DEVELOPMENT OF GIS-BASED GROUND WATER RESOURCES EVALUATION OF THE UPPER AND MIDDLE ROARING FORK VALLEY AREA, PITKIN COUNTY, COLORADO

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Executive Summary

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 two GIS maps 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 its economical exploitability; 2) long term sustainability of the utilization of the resources for water supply; and 3) the vulnerability of the resources to contamination.

The GIS maps and data bases developed for this project are limited to the area subject to previous studies conducted for Pitkin County by HSA (study area), specifically, (1) Middle Roaring Fork study area or MRF (Kolm and Gillson, 2004); and (2) Upper Roaring Fork study area or URF, comprising of the Upper Roaring Fork watershed including the North Star preserve (Kolm and others, 2000; Hickey and others, 2000). The data bases developed for this project include original GIS layers from the aforementioned studies, as well as GIS layers and data bases from Pitkin County, Colorado Division of Water Resources/Colorado Water Conservation Board, Natural Resources Conservation Survey (USDA), and U.S. Geological Survey.

Three case history examples are presented to illustrate the analysis procedure, using the GIS maps and data bases provided in this report, two in the MRF area and one in the URF area. The two MRF sites illustrate the variability of drinking water supplies, both in availability and sustainability, for sites located near to each other. The URF site illustrates that drinking water supplies in areas with sediment-bedrock connectivity are readily available and sustainable. All three sites are vulnerable to ground water pollution due to the absence of protective low-permeability hydrogeologic units between the ground surface and the aquifer units.
1.0 Introduction

Under an agreement with Pitkin County, Hydrologic Systems Analysis, LLC (HSA) of Golden, Colorado, in cooperation with Heath Hydrology, Inc. (HHI) of Boulder, Colorado, was tasked to create a series of GIS (Geographic Information System) maps for use as decision/land use management tools by Pitkin County. These maps identify locations in designated areas of Pitkin County:

A. Where ground water resources are: (i) available in reasonable, sustainable quantities, at reasonable depths, (ii) available in reasonable quantities, at reasonable depths, but vulnerable/not sustainable (e.g., because of artificial recharge, such as leaking ditches or irrigation), and (iii) not available in reasonable quantities, at reasonable depths.

B. Where the ground water table is likely to fluctuate significantly (e.g., due to spring runoff or upland flood irrigation), resulting in a high water table at different times of the year.

C. Where ground water resources are vulnerable (using a rating of High-Medium-Low) to contamination (e.g., because of the absence of a confining layer, shallow water table and a substrate consisting of unconsolidated gravels, alluvium, etc.).

The GIS maps cover the area subject to previous studies conducted for Pitkin County by HSA (referred to as the study area), specifically, (1) State of Ground and Surface Water in the Central Roaring Fork Valley, Pitkin County, Colorado – A Hierarchical Approach Using GIS and 3-Dimensional Hydrogeologic Modeling, June 1, 2004 (referred to as the Middle Roaring Fork study area or MRF) (Kolm and Gillson, 2004), (2) Understanding Mountain Wetland Hydrology; Technical Guidance for Investigating the Hydrologic Function of Wetlands in Complex Terrain, July 2000 (referred to as the Upper Roaring Fork study area or URF, comprising of the Upper Roaring Fork watershed above Aspen and including the North Star preserve) (Kolm and others, 2000), and (3) Preliminary Hydrologic and Biologic Characterization of the North Star Nature Preserve, Pitkin County, Colorado, May 2000 (referred to as the North Star study area, a part of the URF) (Hickey and others, 2000). Note that the second study’s focus was on wetland hydrology and ecology and did not analyze ground water systems in detail. The covered study area is shown in Figure 1.

Computer-based GIS maps provide a flexible and efficient way to display and analyze geographic information. Data from various sources can be collected in local or remotely accessible databases, which can be easily maintained and updated, independently of the display and analysis procedures. Computer-based GIS maps support optimal usage of data obtained from different sources containing features of significant importance in hydrogeologic evaluations at different scales, geographic distribution densities, and different levels of accuracy and information value.
A GIS map consists of a series of layers, each containing a single or multiple topological features. These features can represent a variety of geographic items, such as rivers and lakes, roads, towns and cities, landuse, land ownership, wells, etc. Each feature can be further described with linked attribute tables. All data are collected in a geodatabase and/or sets of layer-related files. At each step of a geographic analysis, individual layers can be analyzed, combined, or/and stored (switched on and off) and individual features interrogated with respect to their attributes. Enlarging (Zooming in to) a particular detail or regionalizing (zooming out) to encompass a larger set of features can be accomplished at any time; the ability to randomly visualize (switch) between layers; and the availability of advanced search, selection and overlay capabilities further enhances the utility of a GIS map.

