

RECOMMENDATIONS FOR FUTURE HYDROGEOLOGIC INVESTIGATIONS

The Water Resources Authority of Jamaica (WRAJ) under the instruction of the Ministry of Water, Jamaica is the organization responsible for water resource management on the island of Jamaica. The management of these ground-water basins involves transmitting and storing varying portions of the area's water supply by coordinating aquifer functions with surface facilities, e.g. reservoirs and pipelines, to meet the water requirements of the area. Water management and resource planning of the Rio Cobre and Rio Minhó-Milk river basins should be optimally designed to use these elements to satisfy the physical demand for water. Transmission characteristics, fresh ground-water storage, and the basin's storage capacity are significant elements of ground-water basins and water management resources. The results of this modeling study indicate that both the alluvial and White Limestone aquifers in these basins: 1) are hydraulically interdependent, 2) are recharged by common sources, and 3) have different K_x/K_z ratios, and 4) should be incorporated into a single water resources management plan.

The results of this modeling study should be used as a guide to the conceptual understanding of the ground-water surface interaction of the Rio Cobre and Rio Minhó-Milk river basins. Future applications of this model depend on its ability to describe the hydraulic behavior of the Rio Cobre and Rio Minhó-Milk River basins. The understanding of the hydrogeologic system was improved substantially after construction and analysis of the ground-water flow model. This approach should not be considered unique or a final tool for interpretation of any hydrogeologic analysis that may follow.

Models are representations useful for guiding further study (Oreskes et al., 1994). Modeling results may be used to indicate where additional data are needed to improve predictions and strengthen conclusions or recommendations to authorities on water resources management issues. The model itself can be utilized as a prediction tool to simulate alternative remedial actions and assist in the long range management of the region's water resources and increased agricultural acreage in the Rio Cobre and Rio Minho-Milk river basins. Further investigation into the ground-water flow of the region is required for ongoing improvement of future water resources decisions. The following is a discussion with suggestions for the WRAJ to improve the water resources management of the Rio Cobre and Rio Minho-Milk river basins from 2000 through 2015.

Well Monitoring and Measuring Hydraulic Head

Despite the regional scale of the ground-water model and its inability to accurately simulate the local variations that exist within the physiographic region, the recorded 1998 measurements of hydraulic head data suggest the need to enforce an active well monitoring program. This well monitoring program should include (1) accurate measurement of hydraulic head, (2) frequent specific-capacity tests for the computation of aquifer transmissivity, (3) the construction of karst well hydrographs to determine hydraulic properties of the near surface karst region of the White Limestone aquifer, and (4) and the construction of potentiometric surface maps. Maps constructed to show changes in the water table gradient on a regular basis can be extremely helpful for water resources management decisions affecting the region by documenting long-term trends. This task needs to be implemented by the WRAJ.

Patterns and Schedule of Pumpage from Wells

Regulated pumping may be used to control the current extraction and distribution pattern of wells in the basins to avoid further contamination from saline intrusion in the Rio Cobre and Rio Minho-Milk river basins. A well system capable of creating a 'capture zone' of the appropriate size, by the addition of wells constructed parallel to the coast, may be used to remove the saltwater contamination and maintain a seaward hydraulic gradient in the Rio Cobre and Rio Minho-Milk river basins. An analytical approach to the design of this well system involves determining the minimum number of injection wells, optimal pumping rates, and the optimum spacing between the wells to limit water level declines in the in order to halt the landward migration of seawater (Javandel and Tsang, 1986). Basin outflow may be intercepted by locating the production wells in the Rio Cobre and Rio Minho-Milk river basins to salvage additional water that would otherwise discharge to sea. Systematic redistribution of basin-wide pumping can create favorable gradients that would increase the capability for additional recharge for the Rio Cobre and Rio Minho-Milk river basins. There needs to be modification of the current basin-pumping pattern. This would require the relocation of wells currently located near the coast to areas near faults inland from the SCFZ and in the highland regions, and would also require the import of additional water via canals used to divert flow from rivers in adjoining basins.

