Unit Symbol	Composition	Hydrogeological Characteristics
Dakota Sandstone (Kd), Dakota Sandstone and Burro Canyon Formation (Kdb); Lower Mancos Shale (Frontier Sandstone) and Dakota Sandstone (Kfd)	Dakota Sandstone and Burro Canyon Formation	Kdb	Well indurated, medium- to coarse-grained quartzose sandstones in well-cemented thick beds and conglomerate with occasional siltstones and carbonaceous shale	Good regional bedrock aquifer system; sandstones have both moderate matrix- and fracture-based permeability; sub-regionally sustainable aquifer with recharge in outcrop areas; mostly protected by overlying Mancos Shale except for outcrop areas.
Morrison Formation and Entrada Formations undivided (Jme); Dakota, Morrison and Entrada Formations - undivided (KJde); Morrison, Entrada and Chinle Formations (JTrmc)	Morrison and Entrada Formations	Jme	Morrison Form. (Jm): Siltstones and claystones throughout with sandstones becoming more common in lower sections, and limestone near base; Entrada Form. (Je): fine-grained, well-sorted sandstones; Je is overlain by Jm	Entrada is a very good, regionally sustainable aquifer with moderate to good matrix- and fracture-based permeability. Morrison shales are confining layers while the lower Morrison sandstones and limestone may serve as local to sub-regional aquifers with sustainability dependent on local recharge conditions.
Chinle Formation (TRc), State Bridge Formation (TRPs), Chinle and State Bridge Formations undivided (TRPcs)	Chinle and State Bridge Formations	TRPcs	Thin even bedded red beds of calcareous siltstone and mudstone becoming sandy near base (Chinle) unconformity on top of interbedded siltstone and sandstone becoming more clayey toward the base (State Bridge)	The Chinle Formation is a very low permeability aquitard and constitutes a major regional confining layer with respect to underlying aquifers. Local sandstone units in the Chinle and State Bridge Formation near outcrops may provide a local water source.
Maroon Formation (PPm), Maroon Formation and Weber Sandstone (PPwm), Minturn Formation (Pm), Gothic Formation (Pg)	Maroon and Minturn Formations	PPmm	Interbedded arkosic sandstones, silt, and mudstones, and conglomerates (Maroon); interbedded shale, siltstone, sandstone, limestone, and conglomerate (Minturn/Gothic)	Arkosic sandstones, conglomerate and limestones form a tight bedrock aquifer with primarily fracture-based permeability; is an aquifer where metamorphosed and well cemented. At the local scale, fracture zones may provide good aquifer conditions. May sustain adjacent or overlying Quaternary aquifers.

Table 1 continued. Correlation of Geological and Hydrogeological Units in Pitkin County and their Composition and Hydrogeological Characteristics.

Geological Unit (from USGS and CGS quads and Leadville 1x2° map) *	Hydrogeological Unit	Hydrogeological Unit Symbol	Composition	Hydrogeological Characteristics
Eagle Valley Formation (Pe), Eagle Valley Evaporite (Pee)	Eagle Valley Formation and Eagle Valley Evaporite	Pe	Tan, reddish brown, reddish grey siltstone, gypsum and carbonate rocks. Evaporite contains anhydrite, halite, gypsum, and light colored mudstone. May have intruded in higher formations.	Generally poor aquifer except where local karst and/or extensive fracturing have developed.
Belden Formation (Pb)	Belden Formation	Pb	Shales interbedded with limestone and dolomite and some sandstone	Mostly a very low permeability aquitard; may act as the confining unit for underlying Leadville Limestone.
Mississippian, Devonian, Ordovician, and Cambrian Rocks (MCR) including Mississippian Leadville Limestone	Leadville Limestone	MI	Thick-bedded massive limestone in upper part; thin- to thick-bedded dolomite in lower part; Gilman Sandstone member at the base (dolomitic sandstone to sandy dolomite)	Significant regional, fractured permeability aquifer with local karst; local aquifer conditions in fractured Gilman Sandstone; presence of extensive mining tunnels near outcrops provide significant additional fracture-zone-like permeability; interconnected and scattered nonconnected mineworking tunnels are present in the vicinity of the Leadville outcrops.
Precambrian Granites and Gneisses (Xb, Xfh, Xg, Xgl, Xh, Yg, pCr)	Precambrian Granites and Gneisses	YXg	Granites and gneisses	Fractured crystalline system with very low matrix permeability; not a (sub-)regional aquifer; may produce locally water in concentrated fracture zones and support adjacent Quaternary aquifers.

Table 1 continued. Correlation of Geological and Hydrogeological Units in Pitkin County and their Composition and Hydrogeological Characteristics

3.0 Development of County-wide Hydrogeological GIS Data Bases

The development of the county-wide hydrogeological GIS layers consisted of four steps:

1. Digitizing geological maps and creating hydrogeological GIS layers for the URF study area.
2. Completing the hydrogeological mapping of unmapped sections between previous study areas as shown in Figure 1.
3. Modifying the structure of the hydrogeological GIS data bases produced as part of the MRF, CSC, and CRWS studies in preparation of the construction of a single county-wide set of hydrogeological data bases.
4. Preparing county-wide GIS layers and data bases of the major hydrogeological units.

These county-wide GIS layers are used in phase 3 of the project to create maps of availability, sustainability, and susceptibility (or vulnerability) of the groundwater resources in Pitkin County.

