GROUNDWATER PROTECTION AND DEVELOPMENTAL CONSIDERATIONS IN THE KINGSTON–ROSENDALE AQUIFER SYSTEM; ULSTER COUNTY, N.Y.

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Abstract

The Kingston–Rosendale karst aquifer system comprises a unique combination of natural and manmade components that make it extremely vulnerable to permanent water quality degradation. Since the hydrologic complexities of this system remain largely unknown, it is imperative that this untapped resource be carefully managed. A thorough study of hydrologic susceptibility is required prior to urbanization of the recharge zone.

The system is characterized by a complex network of natural caves, sinkholes, sinking streams, and springs in strata exposed along the western margin of the Hudson Valley. The major karst-forming units in this sequence (including the Rondout, Manlius, Coeymans, and Onondaga Formations) were strongly deformed during Appalachian orogenic events. In places, this deformation resulted in regional fracture and fault networks that contributed to the development of deep, strike-parallel, aquifers bounded by mixed carbonate/clastic and clastic units (e.g., Kalkberg, New Scotland, Esopus Formations). Mining associated with the natural cement industry during the 19th and early 20th centuries further complicates the karst system in the Kingston–Rosendale area. These activities disrupted and unnaturally integrated pre-existing karst aquifers.

Currently, aquifer recharge areas, groundwater flow directions and discharge points, existing use, safe-yield, water quality, and contaminant threats in the Kingston–Rosendale karst aquifer system remain largely undefined. The need for watershed protection in the system was recently highlighted by its proposed addition to the New York State Open Space Conservation Plan. Preliminary mapping within the karst aquifer system is generating the foundation for a new GIS database. This GIS system integrates karst features, mines, quarries, geologic mapping, hydrologic basins, as well as the tracer testing, pumping, and field data

necessary to provide a scientific rationale for karst aquifer protection under proposed development schemes. For example, our mapping clearly illustrates that a portion of the proposed 2,182-unit Landing at Kingston and Ulster project receives recharge from a 1 km^2 catchment that drains directly into the Kingston–Rosendale karst aquifer system.

Introduction

Karst hydrologists have long recognized the importance of protecting water resources within carbonate aquifer systems, much like the more widely acknowledged well head protection programs. However, community planning organizations are often unaware of the implications of developing karst regions. For example, Ulster County, a region characterized by widespread karst in the central Hudson Valley of New York, had neither acknowledged the presence of karst features nor implemented programs to protect karstic groundwater resources as recently as 1996 (Rubin and Privitera 1997). Karst aquifers are elaborate underground plumbing systems through which water flows in discrete conduits (Palmer 1990).

Delineation of recharge basins or watersheds tributary to karst aquifers and springs in Ulster County is difficult because karstic flow paths developed before glacial advances reshaped surface topography and filled deep stream valleys with sediments. In addition, many of Ulster County's karst aquifers are complicated by structural deformation, relict regional base levels graded to deep paleo-valleys, and mining activity. These factors combine to form localized, kilometer-scale, flow paths between water infiltration points and aquifer discharge at springs. Tracer analyses are the only reliable means of determining groundwater flow directions, destinations, and velocities in karst aquifers.

Ulster County is characterized by low mountains, river valleys, and glacially sculpted lakes. Geologically, the county comprises a bedrock of sedimentary rocks overlain by unconsolidated sediments and soil horizons. Along the western margin of the Hudson River in eastern Ulster County, the bedrock consists of a narrow belt of carbonate and clastic sedimentary rocks. Groundwater flow through these strata is primarily through fractures, conduits, and caves. Solutionally aggressive surface and groundwater preferentially enlarges some high angle joints and low angle fractures (bedding planes) and fault planes. This produces an aquifer in which groundwater is channeled down a continuum from narrow fractures (similar to sandstone or shale fractured bedrock aquifers where groundwater flow is slow), to larger solution channels, and ultimately to conduits or caves large enough to physically survey and carry aggressive, rapidly flowing, groundwater. Groundwater is discharged from these aquifers down gradient in one or more springs.

In 2005 the New York State Region 3 Open Space Advisory Committee Report identified Ulster County as a conservation priority project and proposed it as a "Karst Aquifer Region" (2005). This Advisory Committee report outlines a series of conservation objectives that include watershed protection, habitat protection, and promotion of recreation in the context of the following general description of the Ulster County Karst Aquifer Region:

> **"KARST AQUIFER REGION {NEW, 38} -** The Karst Aquifers are situated in a narrow band of carbonate rocks that extend throughout Ulster County, generally parallel with the Hudson River and trending south-southwest, through portions of Saugerties, Kingston, Esopus, Marbletown, Rosendale, Rochester and Ellenville, continuously outcropping just northwest and along the flank of the Shawangunk Mountain Ridge. This region is characterized by such features as caves, sinkholes, mines, springs, lakes and sinking streams. The area is rich in biological, geological and historical resources, provides diverse outdoor recreational opportunities and critical water reserves."

