## 6. Conclusions and Recommendations

Under an agreement with Pitkin County, Hydrologic Systems Analysis, LLC (HSA) of Golden, Colorado, in cooperation with Heath Hydrology, Inc. (HHI) of Boulder, Colorado, created a GIS-based, step-wise, ground water resources evaluation procedure for use as decision/land use management tools by Pitkin County. The procedure, supported by a GIS map and supporting data bases, guides the site-specific analysis with respect to: 1) ground water resources availability in terms of sufficient quantities for the purpose of its usage, and economical exploitability (*e.g.*, at reasonable depth and with sufficient permeability); 2) long-term sustainability of the utilization of the resources for water supply (*i.e.*, presence of long term continuous recharge mechanisms, and absence of excessive water table fluctuations, for example, due to spring runoff, upland flood irrigation, and drought); and 3) the vulnerability of the resources to contamination. In addition, the GIS map provides information with respect to wells for which augmentation is required, and shows well applications approved (*i.e.*, permitted wells, drilled or not drilled) or denied, and wells actually drilled. Note that availability and sustainability should be judged in relation to well yield requirements, presence of other resource usages, ecological requirements, water right issues, and physical constraints, such as limitations on drawdown.

Key elements in this project are the adaptation of the step-wise ground water resources evaluation procedure developed in a previous HSA/HHI study for Pitkin County, as well as the hydrologic systems analysis and the formulation of conceptual models for the study area. The GIS map and supporting data bases focus the non-public lands area of the Crystal River and West Sopris Creek watersheds. The incorporated data bases include delineated hydrogeological units created by HSA/HHI, as well as data bases from Pitkin County, the Colorado Division of Water Resources/Colorado Water Conservation Board, and the Natural Resources Conservation Survey (USDA).

Based on field work and hydrologic systems analysis, five general conceptual models are identified within the regional scale context of the CRSC area: 1) Upper Crystal River (UCR) Subsystem near Redstone, CO; 2) Central Crystal River (CCR) Subsystem; 3) Lower Crystal River (LCR) Subsystem including the Carbondale Collapse; 4) West Sopris Creek (WSC) Subsystem; and 5) the Thompson and Coal Creek (TCC) Subsystem. Each of the five subsystems has a unique set of natural system parameters defining recharge and discharge, ground water levels and fluctuations, ground water flow velocities and direction, and ground water storage. In addition, important anthropogenic hydrologic system parameters include ground water recharge from irrigation and irrigation ditches, and ground water discharge from wells. If water rights and allocations should change for these ditches, the hydrodynamics of the Quaternary glacial and alluvial aquifers would change, and water supplies from ground water may decline or vanish.

Four case history examples are presented to illustrate the analysis procedure, using the GIS map and data bases provided with this report. Site 1 is located in the Upper Crystal River (UCR) hydrogeological subsystem; site 2 is located in the Central Crystal River (CCR) hydrogeological subsystem, site 3 is located within the Carbondale Collapse area of the Lower Crystal River (LCR) hydrogeological subsystem, and site 4 is located in the hills of the West

Sopris Creek (WSC) hydrogeological subsystem. The examples show the existing uncertainties in evaluating local ground water resources due to data limitations, and illustrate the variability of drinking water supplies, in availability, sustainability, and vulnerability, dependent on the local hydrogeology and hydrological system. All four sites are vulnerable to ground water pollution, albeit not at the same level. The examples demonstrate the utility and advantages of the GIS-based analysis procedure and its advantages over simple, one-layer paper maps showing, for example, some general ground water characteristics, and demonstrate the need for site-specific hydrogeologic investigation to obtain quantitative resource management answers and well design parameters.

## 6.1 General Recommendations

Pitkin County has six regions that contain parcels of potentially developable land: 1) Upper Roaring Fork Drainage; 2) Town of Aspen; 3) Middle Roaring Fork Drainage; 4) Castle, Maroon, and Woody Creeks, and Frying Pan River; 5) Snowmass and Capitol Creek Drainage; and 6) Crystal River Drainage. Three levels of information are required in order to fully understand the ground water-derived drinking water availability, sustainability, and vulnerability: 1) Hydrologic Systems Analysis (HSA); 2) Data base and GIS development; and 3) Acquisition of site-specific hydrologic parameters. The hydrogeologic information processing and analysis begins at the conceptual level integrating regional, subregional, and local information, followed by data base development and GIS evaluation. Finally, hydrologic parameters are needed at each specific site based on due diligence.

