

# INSTITUTO DE ACUEDUCTOS Y ALCANTARILLADOS NACIONALES DE PANAMA (IDAAN)

*Presented to:* Ingeniera Julia Elena Guardia,  
Directora Ejecutiva, IDAAN



**Proposal #1050**

**November 2015**

**EMERY & GARRETT GROUNDWATER INVESTIGATIONS, LLC**

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Example of satellite image draped over shaded relief DEM data.

# COVER LETTER

# ***Emery & Garrett Groundwater Investigations, LLC***

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November 11, 2015

Ingeniera Julia Elena Guardia  
Directora Ejecutiva  
IDAAN  
Edificio Sede, Via Brasil  
Ciudad de Panama  
Republica de Panama

**Re: INSTITUTO DE ACUEDUCTOS Y ALCANTARILLADOS NACIONALES DE  
PANAMA (IDAAN) – PROPOSAL NO. 1050**

Dear Directora Ejecutiva Julia Elena Guardia,

In response to your invitation, Emery & Garrett Groundwater Investigations (EGGI) is pleased to submit this technical proposal to conduct a Nationwide Groundwater Resources Assessment for the Republic of Panama. The enclosed document includes a description of the requested groundwater services and information describing our corporate capabilities relative to assessing the potential availability of groundwater resources throughout Panama.

## **Unique and Critical Opportunity for Panama -- Considerable Technical Challenge**

The opportunity to accurately assess *all* of Panama's groundwater resources – including identifying *new* groundwater supplies that have never before been considered – presents a unique and critical opportunity for the Country, and one which Panama cannot afford to miss. Understanding the availability of water resources (and particularly groundwater resources) is a key mandate that was set forth in Panama's National Plan of Integrated Resources (2010-2030). The current drought that Panama is experiencing creates an even greater critical level of need to more fully understand groundwater resources on a National scale.

Given the difficult and hydrogeologically complex nature of the region, accomplishing this goal poses a *considerable technical challenge*. In order to best ensure project success, it is important that Panama work cooperatively and in partnership with a *highly experienced* and *interdisciplinary* groundwater exploration team. Emery & Garrett Groundwater Investigations has a long track record of successfully completing advanced regional groundwater assessments that have *proven* to consistently: (i) identify and map regional and local areas that have a "high" (or substantial) potential for groundwater development; (ii) discover meaningful and *previously undiscovered* groundwater resources; and (iii) lead to the sustainable development of new, high-quality, high-yield groundwater supplies.

We believe that EGGI is the most qualified team for this project and is the "*best*" choice for completing a National Groundwater Resources Assessment for Panama for the following reasons:

## **Project Scope Strongly Correlates with EGGI's Specialized Areas of Expertise**

Both the scope and scale of the Groundwater Resources Assessment for Panama correlates *very well* with EGGI's areas of specialized expertise. While we have proficiency in a wide variety of groundwater-related disciplines, our most differentiated capabilities include (i) groundwater exploration and development within complex hydrogeologic terrains, and (ii) conducting advanced regional groundwater availability assessments across large areas. The Groundwater Resources Assessment for the Panama project integrates EGGI's two core areas of expertise.

## **EGGI is a Specialized and Unique Firm**

Unlike the majority of organizations that perform groundwater services globally, we are *not* an "engineering", "general environmental services", "mineral exploration", or "drilling" company. Instead, as our name implies, we are strictly a professional groundwater services company. Since our founding in 1989, our entire corporate focus has been on the assessment, exploration, development, protection and sustainable management of groundwater resources across a wide variety of complex hydrogeologic settings.

## **Successful Track Record -- Experienced and Respected Groundwater Assessment Experts**

EGGI is widely considered as a highly respected and sought after team of groundwater experts in the United States and has been ***recognized as a leader in advanced groundwater exploration and development internationally***. Our state-of-the-art groundwater exploration science and proprietary tools, developed in-house, provide us with advanced technical expertise and capabilities. We have earned a reputation in the groundwater industry for unraveling very complex hydrogeological problems and providing clear, scientifically-based solutions. On behalf of a diverse mix of public and private sector clients – ***we have successfully completed over 1,500 groundwater investigations and developed over 100 million gallons per day (MGD) of fresh, sustainable groundwater resources.***

To our knowledge, ***no other firm has conducted more successful groundwater exploration and development programs*** in igneous, sedimentary, and metamorphic rocks, limestone regions, and unconsolidated deposits.

## **Interdisciplinary Groundwater Exploration Team**

EGGI's interdisciplinary groundwater exploration team is highly educated and trained in geology, geochemistry, geophysics, hydrology, groundwater modeling, remote sensing, and groundwater hydrogeology, with most members maintaining Masters or Ph.D. degrees in their respective scientific disciplines. One hundred percent (100%) of our ***senior technical staff has worked together as a team on groundwater exploration programs for the past 26+ years, providing over 150 combined years of groundwater exploration experience.***

## **Recognition by Other Professionals**

Over the years, the United States Environmental Protection Agency (EPA), the United States Geological Survey (USGS), the Geologic Society of America (GSA), the National Ground

Water Association (NGWA), and the World Bank have recognized EGGI for providing technical leadership in the field of advanced groundwater exploration and development. We have also been invited to meet, present, and strategize with high level officials<sup>1</sup> at the U.S. Pentagon regarding how we might be able to solve some key military short- and long-term water supply needs at both In-Country and Out-of-Country bases of operation. ***Collectively, our staff has published over 100 recognized scientific professional papers in the field of groundwater exploration.*** Other scientists conducting research in bedrock hydrogeology often reference many of these documents.