3.1 *Digitizing Geological Maps and Creating Hydrogeological GIS Data Bases for the URF Study Area*

As a follow up of hydrogeological studies of the MRF and URF watersheds in Pitkin County performed in the early 2000s, a project was proposed to combine the resulting GIS data bases with an innovative, step-by-step groundwater resources evaluation procedure focused on the developable lands in the MRF and URF watersheds (*Kolm and Van der Heijde, 2006*). The original GIS data bases for the MRF and URF areas were created using early versions of Intergraph's GeoMedia and related software. Because Pitkin County's GIS is based on ESRI's ARC/INFO software, these original data bases had to be transferred and reformatted. While obtaining the original GIS data bases, it was found that the GIS data set for the URF area was no longer available. Furthermore, the county determined that the new project should focus on the areas of the MRF and URF watersheds outside the City of Aspen because of the hydrogeological complexities in the Aspen area. As a result, the 2006 study produced ARC/INFO-compatible hydrogeological layers for the MRF area (between Aspen and Basalt) only (*Kolm and Van der Heijde, 2006*).

In preparation of the development of the county-wide set of hydrogeological GIS layers, the hydrogeological layers for the URF area needed to be created using digitized geological maps together with the results of an HESA. The geological maps used include the Aspen 7.5-minute quadrangle (*Bryant, 1971*), the Hayden Peak 7.5-minute quadrangle (*Bryant, 1970*), and the Leadville 1×2° quadrangle (*Tweto and others, 1978*). An earlier study of the URF watershed included a Watershed System Analysis (*Kolm and others, 2000*), that served as the HESA for the URF area in the current project. The resulting GIS map of the hydrogeological layers is presented in Figure 3.

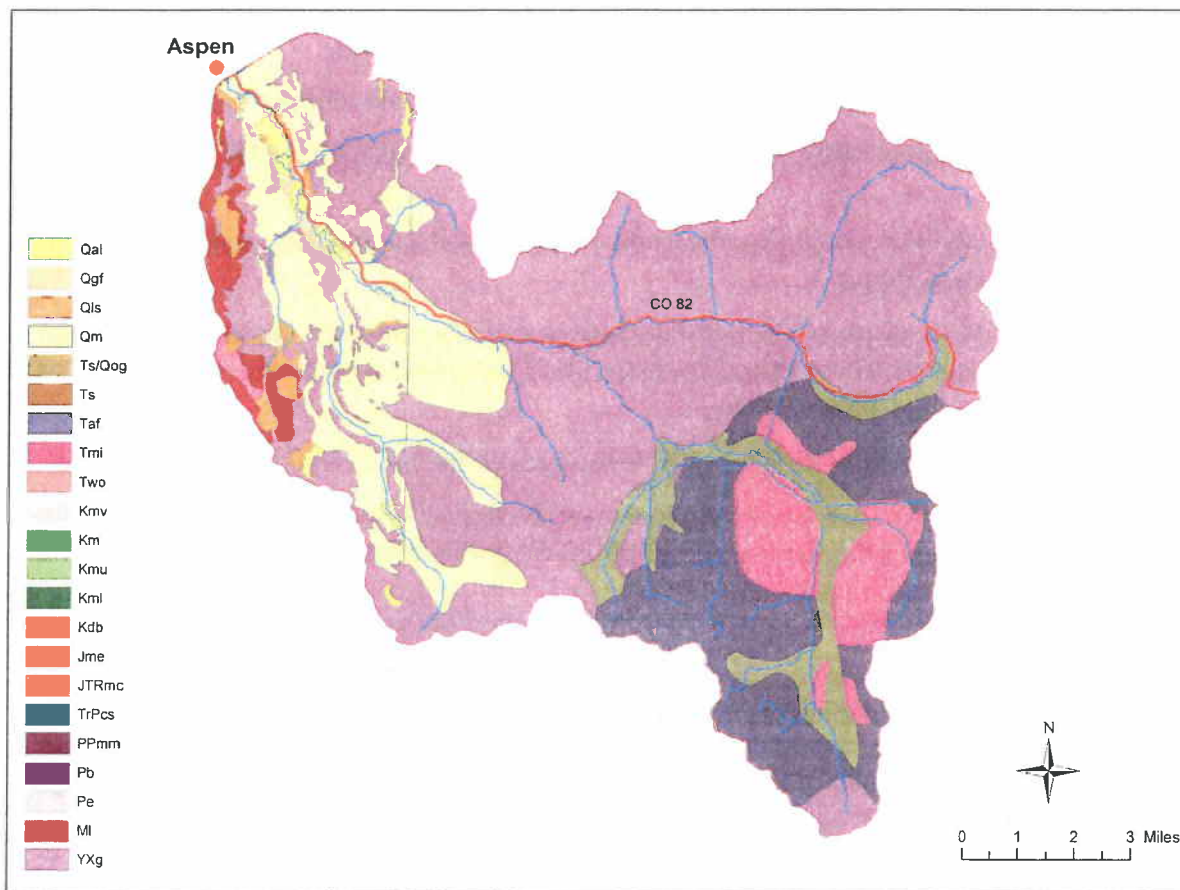


Figure 3. Hydrogeological Units of the Upper Roaring Fork (URF) Study Area, Pitkin County, Colorado.

3.2 *Completing the Hydrogeological Mapping of Unmapped Sections between Previous Study Areas*

The earlier hydrogeological studies in the MRF area were focused on the terraces and valley bottom along the Roaring Fork River and the lower sections of Owl and Brush Creek (*Kolm and Gillson, 2004; Kolm and Van der Heijde, 2006*). The later studies regarding the hydrogeology of Capitol, Snowmass and Sopris Creeks, and the Crystal River covered the entire watersheds. The resulting GIS mapping shows gaps between the Roaring Fork River and Sopris and Snowmass Creeks, as well as in the upper parts of the Owl and Brush Creek watersheds (indicated by the grey-colored area in Figure 1). To address these gaps, available geological maps were digitized and evaluated in the context of the HESAs performed for the neighboring areas (*Kolm and Van der Heijde, 2006 [MRF]; Kolm and others, 2007 [CSC]; Kolm and others, 2008 [CRWS]*). The resulting GIS map of the hydrogeological layers in these gaps are shown in Figure 4.