The GIS-based evaluation of ground water resources in the MRF and URF study areas makes extensive use of the aforementioned GIS capabilities.
2.0 General Background

2.1 Upper Roaring Fork (URF) Study Area

The Upper Roaring Fork study area hydrologic system, including the North Star wetlands, typically consists of four interrelated subsystems: atmospheric, hillslope, regional ground water, and valley bottom (Figure 2). All subsystems are interrelated by hydrologic fluxes that are continuous across shared subsystem boundaries. Spatial and temporal trends in hydrologic processes of each subsystem are controlled principally by variations in several key components of wetland hydrologic structure. The key structural components of URF are terrain, vegetation, land use, geology, geomorphology and soil.

Figure 2. Conceptual Model of the Upper Roaring Fork Hydrologic System.

Terrain and vegetative cover strongly affect the atmospheric subsystem to produce important microclimates. Effects of elevation on precipitation and air temperature are well described, as are effects of slope and aspect on daily solar radiation. Terrain also affects day length, which affects daily solar radiation, as well as local wind speed and direction. Vegetative cover influences evapotranspiration and relative humidity, can reduce solar radiation reaching a snow pack, and modifies heat gain or loss from a snow pack by wind. Geology, geomorphology, and soil have less direct effect on atmospheric processes. However, these components of hydrologic structure can affect the distribution and type of vegetation and land use, which, in turn, can directly influence the
atmospheric subsystem. Atmospheric processes serve as driving mechanisms for water entering and leaving the hillslope and valley-bottom subsystems and wetlands within these subsystems.

The key structural components identified previously (terrain, vegetation and land use, geology, geomorphology and soil) affect hillslope hydrologic processes directly and through complex interactions. Terrain controls on the directions and rates of surface and subsurface runoff have been the subject of hydrologic research for several decades. Micro-topography, as well as vegetation and land use, clearly affect surface water storage and infiltration characteristics. The hydraulic properties of soils, geomorphic and geologic deposits control the storage and rate of water movement in the subsurface.

In mountainous terrain, hillslope soils tend to have high infiltration rates and low to moderate water storage capacity. As a result, overland flow tends to be limited and runoff is dominated by other mechanisms such as intermittent interflow or saturated subsurface runoff. The low to moderate water storage capacity of mountain hillslope soils and underlying geomorphic deposits tends to produce hydrologic conditions that are conducive to vertical water movement. As a result, hillslopes tend to act as ground water recharge areas, but will dry rapidly during periods of low precipitation and snowmelt.

In many mountain settings, the contrast between highly permeable geomorphic deposits and less permeable underlying bedrock can produce shallow local-scale zones of subsurface saturation. Water flows laterally along this zone of permeability contrast toward valley bottoms. Flow from hillslope to valley bottom typically occurs at time scales of weeks to months. As a result, inflow to valley bottom wetlands is delayed and attenuated relative to times of precipitation and snowmelt. The existence of shallow zones of saturation within permeable geomorphic deposits also increases the time available for water to recharge the deeper, regional aquifer system.

Ground water movement and storage within the regional ground water subsystem and valley-bottom subsystem are conceptualized as occurring within a two-aquifer framework (Figure 2). An upper, unconfined unit is defined to include thick glacial, colluvial and alluvial deposits, primarily occurring within the valley-bottom subsystem. Limited geophysical data indicated that deposits are stratified and may form two or more vertically distinct hydrogeologic units. However, data are insufficient to map individual units within these unconsolidated deposits. A deeper, regional aquifer is defined to include the fractured crystalline bedrock. Data characterizing thickness and hydraulic properties of this aquifer are very limited. Therefore, the aquifer was considered to operate as a single hydrogeologic unit. Local-scale ground water flow occurs in shallow and discontinuous unconsolidated sediments of the hillslope subsystem. Ground water movement in these sediments occurs relatively rapidly.