The New York State Region 3 Open Space Advisory Committee recognizes the importance of protecting Ulster County's critical water reserves. The Advisory Committee's intent to prioritize pro-

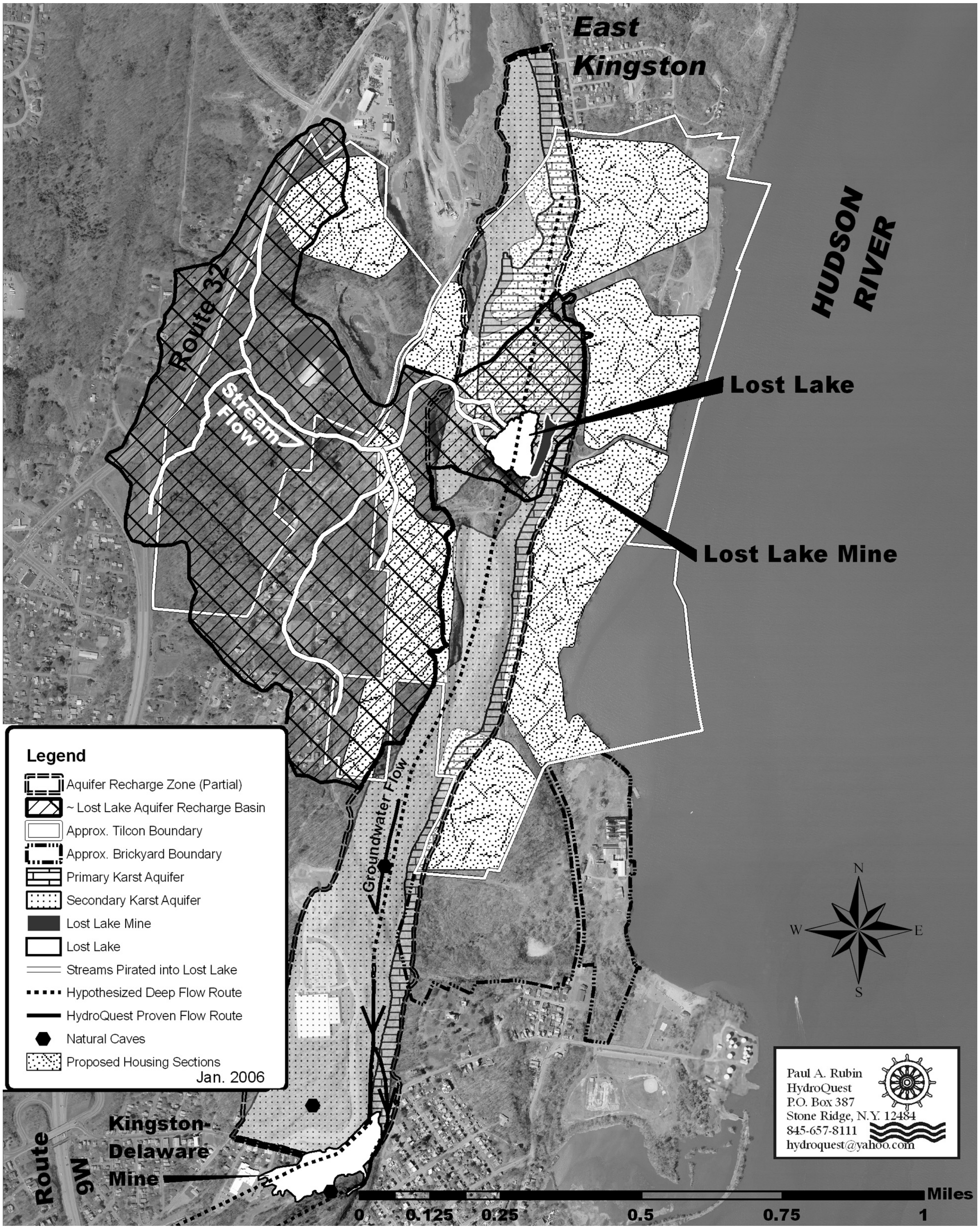

Figure 1. Karst Aquifers and Recharge Zones — Kingston landing Area.

tection of karstic water reserves is supported by Part C of the Federal Safe Drinking Water Act. While the primary focus of the Safe Drinking Water Act is upon the protection of public water systems and public water supplies from contaminants, it is clear that the intent of the United States Congress is to protect unexploited aquifers such as those within the Ulster County Karst Aquifer Region.

The Landing at Kingston and Ulster Case Study

To highlight potential impacts on regional karst hydrology and water quality in Ulster County, this report examines The Landing at Kingston and Ulster project, a proposed residential development (Figure 1). The proposed Landing project provides an excellent opportunity to illustrate the need to fully document the karst hydrology of a sensitive watershed prior to development so that measures to avoid aquifer degradation can be incorporated into the planning process. The Landing project seeks to construct 2,182 residential units and assorted commercial facilities on 524 acres underlain by sedimentary rocks in the City of Kingston and the Town of Ulster. The boundaries of proposed housing and retail clusters are outlined in Figure 1. Note that a significant portion of three proposed development clusters fall within the watershed tributary to Lost Lake (discussed below).

Surface water flowing into carbonate strata underlying the proposed Landing project site recharges the Kingston–Rosendale aquifer system, which is a portion of one of the largest undocumented aquifer systems in Ulster County. Development-related contaminants stemming from The Landing project, as proposed, will almost certainly degrade groundwater quality in this aquifer system. To date, however, the hydrologic impacts of The Landing project remain unaddressed. Scenic Hudson, an environmental organization and land trust working to protect, preserve, and restore the Hudson River and its river front as a public and natural resource, is currently working with the City of Kingston Planning Board and the developer, Kingston Landing Development, LLC, to develop a revised plan that better accounts for economic benefits, environmental considerations, water quality protection, and other concerns. However, it is unclear if this revised development plan will incorporate the measures necessary for protecting karst groundwater resources. Water quality protection in hierologically sensitive karst aquifers can be achieved through strategic planning and methodologies suited for karst terranes (for example, NGWA 1992, Beck and Pearson 1995, Beck and Stephenson 1997).

The need to fully characterize the karst hydrology of the region underlying the proposed Landing project is further emphasized by the Draft Generic Environmental Impact Statement generated by the project developers (ECS 2005). The Impact Statement for The Landing project fails to mention that much of the proposed project site is a recharge zone for a major karst aquifer. This omission is significant in terms of the comprehensive review of potential environmental impacts of any proposed development that is mandated by the New York State Environmental Quality Review Act. Without comprehensive knowledge of regional karst hydrology, developers are not in a scientifically defensible position "to systematically consider the significant environmental impacts, alternatives, and mitigation measures associated with the proposed project" (ECS, 2005).