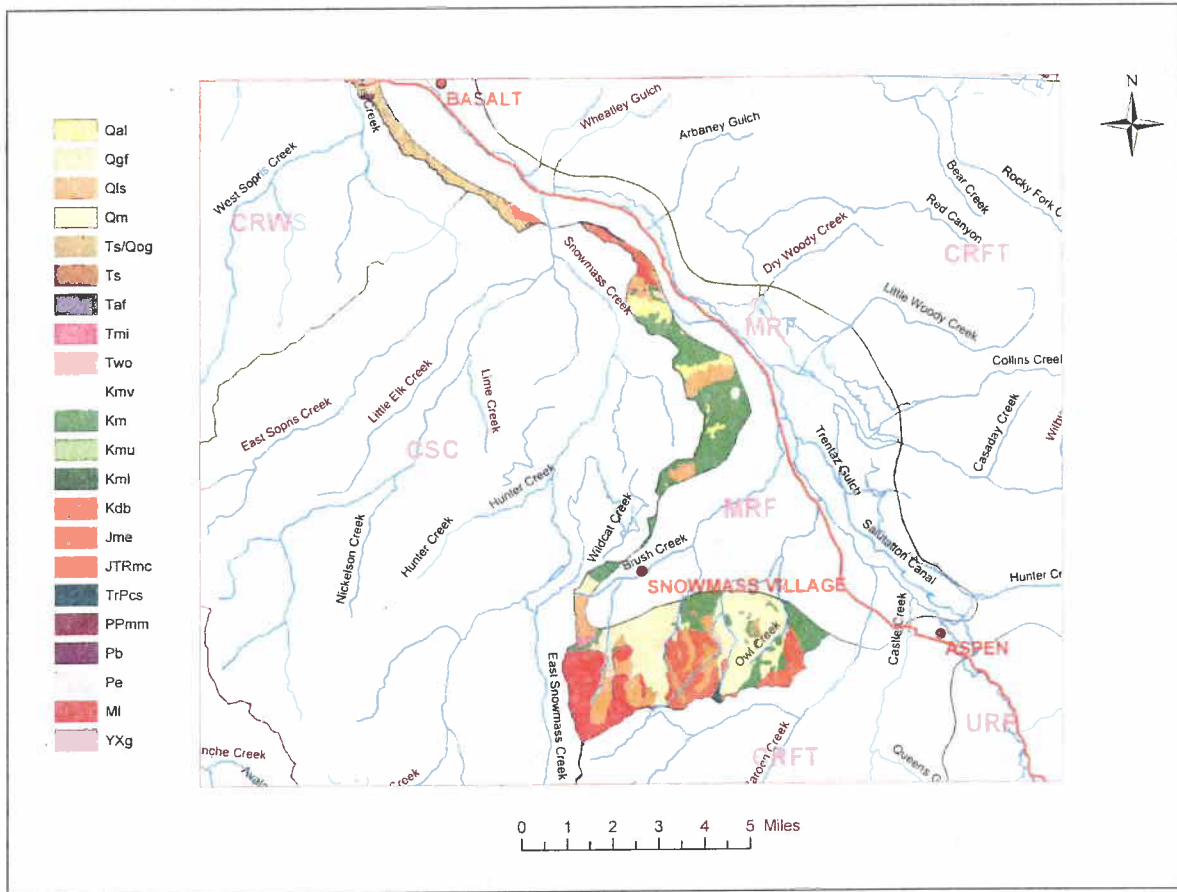


Figure 4. Hydrogeological Units in Mapping Gaps Between Previous Studies.

3.3 *Modifying the Structure of the Hydrogeological GIS Data Bases Produced in the MRF, CSC, and CRWS Studies*

The GIS data bases developed in previous projects were designed without consideration of later integration into a single set of data bases. As a result, each of these data bases had different types of data fields with different field names and different field properties. In preparing to create a single, county-wide data bases, the existing data bases had to be modified to conform with the data base structure implemented in the current CRFT project. Data base fields were replaced while retaining the actual field contents by editing the attribute tables of relevant GIS layers. The resulting set of fields, including fields that will be used in phase 3 of the CRFT project, are shown in Table 2.

Field Name	Field Type	Field Length	Alias
Unit_Name	String	50	Hydrogeological Unit
Hydro_Unit	String	15	Hydro Unit Short Name
Aquif_Type	String	100	Aquifer Type
Aquif_Sust	String	50	Aquifer Sustainability
Aquif_Vuln	String	50	Aquifer Vulnerability

Table 2. Hydrogeological GIS Data Base Structure – Field Definitions.

3.4 Creating County-wide GIS Layers and Data Bases for the Major Hydrogeological Units

The final step in producing county-wide GIS layers and data bases of the hydrogeological units was joining the data bases for each study area into a single, coherent set of data bases. This resulted in two county-wide data bases: quaternary hydrogeological units and bedrock hydrogeological units. Separately, a third hydrogeological data base was developed containing information on hydrogeological structures. These three data bases contain the information that can be displayed in GIS maps through inclusion of specific GIS layers linked to these data bases (see Figures 5, 6, and 7 for the resulting GIS layers).