Regional ground water movement occurs within a complex three-dimensional framework (Figure 2). Recharge from hillsides moves laterally from unconsolidated geomorphic deposits (glacial, colluvial) through a fractured crystalline bedrock aquifer (granites, volcanic materials) toward valley bottoms. Water then moves vertically into thick, unconsolidated glacial, alluvial and colluvial deposits that are highly permeable.
Discharge is to slope (colluvial and alluvial) and riverine (alluvial) wetlands and the Roaring Fork River. The North Star wetland complex is an important valley-bottom wetland and ground water discharge area for the entire watershed.

Wetlands on hillslopes may occur where geomorphic deposits are conducive to shallow subsurface runoff. Water moving along shallow subsurface flow paths may be forced to the surface of a hillslope where variations in terrain or geologic conditions prevent continued movement in the subsurface toward valley bottoms. Wetlands of this type generally are called slope wetlands and may become dry during late summer and fall when the supply of subsurface runoff is exhausted.

Water movement within the regional ground water subsystem is controlled by the hydraulic properties of the fractured crystalline bedrock. However, few wells have been completed in the bedrock of the upper Roaring Fork watershed and only a general description, based primarily on locations of slope wetlands, springs is possible of spatial variations in flow direction or rate. A potentiometric surface of the bedrock aquifer, constructed with a contour interval of 100 meters, shows that recharge occurs predominantly beneath the hillslope subsystem with water moving laterally toward the valley-bottom subsystem. Discharge from the regional ground water subsystem occurs by upward movement into the valley-bottom subsystem. Annual low flow of the Roaring Fork River near the North Star wetlands typically is 0.6 to 0.8 m$^3$/s. These values provided useful constraints for ground water subsystem model simulations described in the Kolm and others (2000) report.

Other structural characteristics indirectly influence ground water movement by controlling recharge processes, as describe previously. Terrain variation strongly controls rates and directions of ground water movement. Topographically low areas, such as the principal valley bottoms and streams, act as locations of regional ground water discharge. Regional ground water movement from hillslope recharge areas to valley-bottom discharge areas typically occurs at time scales of years (Figure 2). Consequently, the long-term sustainability of valley-bottom wetlands during years of drought is a direct result of input from regional ground water.

The valley-bottom subsystem (Figure 2) consists of thick unconsolidated sediments of glacial outwash, lake-bed materials, and modern stream deposits overlying crystalline bedrock. Water enters the valley-bottom subsystem as recharge from snowmelt, ground water discharge from thin lateral moraines and colluvial deposits of adjacent hillslopes, and ground water discharge from fractured bedrock of the regional ground water subsystem. Water leaves the valley-bottom subsystem as seepage to the Roaring Fork River or evapotranspiration from wetlands. Primary hydrogeologic controls on wetland distribution are believed to be streambed hydraulic conductivity storage and saturated thickness, the spatial distribution and magnitude of recharge from the regional ground water subsystem, and the distribution of lateral ground water entering the valley-bottom subsystem from adjacent hillslope areas.
Wetland locations within a valley bottom depend on the balance between hydrologic rates of inflow and outflow. In combination with hydraulic properties of geologic and geomorphic deposits, this flow balance controls the water-table elevation in the valley bottom. Where the water table is near or at land surface, wetlands form. In many cases vegetation type can serve as an indicator of a shallow water table, and can be used to estimate evapotranspiration losses.

2.2 Middle Roaring Fork (MRF) Study Area

The hydrogeologic framework of the Middle Roaring Fork study area hydrological system has 4 distinct hydrogeologic units, including 3 bedrock units, and one unconsolidated unit consisting of various Quarternary and Tertiary deposits (Figure 3). The Dakota aquifer is an unconfined system near its recharge area, and a confined system at depth. The Mancos Shale and the Lower Bedrock units, consisting of Morrison and older rocks, are confining layers throughout most of the system. The unconsolidated hydrogeologic unit is an unconfined aquifer at the subregional scale, and can consist of a variety of aquifers and confining units at the local scale.

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<td>7</td>
<td>Dakota Sandstone</td>
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<tr>
<td>8</td>
<td>Lower Bedrock</td>
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Figure 3: Correlation of Geological and Hydrogeologic Units in the Middle Roaring Fork Study Area.