Sediment Compaction and Land Subsidence

Subsidence is a critical matter in the management of ground-water reservoirs. Excessive pumping stress from ground-water pumpage lowers the roof of an aquifer by

impacting pressure and the compaction of fine-grained sediment. Lowering of ground-water levels in the Rio Cobre and Rio Minhó-Milk river basins below the original land surface elevation could result in significant consolidation of deposits and result in land subsidence in the area, especially in the alluvial regions. Poland (1981) observed subsidence of the land surface in several locations around the world. No previous study has investigated the extent of sediment compaction and land subsidence in Rio Cobre and Rio Minhó-Milk river basins or even on the island of Jamaica. It is highly recommended that the WRAJ or individuals involved in ground-water resource management become aware of the types, cause, areal extent, magnitude, and chronology of the damage resulting from pumping and subsequent subsidence.

Determination of Transmissivity

The transmissivity (T) of carbonate aquifers is the most important parameter to estimate because each component of a multipurpose aquifer system (conduit, fracture, and matrix) contributes different magnitudes of flow, transport, and storage (Shevenell and Goldstrand, 1997). In the well-developed karst region of the White Limestone aquifer Rio Cobre and Rio Minhó-Milk river basins, water levels influence related spring discharges (Bonacci, 1993). The near surface karst regions of the aquifer include shallow submerged conduit systems located in areas with sufficient rainfall for water levels to respond to precipitation events (Walters, 1981; White, 1980). These characteristics represent favorable conditions for using karst well-hydrographs recessions to determine the hydraulic properties of the aquifer. Powers and Shevenell (1993) observed a close agreement exists between transmissivity (T) values calculated using karst-hydrograph recessions and those computed from traditional hydraulic parameter estimation

techniques such as specific-capacity tests in matrix-dominated wells. It is highly recommendable that the WRAJ adopt this procedure for a more accurate analysis of karst hydraulic parameters. This is significant for future hydrologic investigations of the region.

Determination of Streambed Vertical Hydraulic Conductivity

There were no data available on streambed vertical hydraulic conductivity, therefore, simulated values of the streambed hydraulic conductivity is within the range of reported values for unconsolidated stream sediments. The results of this ground-water study indicate that stream conductance is the same in all river reaches within the basins. The model shows only slight sensitivity to changes in the streambed vertical hydraulic conductivity values. Permeameter testing should be done on samples of streambed sediments from the reaches in the Rio Cobre and Rio Minho-Milk river basins should be conducted in the laboratory to estimate the hydraulic conductivities. This extremely important for future modeling studies conducted for the region.

Recharge Operations

Ground-water modeling techniques used in this study may be used to define a suitable recharge pattern for the areal extent of the Rio Cobre and Rio Minho-Milk river basins. The hydrologic budget accounts for returns to and losses from the basins; therefore the pattern and dependence of recharge can be defined to meet this need for ground-water. The results of this modeling study indicate that the White Limestone aquifer is recharged not only from areal precipitation, but also from subsurface inflow along the northern boundary of the study region. The question is what are the possible factors contributing to this subsurface inflow? It is possible that this may result from: 1) the hydraulic gradient along the topographic high above the boundary, 2) streams recharging the area from the adjoining area, 3) structural downthrow of blocks, possibly along E-W striking faults in the adjoining basin to the north, may be facilitating this inflow southward across the upper boundary of the study area. Investigations into these factors would provide interesting findings on the impact on the ground-water flow regime of the region.

Possible new alternative freshwater resources for the Rio Cobre and Rio Minho-Milk river basins are offshore extensions of deep confined sections in the White Limestone aquifer located in coastal regions. The WRAJ should launch an investigation into these offshore extensions of the White Limestone aquifer since the possibility exists that there may be a vast amount of fresh water stored in these areas (Johnston et al., 1982). The WRAJ has considered the import of ground-water into the Rio Cobre and Rio Minho-Milk river basins; therefore, the impetus should be adequate ground-water storage for

future use. A cost-benefit may be derived from storing or banking imported water in inland reservoirs.