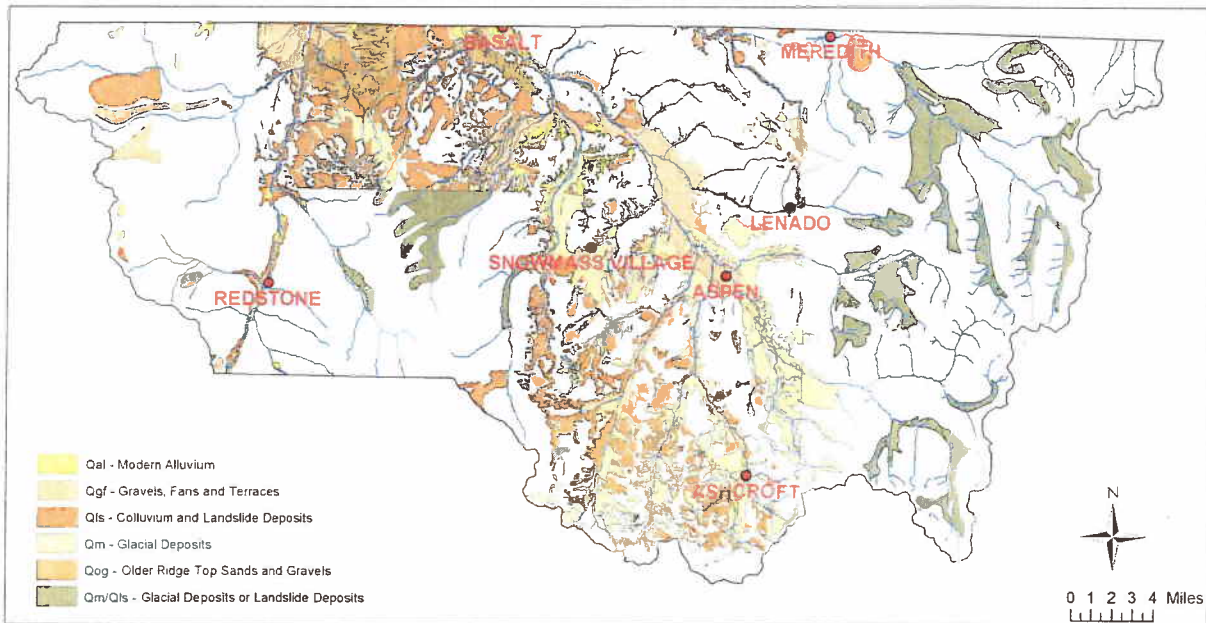


Figure 5. County-wide GIS Layer of Quaternary Hydrogeological Units.

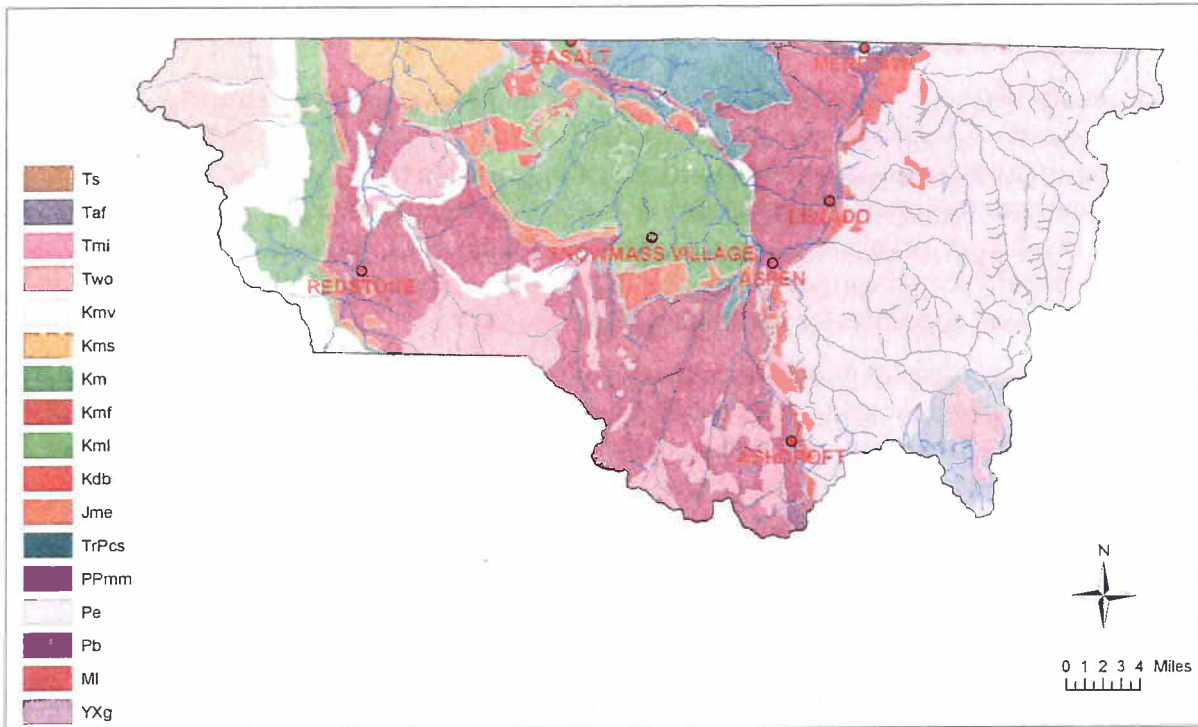


Figure 6. County-wide GIS Layer of Bedrock Hydrogeological Units.