The conceptual model of the ground water flow system consists of inputs and outputs based on climate (infiltration of precipitation and snowmelt), stream functions (gaining or losing), vegetation (evapotranspiration), topography (steepness, aspect, degree of landscape dissection), geomorphology and soils, and human activity (mine tunnels, irrigation ditches and irrigation, urbanization, snow making, ISDS), and geology (Figure 4). Based on the hierarchical approach of Kolm and Langer (2001), no regional system has been identified, and subregional and local scale ground water flow systems dominate (Figure 4) in the Middle Roaring Fork study area.
The saturated hydrogeologic units consist of Quaternary landslide, glacial terrace, and alluvial deposits, and Tertiary sediments (Figure 3 and 4). Although, in some specific situations, the Dakota bedrock unit should be considered an aquifer, in general, it is not a saturated hydrogeologic unit of importance in most of the MRF area. Hence, despite its regional presence as a geologic unit, it does not represent a regional ground water subsystem (Figure 4). Deeper bedrock hydrogeologic units, such as the Leadville Fm., are not considered viable as water sources in this area due to costs of acquisition, due to such issues as drilling depths to water and low yields.

![Figure 4. Conceptual Model of Middle Roaring Fork Ground Water Flow System.](image)

The regional hydrologic inputs include infiltration of precipitation as rain and snowmelt, areas of losing streams and water bodies, and upland irrigation areas. The hillslope subsystem consists of the hydrologic processes of surface and near surface runoff (interflow or through flow – light blue arrows on left slope in Figure 4), saturated ground water flow in some areas (dark blue arrows in Figure 4), and discharge to surface springs and by plants as evapotranspiration. The Terrace subsystems have a unique story described in subsequent paragraphs and figures of local conceptual models. The Valley Bottom subsystems, where stream-aquifer-wetland interactions occur, are areas of both ground water recharge and discharge (Figure 4). These subsystems depend primarily on interactions with the Roaring Fork River, and Brush and Owl Creeks, and the associated wetlands are considered riverine given the lack of a supporting regional or subregional ground water system (Figure 4). There are four general conceptual models within the
regional scale context of the MRF area (Figure 5): 1) Brush Creek Valley Hillslope (BCH) Subsystem near Snowmass Village; 2) West Roaring Fork Valley Hillslope (WRH) Subsystem; 3) Disconnected Glacial Terrace East Roaring Fork Valley Hillslope (DTH) Subsystem; and 4) Connected Glacial Terrace/Mass Wasting East Roaring Fork Valley Hillslope (CMH) Subsystems.

![Figure 5. Location MRF Conceptual Models Cross Sections.](image)

There are two significant hydrogeologic units in the BCH area: (1) Quaternary unconsolidated materials, which are predominantly glacial, colluvial, and alluvial deposits, overlying (2) Mancos Shale (bedrock confining layer) (Figure 6). The Quaternary unconsolidated materials are locally heterogeneous, with predominantly coarser materials in the glacial and landslide deposits, and finer materials in the alluvial deposits. The thickness of the sediments ranges from less than 1 ft. to greater than 100 ft. Estimates of hydraulic conductivity (K) ranges from 10 to 100 ft per day (Harlan and others, 1989). The Mancos shale bedrock is the dominant underlying confining layer with small hydraulic conductivity values less than .01 ft per day. It is possible that the
The Quaternary unconsolidated materials are recharged by infiltration from precipitation that is non-uniformly distributed due to the location of open areas, buildings, and parking lots, and to position in the landscape (Figures 6). The unconsolidated units are variably saturated based on spatial location and seasonal precipitation events. There is both lateral and upward recharge from the faulted saturated Dakota Sandstone into the unconsolidated materials in some locations. Otherwise, the Mancos Shale does not allow lateral or upward movement of ground water from the Dakota aquifer into the unconsolidated materials. The unconsolidated units discharge locally into upper Brush Creek, and into minor tributaries of Brush Creek (Figures 6). Therefore, the local flow system is from the unconsolidated glacial and colluvial materials into unconsolidated alluvium and, finally, to springs, seeps, or Brush Creek. In addition, other sources of discharge from the unconsolidated units are evapotranspiration and well withdrawal (Figure 6).