Examples of Hydrologic Systems Analysis are found in section 2 of this report, as well as in the CSC, MRF and URF reports by Kolm and Others (*2007*), Kolm and van der Heijde (*2006*), and Kolm and Gillson (*2004*). The ultimate goal of this analysis is a conceptual model describing how the hydrogeologic framework and hydrologic system functions. Data base development and GIS Evaluation are described in this report.

Hydrologic parameters, including quantitative measures of aquifer thickness, water table levels (depth to water table), hydraulic conductivity, recharge amounts and ground-water flow paths, are the result of in-depth site analysis and testing. The goal of the third aspect of this analysis is site-specific drinking water well yields and water quality, and the impact of the drinking water well on surrounding wells and ecosystems. The existing data could be analyzed for specific sites and generalized to hydrogeologic regions. However, each new site will need due diligence by the land owner, and the results of their studies can be integrated into the existing data and each hydrogeologic region can be updated continuously.

## 6.2 Recommendations by Site

The Upper Roaring Fork Drainage area has a complete HSA, but lacks the delineation and digitalization of hydrogeologic units. The hydrogeologic data layers could be improved upon by separating the potential unconsolidated aquifers from the bedrock aquifer. The hydrologic parameters for the State Route 82 corridor would need to be evaluated as these were not assessed

as part of the North Star study. The priority for this work is low compared with the assessment needs of other areas.

The Town of Aspen area has no formal HSA completed, and the region is complex due to urbanization, shallow aquifers of various types (moraines, outwash plains, alluvium), and a complex, faulted bedrock system (Leadville Limestone). Some of the GIS data base development is completed, but additional data layers and evaluation are needed – particularly with respect to the hydrogeologic data base. The hydrologic parameters for the Town of Aspen area would need to be evaluated as these were not assessed as part of any of the previous studies. The priority for this work is high compared with the assessment needs of other areas.

The Middle Roaring Fork Drainage area has a complete HSA, and most of the GIS data base development and evaluation is completed. The hydrologic parameters for the Middle Roaring Fork Drainage area would need to be evaluated as these were not assessed in-depth as part of the current study. The priority for this work is low compared with the assessment needs of other areas.

The Castle, Maroon, Woody Creeks, and Frying Pan River areas have no formal HSA completed, and the region is complex due to some urbanization, shallow aquifers of various types (moraines, outwash plains, alluvium), and a complex, faulted bedrock system (including the Leadville Limestone and the Dakota Fm., and Tertiary intrusive rocks). Some of the GIS data base development is completed, but additional data layers and evaluation are needed – particularly with respect to the hydrogeologic data base. The hydrologic parameters for the Castle, Maroon, Woody Creeks, and Frying Pan River areas would need to be evaluated as these were not assessed as part of any of the previous studies. The priority for this work is moderate (Castle and Maroon Creek, and Frying Pan River areas) and high (Woody Creek area) compared with the assessment needs of other areas.

The Snowmass and Capitol Creek areas has a complete HSA, and most of the GIS data base development and evaluation is completed. The region is complex due to the presence of shallow aquifers of various types (moraines, landslide deposits, outwash plains, alluvium), and a complex, faulted bedrock system. The hydrologic parameters for the Snowmass and Capitol Creek areas would need to be evaluated as these were not assessed in-depth as part of the present study. The priority for this work is low compared with the assessment needs of other areas.

The Crystal River area has a complete HSA, and most of the GIS data base development and evaluation is completed. The region is complex due to some urbanization, shallow aquifers of various types (moraines, outwash plains, alluvium), and a complex, faulted bedrock system. The hydrologic parameters for the Crystal River area would need to be evaluated as these were not assessed as part of any of the previous studies. The priority for this work is low compared with the assessment needs of other areas.

In all of these areas, the completion of HSA and GIS data base and evaluation should be concurrent and of higher priority before the hydrologic parameters analysis being undertaken. The higher priority areas are based on the rate at which urbanization is occurring and corresponding demand for permits.

GIS database evaluation can be enhanced by the development of custom tools in ArcToolbox. The stepwise approach of the ground water resources assessment procedure can be maintained, but the extensive use of the information toolbar can be eliminated by predefining layer selections of importance for each of the 10 steps of the procedure.