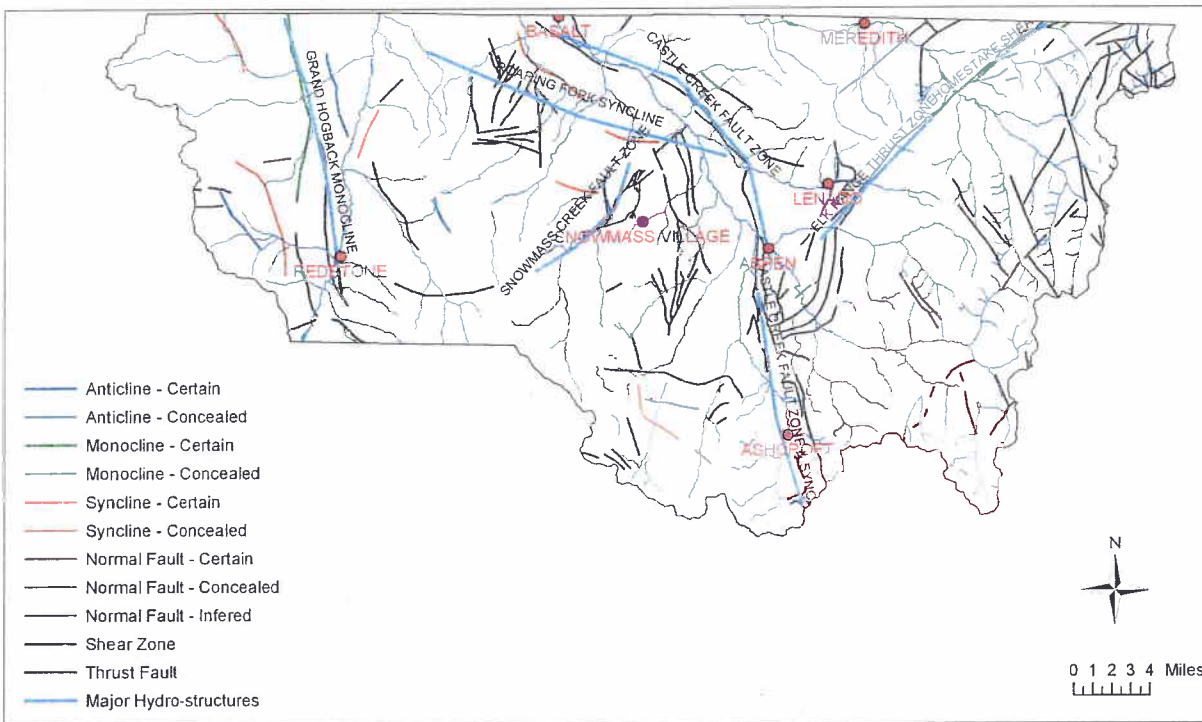


Figure 7. County-wide GIS Layer of Hydrogeological Structures.

3.5 County-wide GIS Map for Use in Conjunction with the Groundwater Resources Evaluation Procedure

The county-wide GIS map, GIS layers, and GIS data bases were prepared using ArcGIS™ (ESRI®, Redlands, California), and require ArcGIS version 8.3 or higher. The GIS map consists of a number of layers representing various types of information that is relevant to the assessment of the groundwater resources at user-specified locations as described in previous project reports (Figure 8). Each layer is linked to a specific data set. Some of the data sets were prepared by Integral specifically for this project, and other data sets were obtained from public sources and were, in some cases, modified for use in the current project.

The GIS map consists of a table of contents (TOC; the left display area of Figure 8) and a map display area (the right display area of Figure 8). The TOC lists the county-wide hydrogeological, hydrological, and anthropogenic layers developed in Phase 2 of the current project. When applying the groundwater resources evaluation procedure to site-specific planning or landuse management issues, these layers should be used together with general geographic, topographic, and land-use layers, as described in Kolm and others (2008). All layers have been georeferenced with respect to Pitkin County's projection and datum: State Plane, Colorado Central Zone, NAD83 (units of measure in feet).