If it were assumed that the contaminants that are of interest (for example, nutrients from ISDS’s and turf grass fertilization) are primarily advective, the contaminant pathways would primarily follow the flow pathways as conceptualized. Given this assumption, several source, transport flow path, and fate scenarios are
hypothesized: 1) If the source of contamination is from the ISDS’s or turf grass fertilization, then the recharge events due to infiltration of precipitation will move the contaminants from the sources into the unconsolidated materials and ultimately Brush Creek by interflow and saturated ground water flow in the glacial, colluvial, and alluvial materials; and 2) In the few areas where the fault controlled Dakota Sandstone aquifer is connected to the unconsolidated materials, the ground water may flow up into the unconsolidated materials and leach the contaminants from local sources to Brush Creek by saturated ground water flow in the glacial, colluvial, and alluvial materials.

There are two significant hydrogeologic units at the WRH site: Quaternary and recent unconsolidated materials (predominantly colluvium and alluvium) overlying the bedrock unit of Mancos Shale (Figure 7). The Quaternary unconsolidated materials are locally heterogeneous (poorly sorted), and consist of clay, silt, sand, gravel, cobbles, and boulders. The thickness ranges from 1 ft to greater than 100 ft. The estimates of hydraulic conductivity range between 1 to 100 ft per day. The Mancos Shale underlies most of the unconsolidated units at the WRH site (Figures 7). This bedrock unit has minimal transmissivity and storage, and is considered a confining unit in the WRH hydrologic system.

Figure 7. Conceptual Model of the West Roaring Fork Valley Hillslope (WRH) Subsystem.
The Quaternary unconsolidated materials are recharged by infiltration from precipitation that is non-uniformly distributed due to the location of open areas, buildings, and parking lots, and position in the landscape. The unconsolidated units are variably saturated based on spatial location and seasonal precipitation events. There is no lateral and upward recharge from deeper bedrock aquifers due the Mancos Shale confining layer (Figure 7).

Ground water moves by primarily interflow and through flow in the unconsolidated units into the alluvium and/or directly into lower Brush Creek and the Roaring Fork River (Figure 7). Other sources of discharge from the unconsolidated alluvium include phreatophytes and well withdrawals.

If it were assumed that the contaminants that are of interest (for example, nutrients from ISDS’s and turf grass fertilization; contaminants from the Pitkin County Landfill) are primarily advective, the contaminant pathways would follow the flow pathways as conceptualized. Given this assumption, the following source, transport flow path, and fate scenario is hypothesized: If the source of contamination is from ISDS’s and turf grass, and the Pitkin County Landfill located within and over the unconsolidated units, then the recharge events due to infiltration of precipitation will move the contaminants from the sources into the unconsolidated materials and ultimately to the alluvium and to Brush and Owl Creeks, and the Roaring Fork River by interflow or by ground water flow.

There are two significant hydrogeologic units at the DTH site: Quaternary and recent unconsolidated materials (predominantly terrace gravels and alluvium) overlying the bedrock unit of the Mancos Shale (Figure 8). The Quaternary unconsolidated materials are locally heterogeneous, and consist of clay, silt, sand, gravel, cobbles, and boulders. The average thickness is variable ranging from less than 1 ft to over 100 ft. The estimates of hydraulic conductivity range generally between 1 to 100 ft per day (Harlan and others, 1989). The Mancos Shale underlies most of the unconsolidated units at the DTH site (Figure 8). This bedrock unit has minimal transmissivity and storage, and is considered a confining unit in the DTH hydrologic system.

The Quaternary unconsolidated materials are recharged by infiltration from precipitation that is non-uniformly distributed due to the location of open areas, buildings, and parking lots, highway and airport location, irrigation ditch location, and position in the landscape. The unconsolidated units are variably saturated based on spatial location and seasonal precipitation events. There is negligible lateral and upward recharge from the underlying bedrock units into the unconsolidated materials in most locations (Figure 8). Ground water in the unconsolidated units laterally recharges the unconsolidated units located topographically below by the interflow process, and the lowest terraces recharge the modern alluvium by interflow (Figure 8). In addition, ditches located on each terrace are influent (losing) and locally recharges the unconsolidated units (Figure 8).
Ground water in the unconsolidated units discharges locally into streams that cut through the terraces, and from the alluvium into the Roaring Fork River. Other sources of discharge from the unconsolidated units include phreatophytes and well withdrawals (Figure 8). Therefore, the local flow system has two components (Figure 8): 1) flow from the unconsolidated materials into cross-cutting streams, into the Roaring Fork River, and 2) flow from infiltration and leakage from the local ditches into the unconsolidated materials, and, finally, into cross-cutting streams and the Roaring Fork River.