Precipitation and Evapotranspiration

Evapotranspiration has been estimated by the WRAJ to be 69-70% of the total precipitation that falls in the basins. Evapotranspiration was not simulated explicitly in the model, but there needs to be a system of recording transpiration in the Rio Cobre and Rio Minho-Milk river basins. Rain gauges limit the extent to which spatially-averaged rainfall is measured over areas, especially those of higher elevations and rugged terrain like the upper Rio Cobre and Rio Minho-Milk river basins. Remote sensing by satellite combined with conventional rain gauge data provide a suitable alternative for quantifying the precipitation input over these basins, especially in areas where there are no or few rain gauges. Although remote sensing cannot measure evapotranspiration directly, remotely sensed measurements methods may be used for extending empirical evapotranspiration relationships in much larger areas (Jensen et al., 1986).

Geophysical Exploration of the Rio Minho-Milk River Basin

Previous geophysical work in the Rio Cobre and Rio Minho-Milk river basins involved gravity studies of the Innswood area of the Rio Cobre and the Vere Plains of Lower Rio Minho basins. The application of powerful geophysical methods like electrical resistivity, ground penetrating radar (GPR), seismic refraction, and seismic reflection are encouraged for the improvement of the water resources management of the region. Gravity gradients across the Vere Plains, in addition to the results of this modeling study,

indicate that the South Coast fault impacts the hydraulic gradient of the Rio Minho-Milk river basins. A critical region of interest observed in this modeling study is the high contrast in horizontal and vertical hydraulic conductivity observed in the White Limestone aquifer (482 m/d) in the lower Rio Minho-Milk river basins. This area is an extremely permeable, ancient carbonate platform of rubbly and nodular limestone traversed by the transcurrent South Coast fault. The South Coast fault lies parallel to the coast, crosses the Vere Plains and ends abruptly, east of the Braziletto Mountains (Figure 3.15). The South Coast fault impacts: 1) the ground-water flow of the Rio Minho-Milk river basin, 2) the flow of ground-water occurring perpendicular to the fault, and 3) the migration of saline ions across the fault to the lower Rio Minho-Milk river basin (Mullings, 1993). An electrical resistivity survey should be performed to detect changes caused by the presence of ground-water plumes with elevated salinity in the Rio Cobre and Rio Minho-Milk river basins. In addition to the South Coast Fault are numerous reverse faults that transect the Rio Minho-Milk river basins. These faults may be significantly impacting the ground-water flow regime in the Rio Cobre and Rio Minho-Milk river basins. Therefore, it would be very useful to design Dual Porosity (DP) models to simulate ground-water flow through these fractures. The model works by simulating flow through the fractures and is accompanied by exchange of water and solute to and from the surrounding porous rock matrix. With the exception of conduit flow in karst, fracture flow models assume both fracture apertures and flow velocities are small so that Darcy's Law is applicable. Aquifer tests may indicate whether a particular system behaves as a dual porosity system so that results can be interpreted to estimate hydraulic conductivities (e.g. Streltsova-Adams, 1978)

The areal extent of the Red Marine Clay throughout the Rio Cobre and Rio Minho-Milk river basins is unknown. This unit is discontinuous throughout areas of the basins. Knowledge of the areal extent of the unit is an important consideration for effect of vertical leakance between the alluvial and White Limestone aquifer and the understanding the hydraulic connection between both units. A seismic reflection and refraction study would be very helpful in determining the continuity and extent of the Red Marine Clay confining unit that separates the upper alluvial and underlying White Limestone aquifer which helps to control vertical flow between the alluvial and White Limestone aquifers.

Another area of critical interest is the configuration of the water table in the Rio Cobre and Rio Minho-Milk river basins. Calibrated results of this modeling study reveal discrepancies with the manner in which water level data are recorded in some areas of the basin. Forty-six well observation points were chosen for the calibration of the model, based on confidence in what was felt to represent a general surface of the water table. Errors in recorded datum for reference points and the water levels are probably the main cause for the lack of calibration of these observation points. All monitoring wells should be accurately surveyed to assure accurate water-level measurements.