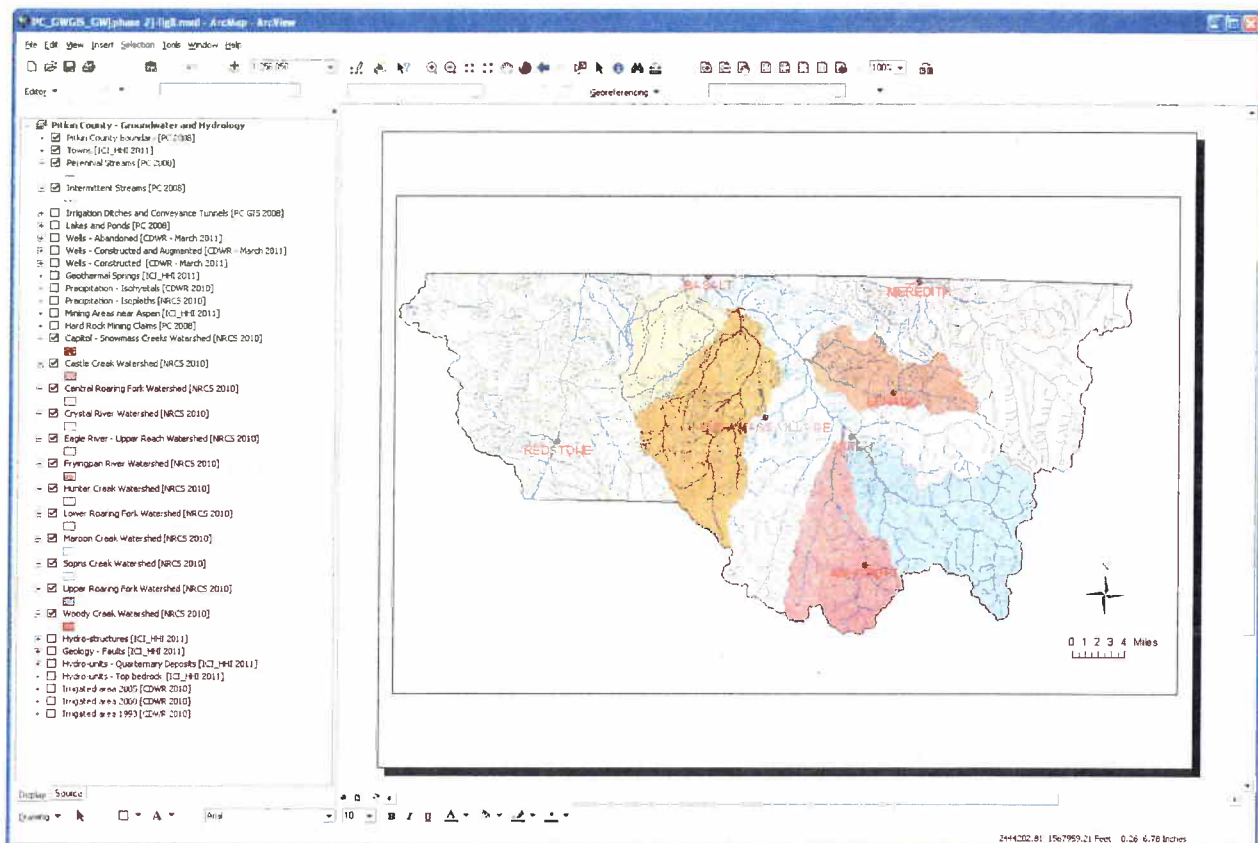



Figure 8. County-wide GIS Map showing the Watersheds and Stream Layers. (The Left Display Area is the Table of Contents (TOC) Showing All Available Layers and the Legend for Activated Layers; the Right Side of the Window Is the Map Display Area showing the Activated Layers.)

Each line in the TOC is a GIS layer representing a set of features of the same type, such as streams, irrigated acreage, hydrogeological units, and wells. By selecting a check box in the TOC, elements of the activated layer become visible in the map display area. A layer may consist of point values (e.g., wells), line features (e.g., streams, ditches), and area features (e.g., hydrogeologic units). Right-clicking a layer and selecting **Open Attribute Table**, provides additional information on the layer, such as the names of particular features.

The map is designed to show relevant labels (text) that are based on the contents of one of the fields in the attribute table, such as stream name or well number. When zooming in on a particular area of the map, additional information of a selected layer can be displayed by activating the **Label** feature.

1. Right-click the desired layer and select **Label**.
2. Right-click the layer, select **Properties**.
3. Click the **Label** tab.
4. Select the appropriate field in the database table.

Database information regarding a particular feature on the map can also be obtained by:

1. Click the identify option () on the **Tools** toolbar
2. Click the feature of interest. The **Identify Results** window appears.
3. Select the appropriate layer.

The county-wide GIS map calls up various files from the PCGW_database subdirectory. This subdirectory should be in a relative path with respect to the ArcGIS GIS map project file ('mxd' extension). A detailed description of the source of the GIS layers can be found in Appendix 1.

4.0 References

- Bryant, B. 1969. *Geologic Map of the Maroon Bells Quadrangle Pitkin and Gunnison Counties, Colorado*. U.S. Geological Survey, Geologic Quadrangle Map GQ-788, scale 1:24000.
- Bryant, B. 1970. *Geologic Map of the Hayden Peak Quadrangle, Pitkin and Gunnison Counties, Colorado*. U.S. Geological Survey, Geologic Quadrangle Map GQ-863, scale 1:24000.
- Bryant, B. 1971. *Geologic Map of the Aspen Quadrangle, Pitkin County, Colorado*. U.S. Geological Survey, Geologic Quadrangle Map GQ-933, scale 1:24000.
- Bryant, B. 1972a. *Geologic Map of the Highland Peak Quadrangle, Pitkin County, Colorado*. U.S. Geological Survey, Geologic Quadrangle Map GQ-932, scale 1:24000.
- Bryant, B. 1972b. *Map Showing Ground-water Potential in the Aspen Quadrangle, Pitkin County, Colorado*. U.S. Geological Survey, Miscellaneous Geologic Investigations Map I-785-B, scale 1:24000.