![Figure 8. Conceptual Model - Disconnected Glacial Terrace East Roaring Fork Valley Hillslope (DTH) Subsystem.](image)

If it were assumed that the contaminants that are of interest (for example, nutrients from ISDS’s and turf grass fertilization; metals and organics from the airport and major highways) are primarily advective, the contaminant pathways would primarily follow the flow pathways as conceptualized. Given this assumption, several source, transport flow path, and fate scenarios are hypothesized: 1) If the irrigation ditches were a source of contaminants, then the contaminants would travel through the unconsolidated terrace gravels to crosscutting streams and transported to the Roaring Fork River; and 2) If the source of contamination is from the ISDS’s and turf grass fertilization, or from the airport and highway runoff into the unconsolidated units, then the recharge events due to infiltration of precipitation will move the contaminants from the sources through the unconsolidated materials by interflow or saturated flow, and ultimately to tributaries and/or directly to the Roaring Fork River.
There are two significant hydrogeologic units at the CMH site: Quaternary and recent unconsolidated materials (predominantly terrace gravels and mass wasting deposits) overlying the bedrock unit of the Mancos Shale (Figure 9). The Quaternary unconsolidated materials are locally heterogeneous, and consist of clay, silt, sand, gravel, cobbles, and boulders. The average thickness is variable ranging from less than 1 ft. to greater than 100 ft. The estimates of hydraulic conductivity range generally between 1 to 100 ft per day (Harlan, and others, 1989). The Mancos Shale underlies most of the unconsolidated units at the CTH site (Figure 9). This bedrock unit has minimal transmissivity and storage, and is considered a confining unit in the CMH hydrologic system.

![Conceptual Model - Connected Glacial Terrace/Mass Wasting Units East Roaring Fork Valley Hillslope (CMH) Subsystem.](image_url)

Figure 9. Conceptual Model - Connected Glacial Terrace/Mass Wasting Units East Roaring Fork Valley Hillslope (CMH) Subsystem.

The Quaternary unconsolidated materials are recharged by infiltration from precipitation that is non-uniformly distributed due to the location of open areas, buildings, and parking lots, irrigation ditch location, and position in the landscape. The unconsolidated units are variably saturated based on spatial location and seasonal precipitation events. There is negligible lateral and upward recharge from the underlying bedrock units into the unconsolidated materials in most locations (Figure 9). Ground water in the unconsolidated terrace units laterally recharges the unconsolidated terrace units located topographically below by ground water flow through mass wasting units, and the lowest terraces and mass wasting units recharge the modern alluvium by ground
water flow (Figure 9). In addition, ditches located on each terrace or mass wasting unit are influent (losing) and locally recharges the unconsolidated units (Figure 9).

Ground water in the unconsolidated units discharges locally into streams that cut through the terraces, and from the alluvium into the Roaring Fork River. Other sources of discharge from the unconsolidated units include phreatophytes and well withdrawals (Figure 9). Therefore, the local flow system has two components (Figure 9): 1) flow from the unconsolidated materials into cross-cutting streams, into the Roaring Fork River, and 2) flow from infiltration and leakage from the local ditches into the unconsolidated materials, and, finally, into cross-cutting streams and the Roaring Fork River.