The present report stems from material presented at the November 2005 National Cave and Karst Management Symposium (Rea 2006). In the context of a review of the geology and the hydrology of the proposed Landing at Kingston and Ulster project site, the findings presented herein are an example of the need conduct a comprehensive hydrogeologic investigation in karst terranes prior to proposing a development scenario. In this way, critical water reserves can be protected. The material presented here is consistent with the New York State Region 3 Open Space Advisory Committee's intent to identify and protect karstic groundwater resources.

Karst Geology and Hydrology

The Kingston–Rosendale karst aquifer system is characterized by a complex network of natural caves, mines, sinkholes, sinking streams, and springs in strata exposed along the western margin of the Hudson Valley. The major karst- and cave-forming units in the Kingston–Rosendale karst aquifer system include the Late Silurian Rondout Formation and the Middle to Late Devonian Manlius, Coeymans, and Onondaga Formations (Burmeister 2005, Epstein and Little 1987, Hoar and Bowen 1967, Laporte 1964a 1964b 1967, Leeds 1989, Marshak and Tabor 1989, Marshak 1990, Rickard 1962 1963, Sanders 1956, Tabor 1985, Van Ingen and Clark 1903, Waines and Hoar 1967, Waines 1976, Wanless 1921, Warren 1987). These strata were strongly deformed during Appalachian orogenic events. In places, this deformation resulted in regional fracture, joint, tectonic cleavage, and thrust fault networks that contribute to the development of deep, strike-parallel, aquifers that function as one hydrologic unit. These aquifers are bounded by relatively impermeable mixed carbonate/clastic and clastic units in the same Late Silurian through Late Devonian sequence (for example, Kalkberg, New Scotland, Esopus Formations). Mining associated with the natural cement industry during the 19th and early 20th centuries further complicates the karst system in the Kingston–Rosendale area. These activities disrupted and unnaturally integrated pre-existing karst aquifers.

Evidence of the integration of karst aquifers through mine excavation is visible in many of the region's abandoned cement mines. One of the best examples of natural caves intersected by mining operations is preserved in the Kingston–Delaware Mine, a portion of which underlies Hasbrouck Park in Kingston. A natural cave stemming from the Kingston–Delaware Mine was used to ventilate a large mushroom plantation. Other karst features visible in mines include the undersides of sinkholes that required additional support of mine ceilings, dissolutionally enlarged ceiling joints infilled with glacial sediments, streams flowing through mines, and massive water infiltration through the epikarst and mine ceilings coincident with rain and snow melt events.

Karst-forming stratigraphic units in the Kingston–Rosendale aquifer system characterized by massively bedded and relatively pure limestone or dolostone make up a hydrologic unit known for excellent cave-forming character and are referred to here as the Primary Karst Aquifer (for example, Rondout, Manlius, Coeymans Formations: Figure 1). While little of the Onondaga Formation lies within The Landing project area, it is also known for its excellent cave-forming character. The Secondary Karst Aquifer comprises carbonate units with shaly interbeds that are unlikely to develop conduits as large as those in the Primary Karst Aquifer and are more likely to stratigraphically confine aquifer development (for example, Kalkberg and New Scotland Formations). Extensive faulting, folding, and fracturing present here in the southern terminus of the Hudson Valley fold-thrust belt (Marshak 1990) effectively results in both karst aquifers functioning as one hydrologic unit. Primary and secondary karst aquifers are bounded by predominately clastic sedimentary strata that hydrologically separate these aquifers (for example, Esopus Shale and various sandstone, wackestone, and conglomerate units).

The proposed Landing project area (Figure 1) is underlain by a sequence of strongly deformed sedimentary rocks that include several of the karst-forming units of the Kingston–Rosendale karst aquifer system, including the Rondout, Manlius, and Coeymans Formations. These carbonate units are bounded by relatively impermeable clastic rocks to the east and west (Figure 1). For this reason, deep groundwater flow in the project area occurs parallel to the strike of the karst-forming units. The strike-parallel flow of groundwater is well documented in deformed strata. For example, Rubin and Lemiszki (1992) document strike-parallel karst development and groundwater flow in the vicinity of Oak Ridge, Tennessee, in a geologic setting that is very similar to that of the proposed Landing project area. Fluorescein tracer analysis of groundwater flow paths, conducted by HydroQuest in the Primary Karst Aquifer immediately south of the proposed project site clearly illustrate a southerly, strike-parallel, groundwater flow direction.

The Complexities of Karst in Ulster County

Karst and cave development in the central Hudson Valley, and more specifically in the Ulster County Karst Aquifer Region, has long been a subject of interest among geologists and hydrologists (Darton 1894, Board of Water Supply 1910, Berkey 1911, Matson and Waines 1985, Rubin 1987 1991 1995, Nardacci 1991, Rubin and Privitera 1997, Folsom 2003). Caves in this region have attracted the attention of National Speleological Society members and resulted in several published articles. Among the region's better known cave systems is the Surprise Cave system in Westbrookville, south of Ellenville, which contains a complex cave with a mapped length of over 3 kilometers. Numerous other caves are documented in the region. An excellent synthesis of known caves both north and south of Kingston is presented in Nardacci (1991), which includes a map and description of Salamander Cave. This locality is a short distance south of the proposed project site and occurs in the same belt of carbonate rocks as the Primary and Secondary aquifers near Kingston. In addition, caves immediately south of the proposed Landing project area are discussed by Rubin and Privitera (1997).