- Bryant, B. 1979. *Geologic of the Aspen 15-minute Quadrangle, Pitkin and Gunnison Counties, Colorado*. U.S. Geological Survey, Professional Paper 1073.
- Freeman, V.L. 1972a. *Geologic Map of the Ruedi Quadrangle, Pitkin and Eagle Counties, Colorado*. U.S. Geological Survey, Geologic Quadrangle Map GQ-1004, scale 1:24000.
- Freeman, V.L., 1972b. *Geologic Map of the Woody Creek Quadrangle, Pitkin and Eagle Counties, Colorado*. U.S. Geological Survey, Geologic Quadrangle Map GQ-967, scale 1:24000.
- Gaskill, D.L. and L.H. Godwin. 1966. *Geologic Map of the Marble Quadrangle, Gunnison and Pitkin Counties, Colorado*. U.S. Geological Survey, Geologic Quadrangle Map GQ-512, scale 1:24000.
- Gaskill, D.L., J.H. Kramer, J.A. Thomas, and S.G. Zahony. 1991. *Geologic Map of the Gothic Quadrangle, Gunnison County, Colorado*. U.S. Geological Survey, Geologic Quadrangle Map GQ-1689, scale 1:24000.
- Godwin, L.H. 1968. *Geologic Map of the Chair Mountain Quadrangle, Gunnison and Pitkin Counties, Colorado*. U.S. Geological Survey, Geologic Quadrangle Map GQ-704, scale 1:24000.
- Kolm, K.E., K.C. Glover, and J.C. Emerick. 2000. *Understanding Mountain Wetland Hydrology: Technical Guidance for Investigating the Hydrological Function of Wetlands in Complex Terrain*. Report prepared by Colorado School of Mines for U.S. EPA, Region VIII.
- Kolm, K.E., and R.G. Gillson, III. 2004. *State of Ground and Surface Water in the Central Roaring Fork Valley, Pitkin County, Colorado*. Report prepared by HSA for Pitkin County Commission of County Commissioners.
- Kolm, K.E., and P.K.M. van der Heijde. 2006. *Development of GIS-based Ground Water Resource Evaluation of the Upper and Middle Roaring Fork Valley Area, Pitkin County, Colorado*. Report prepared by HSA and HHI for Pitkin County Commission of County Commissioners.
- Kolm, K.E., P.K.M. van der Heijde, and M. Dechesne. 2007. *GIS-based Ground Water Resources Evaluation of the Capitol and Snowmass Creek (CSC) Study Areas, Pitkin County, Colorado*. Report prepared by HSA and HHI for Pitkin County Commission of County Commissioners.
- Kolm, K.E., P.K.M. van der Heijde, and M. Dechesne. 2008. *GIS-based Ground Water Resources Evaluation of the Crystal River and West Sopris Creek (CRWS) Study Area, Pitkin County, Colorado*. Report prepared by HSA and HHI for Pitkin County Commission of County Commissioners.
- Kolm, K.E., and P.K.M. van der Heijde. 2011. *Hydrologic and Environmental Systems Analysis and Formulation of Conceptual Models for the Central Roaring Fork Tributaries (CRFT), Pitkin County, Colorado*. Report prepared by Integral Consulting Inc. for Pitkin County Commission of County Commissioners.

Mutschler, F.E. 1970. *Geologic Map of the Snowmass Mountain Quadrangle, Pitkin and Gunnison Counties, Colorado*. U.S. Geological Survey. Geologic Quadrangle Map GQ-853, scale 1:24000.

Streufert, R.K., B.L. Widman, and R.M. Kirkham. 1998. *Geologic Map of the Basalt Quadrangle, Eagle, Garfield and Pitkin Counties, Colorado*. Colorado Geological Survey. OFR 98-1, scale 1:24000.

Streufert, R.K. 1999. *Geologic Map of the Mount Sopris Quadrangle, Garfield and Pitkin Counties, Colorado*. Colorado Geological Survey. OFR 99-7, scale 1:24000.

Tweto, O., T.A. Steven, W.J Hail, Jr., and R.H. Moench. 1976. *Preliminary Geologic Map of the Montrose 1°×2° Quadrangle, South-western Colorado*. U.S. Geological Survey. Miscellaneous Field Studies Map MF-761.

Tweto, O., R.H. Moench, and J.C. Reed, Jr. 1978. *Geologic Map of the Leadville 1°×2° Quadrangle, Colorado*. U.S. Geological Survey. Miscellaneous Investigations Series Map I-999.

Appendix 1

Data Sources

1. NRCS (U.S. Department of Agriculture – Natural Resources Conservation Service)

The data bases for one of the precipitation layers (isopleths) as well as for the watershed layers of the county-wide GIS map were obtained from the *NRCS Data Gateway* web site. The precipitation data were developed using PRISM (Parameter elevation Regression on Independent Slopes Model), which uses a rule-based combination of point measurements and a digital elevation model (DEM) and includes consideration of topographic facets. The watershed layers and data bases were derived from a single NRCS data base containing all watersheds that are fully or partially within Pitkin County. The NRCS data source and additional information can be found at: <http://datagateway.nrcs.usda.gov/GatewayHome.html>. The GIS map layer based on this data set is referenced as 'NRCS 2010'.

2. CDWR (Colorado Division of Water Resources)

There are three data bases in the county-wide GIS map that were obtained from the Colorado Division of Water Resources (CDWR) web site: 1) wells (abandoned, constructed, or constructed and augmented; as of March 2011); 2) precipitation isohyets; and 3) irrigated areas as of 1993, 2000, and 2005. Layers based on these data are referenced as 'CDWR 2010' or 'CDWR March 2011'. The well data source can be found at <http://www.dwr.state.co.us/WellPermitSearch/default.aspx> (Figure A1). To search:

- a. Click the **Actions** tab.
- b. Set the search period
- c. Click the [+] next to **Additional Filters**.
- d. Select the **Limit to Geographical Area** check box and choose an option from the dropdown list. More than one option may be chosen by holding down SHIFT or CNTL and clicking the selections.
- e. Select the **Limit to Use** check box and choose an option from the dropdown list. More than one option may be chosen by holding down SHIFT or CNTL and clicking the selections.
- f. Select the **Limit to Status** check box and choose an option from the dropdown list. More than one option may be chosen by holding down SHIFT or CNTL and clicking the selections.
- g. Click **Search**.
- h. Click **Export Results** to save the resulting comma separated values file to a local drive. This file can then be opened with Microsoft® Excel and other programs.

The precipitation and irrigation data sets are CDWR Division 5 subsets (Colorado River Basin). The irrigated areas layers are based on compilations of the irrigated lands data from the four Western Slope Divisions of the CDWR. These data sets provide a single year snapshot of the irrigated lands and crop types of the western slope of Colorado. In the GIS map, the 2005 data layer lies on top of the 2000 data layer, which in turn lies on top of the 1993 data layer,

showing the irrigated acreage taken out between 1993, 2000, and 2005. The CDWR data source for irrigated areas and precipitation (and other hydrologic information) can be found at: <http://water.state.co.us/DataMaps/GISandMaps/Pages/GISDownloads.aspx>.