If it were assumed that the contaminants that are of interest (for example, nutrients from ISDS’s and turf grass fertilization) are primarily advective, the contaminant pathways would primarily follow the flow pathways as conceptualized. Given this assumption, several source, transport flow path, and fate scenarios are hypothesized: 1) If the irrigation ditches were a source of contaminants, then the contaminants would travel through the unconsolidated terrace gravels to crosscutting streams and transported to the Roaring Fork River; and 2) If the source of contamination is from the ISDS’s and turf grass fertilization, then the recharge events due to infiltration of precipitation will move the contaminants from the sources through the unconsolidated materials by interflow or saturated flow, and ultimately to tributaries and/or directly to the Roaring Fork River.
3.0 GIS Layers Included In The Maps

HSA/HHI prepared two GIS maps within the ArcMAP™ program (version 8.3, 2002) of ArcGIS™ system (ESRI®, Redlands, California):

1) Map 1: MRF Study Area [file: PitkinCounty_GWGIS_MRF.mxd]; this map focuses on the ground water resources in the Middle Roaring Fork study area as described in Chapter 1 (Figure 10); and

2) Map 2: URF Study Area [file: PitkinCounty_GWGIS_URF.mxd]; this map covers the Upper Roaring Fork watershed while focusing on the ground water resources in its lower section in the vicinity of the North Star preserve upstream from the City of Aspen as described in Chapter 1 (Figure 11).

Utilizing the GIS maps requires running the ArcMAP program version 8.3 or higher. The decision to prepare two separate maps was made to optimally use the disparate format of the available (hydro)geologic information and to retain ease of usage of the maps.
These maps call various files included in seven relative-path subdirectories: 1) Colorado DSS; 2) Geology Maps; 3) MRF GIS Files; 4) NRCS Data Gateway; 5) Pitkin County GIS; 6) URF GIS Files; and 7) Wells_DWRSC Pitkin. The directories reflect the various data sources used for the maps. Selection of the relative-path option of ArcMAP provides for straightforward portability between computers. Note, that the files that represent state-wide or multi-county data have been clipped to show only the Pitkin County area coverage.

The ‘Colorado DSS’ subdirectory contains 3 sets of GIS files downloaded from the Colorado Decision Support System (CDSS), which is under development by the Colorado Water Conservation Board and the Colorado Division of Water Resources (http://165.127.23.116/website/cdss/). These file sets are: 1) state-wide presence of an alluvial aquifer; 2) irrigated areas on the West Slope as of 1993; and 3) irrigated areas on the West Slope as of 2000. Layers based on these data are referenced as ‘CDSS 2005’. 
The ‘Geology Maps’ subdirectory contains files for the georeferenced and rectified USGS geologic map of the Aspen 1:24,000 quadrangle (Bruce Bryant, 1971, U.S. Geological Survey Map GQ-933) and the GIS (shape) files for the USGS Geologic Map of the Leadville 1° x 2° Quadrangle (Ogden Tweto, Robert H. Moench, and John C. Reed, Jr., 1978, U.S. Geological Survey, Misc Investig. Series Map I-999). These files have been projected on the Colorado State Plane Central Zone (NAD 1983; ft) and are used in the URF map as the main (hydro)geologic data base. The coverage provided by the Aspen geologic map is more detailed than that provided by the Leadville geologic map. Therefore, the Leadville map should only be used in areas outside the coverage of the Aspen map. A separate legend file for both geologic maps is included in their respective subdirectories. The (hydro)geologic maps for the MRF area are described in the next section. Layers based on these data are referenced as ‘USGS 1971’ (Aspen map) and ‘USGS 1978’ (Leadville map).

The ‘MRF GIS Files’ subdirectory contains original and updated shape files from the Middle Roaring Fork ground water study (see Chapter 1). These files pertain primarily to the area’s (hydro)geology as described in Chapter 2. Layers based on these data are referenced as ‘MRF Study 2004’.

The ‘NRCS Data Gateway’ subdirectory contains county-wide annual precipitation data from the Natural Resources Conservation Service (USDA). These data have been developed using PRISM (Parameter elevation Regression on Independent Slopes Model) which utilizes a rule-based combination of point measurements and a digital elevation model (DEM) (http://datagateway.nrcs.usda.gov/GatewayHome.html). Layers based on these data are referenced as ‘USDA_NRCS 2005’.

The ‘Pitkin County GIS’ subdirectory contains the shape, DEM and DRG files from the Pitkin County GIS as well as the relevant meta files as received in September 2005. Coverages include county border and area; roads; streams, lakes and ponds (waters layer); (irrigation) ditches; parcels, subdivisions, and structures; forest and open space coverage; and 10ft elevation contours for selected areas, topographic maps, and the county-wide digital elevation model (DEM). Pitkin County GIS data are based on the State Plane, Colorado Central Zone projection and the North American Datum of 1983 (NAD83) with units of measure in feet. Pitkin County’s GIS data were made available to HSA by the County as part of the project agreement. Layers based on these data are referenced as ‘PC GIS 2005’.