Pompeys Cave, located southwest of the Town of Rosendale in the Ulster County Karst Aquifer Region, is perhaps the best known cave system in the Kingston–Rosendale aquifer system (Figure 2). In an example of the type of karst investigation necessary for the development of sound resource management decisions, Folsom (2003) described the hydrology of the 1,600 meter Pompeys Cave system through geologic mapping, cave surveys, tracer analysis, and GIS analyses. Folsom (2003) also examined the dry streambed superjacent to the main cave system, which acts as an overflow for the creek in times of flood. Fluorescein was injected into numerous locations where the Kripplebush Creek flows into the karst aquifer to document groundwater flow routes through the cave system. Fluorescein tracer was then observed discharging in three spring resurgences prior to flowing into the Rondout Creek. The Pompeys Cave system is a classic karst setting that is ideal for educational, scientific, and recreational purposes. At this time, the Northeastern Cave Conservancy is negotiating with the land owner to purchase and protect the cave, the overlying and seasonally dry streambed, and groundwater resources.

The karst hydrology of the Pompeys Cave system differs from that of the proposed Landing site in that the orientation of cave passages and groundwater flow is not controlled by steeply dipping carbonate beds sandwiched between relatively impermeable clastic rocks. Instead, preliminary analysis indicates that much of Pompeys Cave is developing along the strike of a thrust fault, while other portions of the cave system are developing along dissolutionally enlarged fractures graded to a stream base level. The moderate dip of the Manlius Formation within Pompeys Cave has not significantly influenced the groundwater flow route, as is common in the dipping carbonates beneath the Landing site.

Much like a surface stream, discharge along the underground portion of Kripplebush Creek within Pompeys Cave is highly variable and responds rapidly to rainfall and snow melt events. Flow through the Pompeys Cave system is so rapid that it has none of the ability to cleanse contaminants that is commonly associated with slow, non-turbulent, groundwater flow through sediment or narrow bedrock fractures. For this reason, groundwater flow through Pompeys Cave is extremely vulnerable to contamination associated with development anywhere within the catchment basin that recharges this system.

The karst hydrology of the Ulster County karst aquifer region is further complicated by mines excavated into the carbonate units of the Primary Karst Aquifer during the 19th and early 20th centuries . While more than 50 historic cement mines have been explored and documented within the Ulster County Karst Aquifer Region, the entrances to many more have either been sealed and are impossible to enter or are lost and forgotten. These mines disrupt and unnaturally integrate pre-existing karst aquifers. Few historic maps of the mines remain, hindering attempts to assess the true extent of unnatural karst aquifer integration.

The unnatural integration of groundwater flow routes in the Kingston–Rosendale karst aquifer system has, in places, resulted in vast underground reservoirs. These groundwater reservoirs represent valuable, untapped resources that must be protected in anticipation of increased future demand. The extremely rapid nature of groundwater flow through the Kingston–Rosendale aquifer system adds to the hydrologic vulnerability of this system. As with the Pompeys Cave example, little natural cleansing occurs as groundwater flows through this system. Thus, groundwater protection via land use management should be conducted with a comprehensive understanding of these important groundwater resources.

The importance of understanding the complexities of the Kingston–Rosendale karst aquifer system in regards to water quality management is highlighted in a 1996 hydrograph (Figure 3) of water level fluctuations on the western lake within the Kingston–Delaware Mine (Rubin and Privitera 1997). The western lake is an underground flooded