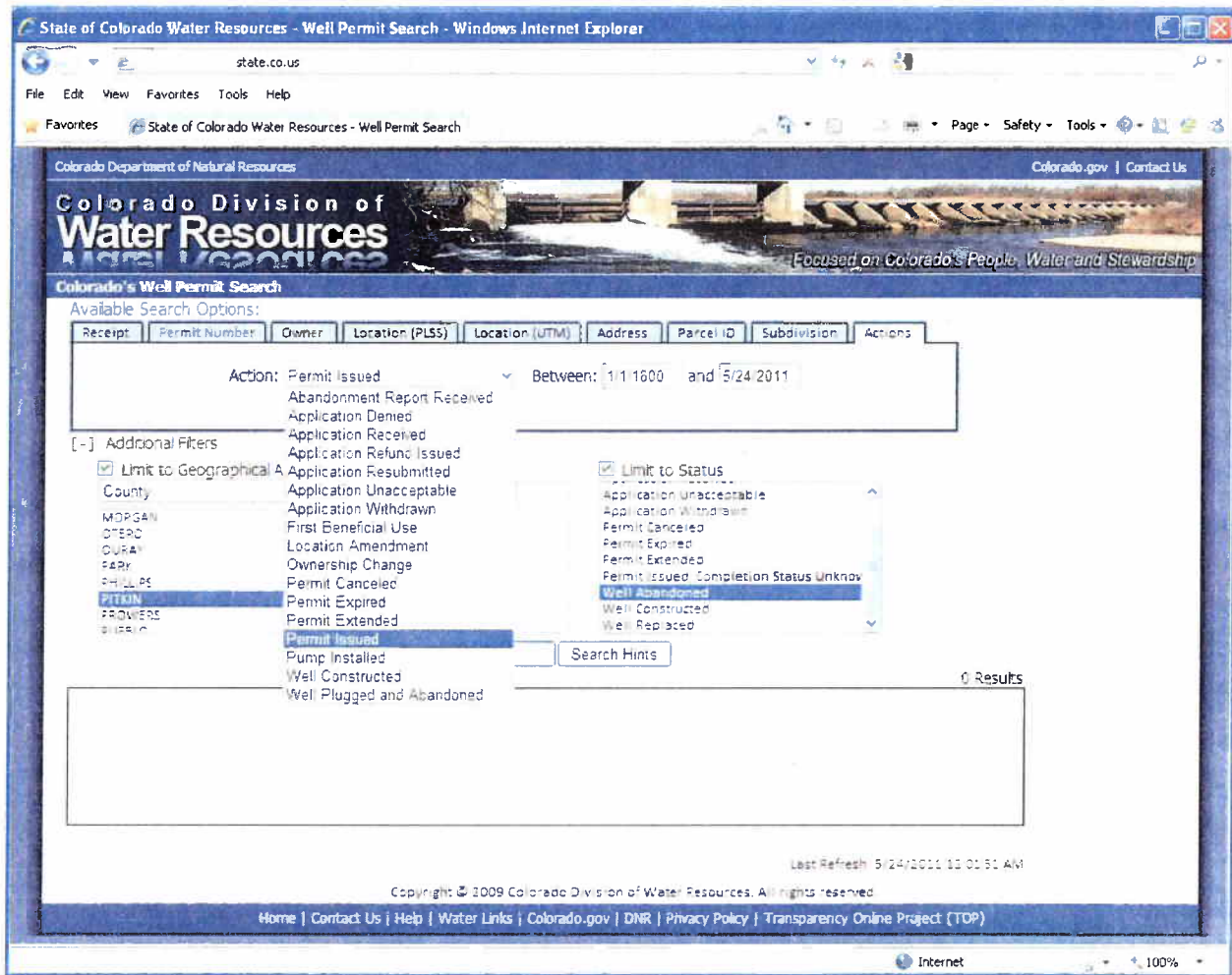


Figure A1. The Colorado's Well Permit Search screen on the Colorado Division of Water Resources (CDWR) website.

3. PC (Pitkin County/City of Aspen GIS)

There five data bases obtained from the Pitkin County/City of Aspen GIS Department: 1) Pitkin County boundary, 2) streams, 3) lakes and ponds, 4) ditches, and 5) mining claims. The streams data base has been used to create two separate layers: streams-perennial (or continuous) and streams-intermittent. Note that the ditch layer includes active and non-active ditches, as well as primary, secondary, and tertiary ditches, but that a distinction between active and inactive ditches and the size of the ditches cannot be determined within this GIS layer. Additional field verification is needed to assess the hydrologic importance of individual ditches. Pitkin County's GIS data were made available by the County as part of the project agreement. Layers based on these data are referenced as PC 2008.

4. ICI_HHI (*Integral Consulting Inc in cooperation with Heath Hydrology Inc.*)

There are a number of data bases developed by Integral Consulting Inc in cooperation with Heath Hydrology Inc. They include two county-wide hydro-units layers (quaternary hydrological units and bedrock hydrogeological units) as described above, a hydro-structures layer (zones with geological structures of hydrogeologic importance), a geological faults layer, a layer showing mining areas near the town of Aspen with specific hydrogeological characteristics, and layers showing locations of towns and geothermal springs. The hydro-structures data base is derived from Bryant (1979); the geological faults data base is based on a GIS version of the Leadville 1°×2° geological quadrangle map (*Tweto and others 1978*); and the hydrogeologic Mining areas data base is a digitized version of Bryant (1972b). All layers produced by Integral Consulting Inc. are referenced as 'ICI_HHI 2011'. Note that because the geologic maps used for the digitizing are different in scale, the digitized maps show different levels of resolution with respect to the (hydro)geology.