The ‘URF GIS Files’ subdirectory contains shape files constructed from CAD files (DGN format) from the Upper Roaring Fork studies (see Chapter 1). Note that not all URF shape files have been included in the final URF map as they duplicate other source layers in the map. Layers based on these data are referenced as ‘URF Study 2000’.

The ‘Wells_DWRSC_Pitkin’ subdirectory contains a subset of the February 28, 2002 version of the state-wide well data base, maintained by the State of Colorado Division of Water Resources. This data set was obtained in 2002 from the State on CD as part of the MRF study (http://www.water.state.co.us/pubs/welldata.asp). The subset is
restricted to Pitkin County (county code 49) and includes both well permits (drilled or not) and drilled wells. The attribute table [right-click on layer in contents column] includes fields for drill and completion date, total well depth and depth to water (water table). The subdirectory contains the file ‘WELL_DATA_FIELDS.doc’ with explanations of the fields in the wells attribute table. This subdirectory also contains well-related shape files from the MRF area ground water study most of which, due to their limited coverage, have not been used in the MRF GIS map. Only the subset containing geologic layer descriptions in the attribute table has been included. Layers based on these data are referenced as ‘CWCB Feb 2002; CSP83’.

Note that the files in the ‘Colorado DSS’, ‘Pitkin County GIS’, ‘NRCS Data Gateway’ and ‘Wells_DWRCS_Pitkin’ directories require regular updating from the data source/owner/custodian.

The GIS layers of the MRF and URF maps contain four types of geographic information: 1) general geographic information (county border, roads, parks, parcels, structures, etc); 2) hydrologic information (precipitation, streams, lakes/ponds, ditches, irrigated areas); 3) hydrogeologic information (alluvial aquifer, hydrogeologic units, wells); and 4) topographic information (topo maps, DEM, 10ft elevation contours). Type 1 information is used to locate the site of interest and obtain some general geographic data. Type 2 and Type 3 information is integral to the evaluation of ground water resources. Type 4 information provides elevation and background data as needed. All layers have been georeferenced with respect to Pitkin County’s projection and datum: State Plane, Colorado Central Zone, NAD83 (ft).

The MRF and URF GIS maps consist of a ‘table of contents’ (the left display area of Figures 10 and 11) and a ‘map display area’ (the right display area of Figures 10 and 11). Each line in the table of contents is a GIS layer representing a set of features of the same type, such as streams, parcels, wells, etc. Each layer is linked to one or more files in the GIS database. “Left clicking” the square in front of the layer reveals the layers graphic representation characteristics (e.g, line color, point symbol, colored variable range, etc). “Right clicking” the layer opens a menu that includes an option to ‘Open Attribute Table’ and an option to show ‘Label Features’. The maps are designed to show relevant labels for most of the layers based on the contents of one of the fields in the attribute table, such as stream name, well number, etc.

Individual features can be identified using the ‘Identify’ option (i) from the ‘Tools’ toolbar and selecting the appropriate layer in the pop-up ‘Identify Results’ window. The pop-up table shows the information from the attribute table for the selected feature. Some information in the attribute tables of specific interest to the current project is given in Table 1.
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<th>GIS Layer</th>
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<th>Comments</th>
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<td>precipitation in inches/year</td>
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<td>County-wide Irrigation 1993 &amp; 2000</td>
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<td></td>
<td>Type</td>
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<tr>
<td></td>
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<td>length of stretch</td>
</tr>
<tr>
<td>Wells</td>
<td></td>
<td>many fields of interest such as yield, depth to bottom, depth to water table, surface elevation; see the file WELL_DATA FIELDS.doc of which a hard copy is included in Appendix A.</td>
</tr>
<tr>
<td>MRF Wells with Geology</td>
<td>see Wells layer</td>
<td>includes additional fields describing top bedrock, depth to base, thickness and lithology of top 3 geological units</td>
</tr>
</tbody>
</table>

Table 1. Selected Attributes of Interest in Evaluating Ground Water Resources.