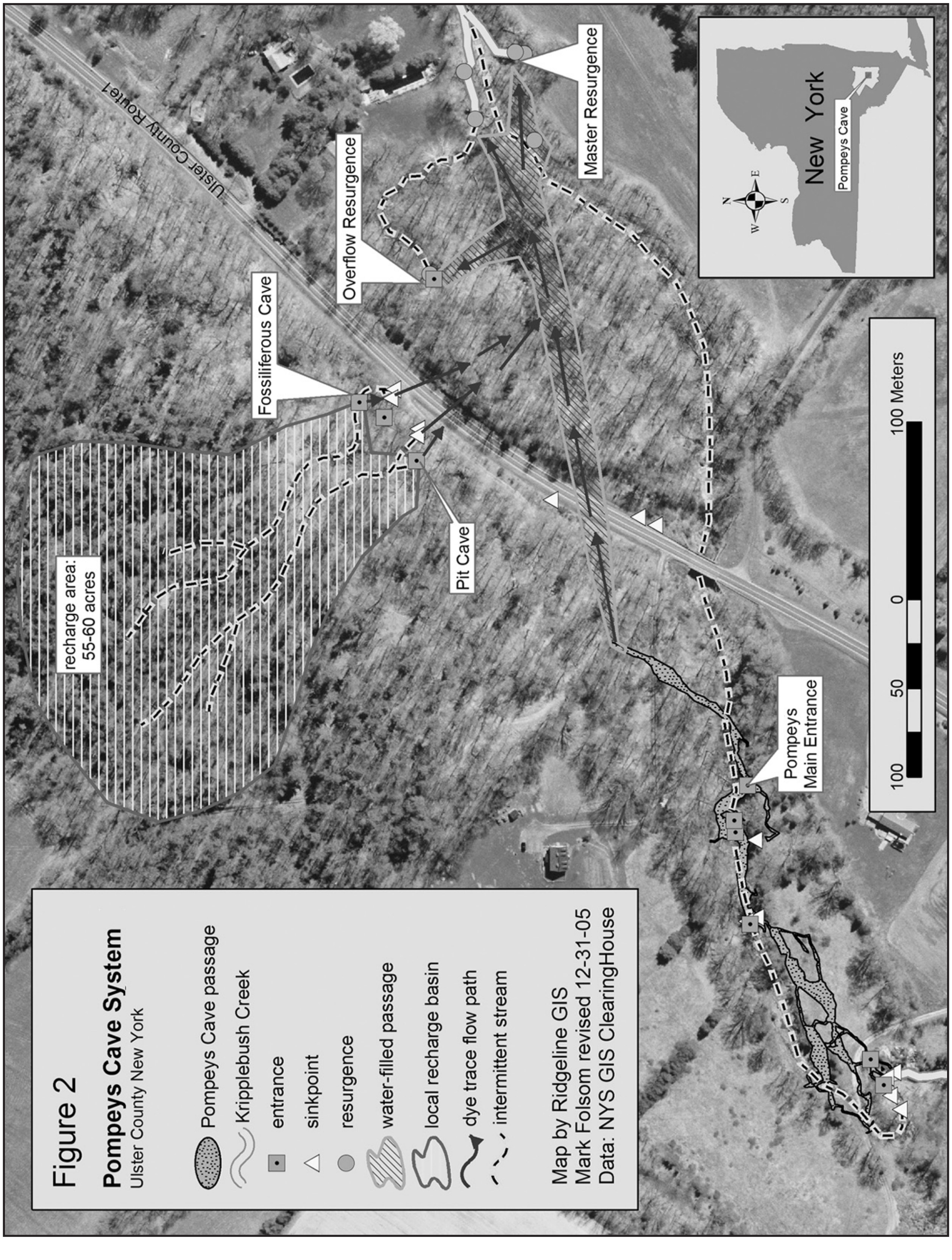

Figure 2
Pompeys Cave System
Ulster County New York
Pompeys Cave passage
Kripplebush Creek
entrance
sinkpoint
resurgence
water-filled passage
local recharge basin
dye trace flow path
intermittent stream
Map by Ridgeline GIS
Mark Folsom revised 12-31-05
Data: NYS GIS ClearingHouse
recharge area:
55-60 acres
Pit Cave
Fossiliferous Cave
Overflow Resurgence
Master Resurgence
Ulster County Route1
Pompeys
Main Entrance
100 50 0 100 Meters
New York
Pompeys Cave
N
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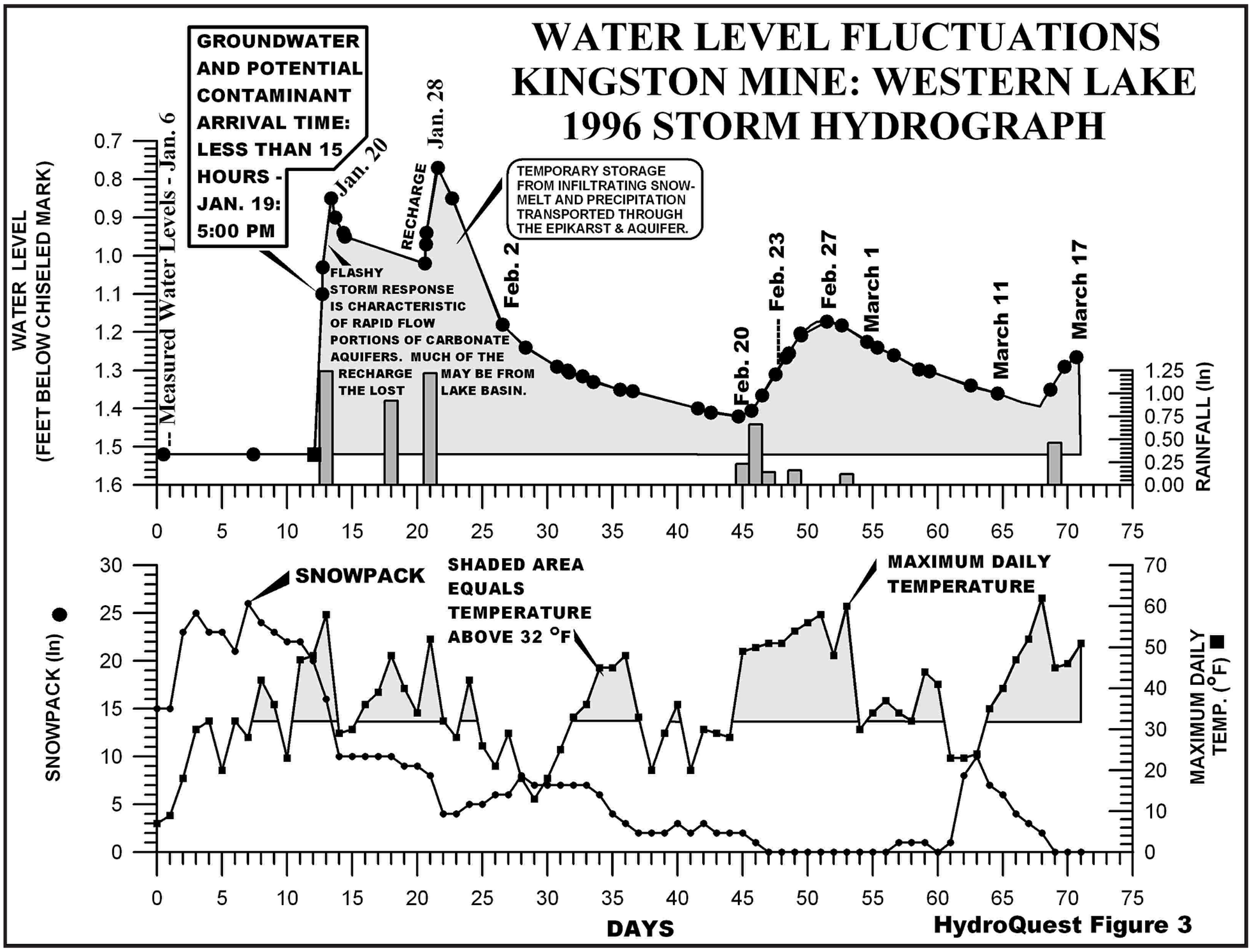
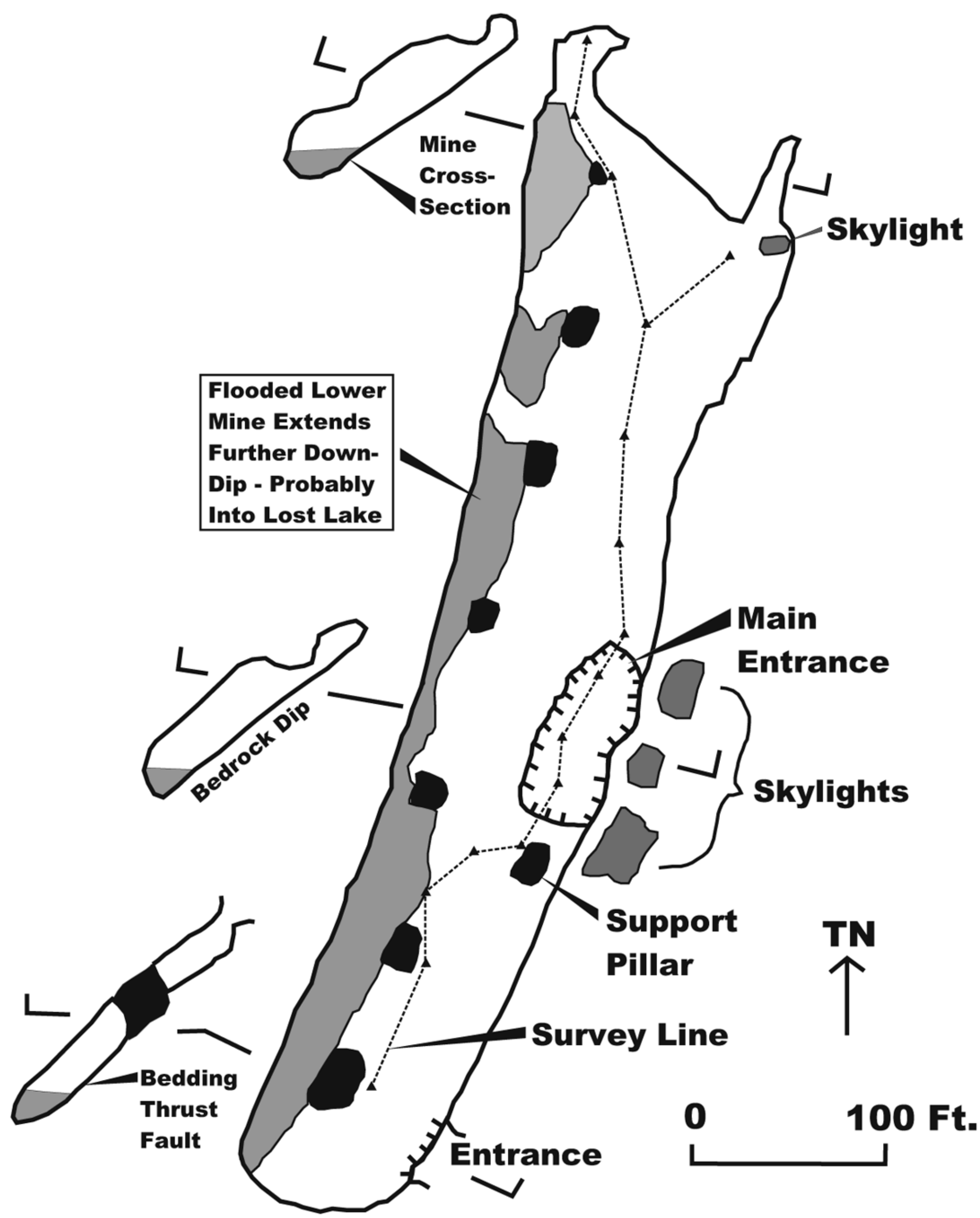


portion of the Kingston–Delaware Mine that intersects strata in the karst aquifer. Rapid changes in the lake level of the western lake in response to storm water infiltration were recently measured as part of a study of the Kingston–Rosendale karst aquifer system (Rubin and Privitera 1997). The results of this study document several key points: (1) rising and falling of lake levels in response to storm events documents rapid groundwater infiltration, flow, and discharge throughout the active karst aquifer system, (2) the amount of water required to significantly raise and maintain the western lake surface (of greater than 0.6 acres) in the mine requires a large recharge area, and (3) the groundwater recharge zone capable of maintaining measured lake levels of 0.23 meters (0.75 feet.) must lie north of the Kingston–Delaware Mine lake (Rubin and Privitera 1997). The extremely flashy or rapid rise in the level of the western lake (less than 15 hours: Figure 3) documents the aquifer's nearly immediate response to infiltration and, thus the extremely vulnerable nature of the aquifer and mine reservoir should contaminants enter the system from the recharge basin. Rubin and Privitera (1997) conclude that changes in the Kingston–Delaware Mine lake levels are characteristic of rapid flow portions of carbonate aquifers (that is, turbulent flow through solution conduits) and suggested that the recharge zone for this subterranean lake lies to the north, inclusive of the Lost Lake basin area.

Lost Lake Hydrology

The Lost Lake mine, a historic cement mine located within the Lost Lake basin, was recently mapped in the region immediately east of Lost Lake (Figures 1 and 4). The Lost Lake mine is a typical room-and-pillar style mine excavated into the steeply west-dipping and faulted strata of the Rondout Formation. The lowest levels of the Lost Lake mine are flooded and may be directly connected with Lost Lake. It is also possible that flooded portions of Lost Lake mine extend along strike far to the south-southwest towards the Kingston–



LOST LAKE MINE: SKETCH MAP **Fig. 4**

Delaware Mine.

Lost Lake is a roughly 1.8-hectare (4.5-acre) closed lake with no surface water outlet. The lake is situated in an abandoned cement quarry (Figure 1). The carbonate strata beneath Lost Lake include the Rondout and Manlius Formations of the Primary Karst Aquifer in the Kingston–Rosendale karst aquifer system. Units of the Primary Karst Aquifer at Lost Lake are bounded to the east (down section) by the Lake Ordovician greywacke and shale of the Martinsburg Formation and to the west (up section) by units of the Secondary Karst Aquifer, including the Kalkberg and New Scotland Formations. Immediately west of the northern terminus of Lost Lake, shales are thrust against steeply upturned carbonate beds. Fault breccia, veins, mineralization, and slickensides are present at the contact. Detailed geologic mapping of this shale unit would clarify how these relatively impermeable rocks affect the aquifer boundary north of Lost Lake.

In addition, strata exposed at Lost Lake are folded in a broad syncline, which is exposed in the face of a cliff along the southern margin of the lake. This syncline, as with others along the eastern margin of the carbonate belt near Kingston, is likely a thrust-fault related fold and, therefore, is associated with a complex array of faults and fractures (Burmeister 2005). Thus, meteoric waters infiltrating through the abandoned Lost Lake mine, sinkholes. and dissolutionally enlarged fractures in the deeply eroded epikarst will flow southward, parallel to the strike of strata in the Primary Karst Aquifer and the network of faults and fractures it contains.

Lost Lake receives recharge from a 1 km^2 (0.45 mi^2) catchment that drains directly into the Lost Lake Aquifer, a portion of the regional Kingston–Rosendale karst aquifer system (Figure 1). The extent of the Lost Lake watershed boundaries were determined using topographic data, digital elevation data, high resolution photo imagery, and limited field reconnaissance. Additional field reconnaissance, particularly in quarried areas would resolve the northwest boundary. The minimum vertical elevation between the surface of Lost Lake and the lowest watershed divide is on the order of 25 meters.

Surface water entering Lost Lake flows over both carbonate and clastic sedimentary rocks and is ultimately pirated into the karst aquifer. Flow measurements recently collected by HydroQuest suggest that as much as 10 million gallons of surface water per day (15 cfs; 37,000 m^3/day) flows into Lost Lake and into the underlying karst aquifer. During periods of high runoff, the water level of Lost Lake increases up to 0.75 meters, only to return to its former level over a short period of time. However, groundwater flow paths down gradient from the Lost Lake recharge zone remain unresolved. Similarly, it is unclear what receptors potentially receive water from the Lost Lake region (for example, streams, springs, wells, etc.).

In contrast to the relatively shallow Pompeys Cave system, the groundwater flow paths that extend from the Lost Lake recharge zone are likely long and deep. In the Kingston–Delaware Mine, cave divers documented the depth of flooded, vertically-bedded portions of the eastern lake section as being in excess of 100 meters. The observed depth of the Kingston–Delaware Mine is well below the surface level of the nearby Hudson River (Figure 1). These deep flow paths almost certainly follow a combination of natural conduits in strongly deformed carbonate rocks and historic cement mines. At a minimum, it is likely that groundwater flow paths stemming from Lost Lake are hydrologically connected to flooded portions of the Kingston–Delaware Mine, the Hasbrouck Mine, a surface stream, and possibly Marys Well, which is a spring used for drinking by many Kingston area residents. Thus, the implications for the introduction of development-related contaminants within the Lost Lake catchment are considerable.

What is clear, however, is that waters within the Kingston–Rosendale karst aquifer system represent a considerable groundwater resource. Studies of groundwater yield associated with an historic mushroom operation in the Kingston–Delaware Mine (Figure 1) indicated that groundwater in excess of one million gallons per day may be available for consumption. Tracer dilution testing documented a western lake volume on the order of 80,000,000 gallons (Knaust pers. comm.). Standard tracer analysis (that is, ASTM D-5717-95; ASTM, 1995) of waters recharging the karst aquifer system at Lost Lake would do much to both delineate complex local and regional groundwater flow paths and to identify potential contaminant receptors.

Groundwater Contaminant Risk and the Need for Karst Aquifer Protection

A portion of the proposed Landing project site is underlain by a karst aquifer. The hydrogeology of the site and the potential environmental impacts of directly introducing development-related contaminants into a hypersensitive aquifer (according to the classification of Quinlan *et al*., 1992) are not addressed in the project Draft Generic Environmental Impact Statement. Karst aquifers are extremely vulnerable to contamination as contaminants move rapidly (sometimes at rates of kilometers per hour) and without any natural cleansing (Ford and Williams, 1989). Storm water discharges, pesticides, herbicides and spills incident to karst aquifers can degrade groundwater aquifers and reservoirs within hours or days. Groundwater resource contamination, monitoring strategies, and land use planning concerns specific to karst aquifers are areas of active research (for example, ASTM 1995, Beck 1993 1995, Beck and Wilson 1987, Quinlan 1989, Rubin 1992, Quinlan *et al*. 1992, and references therein). As a result of these concerns, the U.S. Environmental Protection Agency actively supports remedial investigations, strategy development, and conferences devoted to better understanding karst aquifers.

The American Society for Testing and Materials *Standard guide for the design of ground-water monitoring systems in karst and fractured-rock aquifers* (1995) was developed with funding from the U.S. Environmental Protection Agency in response to the need for a method to characterize karst aquifer systems and their groundwater flow paths. Unless the project Applicant can avoid development over the recharge basin tributary to Lost Lake, a standard engineering tracer investigation should be conducted [ASTM D 5717-95] designed to determine groundwater flow directions, destinations, and velocities within the karst groundwater basin. Similarly, plans to develop the proposed Landing project above a major karst aquifer should be predicated on knowledge of baseline groundwater chemistry, knowledge of the aquifer system, an assessment of likely contaminant inputs, and chemical loading calculations designed to determine the aquifer's ability to assimilate contaminants (Rubin 1992). Clearly, development and potential contaminant influx to an important groundwater flow and aquifer system should not be permitted with no knowledge whatsoever as to where contaminants might go or what they might contaminate.

Storm water runoff containing development-related contaminants is a threat to the water quality in karst aquifer systems. Hydrocarbon contamination is particularly serious in karst aquifers, as the likelihood of successful remediation is poor. Recker (1992) found that hydrocarbons stemming from a gasoline spill remain in the fractured epikarst and become a continuing source of groundwater contamination. Gasoline fumes associated with a similar contaminant event in a Bowling Green, Kentucky, karst aquifer seeped into overlying buildings. Ewers *et al.* (1992) document that hydrocarbon transport in the turbulent flow of karst conduits occurs as globules of entrained free product as well as a dissolved phase and can move at nearly the velocity of water. Ewers *et al*. (1992) further illustrate that once turbulent flow regimes become laminar (that is, slow moving), concentrated hydrocarbons separate from water and can collect or be trapped in high points along the conduit ceiling. In terms of the proposed Landing project, contaminants that flow into Lost Lake and the Lost Lake Aquifer are likely to concentrate both on the surface of mine lakes and throughout the aquifer. Based on the results of multi-tracer investigations of diffuse or conduit flow in karst aquifers, Quinlan and Ray (1992) concluded that successful remediation of contamination in most karst aquifer systems would be nearly impossible. The risk of contaminating the groundwaters of New York State under and down gradient from the proposed Landing project development site is great.

Karst Resource Management: Why Protect Ulster County's Karst Aquifers?

The population density in Ulster and surrounding counties is rapidly increasing. In response, the demand for clean, potable, water is also increasing. It is critical that available water resources are identified and protected for current and future use. Water resources in Ulster County's karst aquifer systems require particularly sound protection and management programs. These resources include underground mine reservoirs, including those associated with abandoned cement mines, and their aquifer recharge areas. When possible, remediation of contaminated water supplies can cost municipalities millions of dollars. To avoid this unnecessary and prohibitive expense, community planners must have the foresight to protect groundwater resources from contamination. Potential contaminants include storm water runoff chemicals (for example, hydrocarbons, pesticides, herbicides, deicing agents, septic wastes, and agricultural and industrial contaminants.)

Testing some decades ago in the Kingston–Delaware Mine indicates that groundwater in excess of one million gallons per day may be available for consumption. This groundwater represents an important, marketable, source of potential revenue.

Steps in Protecting and Managing Ulster County Karst Aquifers

The first steps in protecting the critical water reserves in the Karst Aquifer Region are to inventory karst features, characterize karst aquifers, and delineate aquifer recharge areas. Maps and information regarding karst aquifers and their recharge basins should be compiled in a comprehensive Geographic Information System (GIS) database that is actively maintained and easily accessible by all parties involved in land use planning. The proper development of quality Ulster County karst aquifer maps suitable for land use planning purposes must include data regarding the locations and survey maps of caves and abandoned cement mines, an inventory of important karst features (for example, sinkholes, sinking streams, caves, springs, and mines in Ulster County), detailed boundaries of significant karst aquifers based on geologic mapping (Burmeister 2005, Marshak 1990, Leeds 1989) and data collected through field observations and tracer analyses.

Conclusions and Recommendations

To protect groundwater resources, the potential risks to aquifer systems must be fully considered when planning developments. The need for careful planning and water quality protection programs is particularly important when developing in hydrologically sensitive areas like those above karst terranes, where groundwater flow is rapid and contaminant remediation is generally impossible. For these reasons, recharge zones for karst aquifer systems must be identified and actively protected by developers and community planning organizations. In general, considerations for developing in karst regions should be based upon (1) identification and hydrogeologic characterization of regional karst aquifers (for example, via ASTM D 5717-95), (2) assessment of the vulnerability of karst aquifer systems to pollutants, and (3) the design and implementation of programs to protect underlying karst aquifers.

Currently, the environmental impact assessment for the proposed Landing project does not recognize that portions of the proposed site overlie the recharge zone for the Lost Lake karst aquifer, which is hydrologically interconnected with a much broader, regional karst aquifer system. Similarly, the current Draft Generic Environmental Impact Statement for *The Landing* project contains none of the groundwater flow maps, baseline groundwater chemistry data, potential incident contaminant loading assessments, or contaminant assimilation assessments that are critical for evaluating and protecting the underlying karst aquifer system. More significantly, the current Draft Generic Environmental Impact Statement fails to note the presence of at least one historic cement mine within the proposed project area, which further complicates the hydrology of the local karst aquifer system and greatly increases the potential risks to the groundwater it contains. In addition to their hydrological significance, these historic mines should also be recognized as potential Indiana Bat (*Myotis sodalis*) hibernacula. Clearly, the hydrology of the Lost Lake recharge zone requires additional study as part of the Draft Generic Environmental Impact Statement process before development can proceed. Development within the Lost Lake recharge zone may jeopardize water quality of a currently unutilized, high-yield, groundwater resource that may prove to be an important resource for the City of Kingston.

The City of Kingston Planning Board and Kingston Landing Development, LLC, have two options for protecting the quality of groundwater in the karst aquifer underlying the proposed Landing project site and in the spring(s) and stream(s) where this aquifer discharges. The first option would involve adjusting development boundaries to avoid overlap with the Lost Lake recharge zone and minimize all potential contaminant inputs through a no development approach. The second option requires a thorough study of the karst hydrogeology both within and beyond the project area prior to development of the recharge zone. The complex nature of the Kingston–Rosendale aquifer system makes it very important to delineate groundwater flow paths and potential contaminant receptors via standard tracer techniques (that is, ASTM D-5717-95) prior to development. Thus, development of the Landing site should be conducted according to the Open Space Advisory Committee's proposal to include karst aquifer watershed protection in the New York State Open Space Conservation Plan.

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