### **Blue Chip Client List and Client Satisfaction**

EGGI has successfully provided innovative groundwater services on behalf of a wide variety of public and private clients. Our blue-chip client list ranges from public water authorities, municipal utilities, U.S. Federal agencies, specific Counties, and individual States to private real estate developers and global Fortune 500 companies within the industrial, power, oil and gas, and agriculture sectors.

Existing and prior clients for whom EGGI has conducted groundwater investigations have become our best professional references. We receive, on a regular basis, letters from our clients stating how pleased they are with our work, and ***we do not know of a single client that would choose another groundwater services firm after having worked with us.***

### **Proprietary Groundwater Exploration and Groundwater Assessment Methods**

Since the late 1980s, EGGI's senior team members have developed and continually improved upon a systematic, scientific process of regional *groundwater* resources assessment. This innovative program includes the use of satellite imagery, multiple platforms of aerial photography, digital elevation models, geologic mapping, regional analyses of structural geology, bedrock fracture fabric data, geophysical analyses (including aerial, ground surface, and borehole methods), existing well data, statistical analysis, and in situ hydrogeologic testing, among other tools. Using these techniques, we helped advance the process of exploration and development of groundwater resources (high yielding wells) in fractured crystalline and sedimentary bedrock. Furthermore, we significantly improved traditional methods of groundwater exploration in karst, alluvial, glacial, and coastal plain geologic settings.

Our exploration program's "continual focusing process", from initially large regional study areas down to favorable zones suitable for developing new, sustainable groundwater resources has proven *highly successful* over the years, eliminating the "wildcatting" aspects of groundwater development.

### **Brief Examples of EGGI's Advanced Regional Groundwater Availability Assessments**

We have successfully performed regional groundwater availability assessments, across a wide variety of locations and challenging hydrogeologic terrains, for hundreds of clients, including County Water Authorities, State run organizations, municipalities, large international consortiums, oil and gas operators, and real estate developers. Two specific project examples

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<sup>1</sup> At the senior level of two- and three-star Generals.

include the 10-County region surrounding the City of Atlanta, Georgia, and the entire Country of the Dominican Republic (“DR”).

### ***Greater Atlanta Region***

EGGI evaluated the favorability for new groundwater development in the entire 10-County region surrounding the City of Atlanta, Georgia. EGGI determined what regional areas were favorable (and unfavorable) based upon a detailed evaluation of rock type, geologic setting, presence of major contaminant threats, and other important hydrogeological factors. Land masses in each County<sup>2</sup> that were deemed to be unfavorable for groundwater development were subsequently excluded from further consideration. Each County was then objectively ranked in terms of its overall favorability for new groundwater development. During later phases of investigation, favorable sub-areas within each County were identified for specific groundwater development activities. ***EGGI’s regional investigation determined that over 100 million gallons per day (MGD) of previously undetected renewable groundwater resources could be developed within the 10-County region of Atlanta.*** To date, EGGI has identified nearly 15 MGD of new groundwater resources at site specific locations within three of the ten Counties and continues to consistently identify and sustainably develop *new* groundwater resources throughout the northern Georgia region.

### ***Dominican Republic***

In the Dominican Republic (DR), EGGI evaluated the potential to sustainably develop incremental groundwater resources throughout the entire Country; a study area of roughly 48,000 km<sup>2</sup>. EGGI utilized a numerical model approach to determine which hydrogeologic settings were most favorable for groundwater development and incorporated data sets covering (i) groundwater recharge favorability (including rainfall, aridity, drainage density, etc.) and (ii) hydrogeologic favorability (incorporating bedrock type and structure, nature of unconsolidated deposits, occurrence and trend of remotely sensed lineaments, etc.). A total of 79,857 lineaments were identified as part of this process and were subsequently analyzed using proprietary EGGI software programs. The Regional Groundwater Favorability Model numerically categorized and objectively ranked each and every 100 square meters in the DR relative to that location’s potential to obtain sufficient recharge and potentially produce significant new groundwater resources. The model formed the basis for the creation of both National *and* Province-based Regional ***“Groundwater Development Potential Maps”***, enabling the assessment of relative groundwater resources availability at any given location, anywhere in the Country. Based on the results of the investigation, EGGI is actively working to structure several follow-on groundwater development projects, including a groundwater investigation for the Capital City of Santo Domingo.

### **Project Approach / Purpose of Investigation**

EGGI will conduct the Groundwater Resources Assessment for the entirety of the Republic of Panama in a similar manner to EGGI’s other regional groundwater projects. ***Our proposed investigation would be the most advanced and comprehensive regional groundwater assessment completed to date at this scale in Panama.*** The resulting map products will provide

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<sup>2</sup> Counties ranged in size from 200 square miles to 350 square miles.

critical information needed to prioritize and rank areas and sub-areas within the Country relative to their “*Groundwater Development Potential*” and will help to identify specific areas where additional and more detailed groundwater development efforts should/could be focused. Together with the newly compiled and analyzed data sets, EGGI’s maps can:

- 1) Serve to identify available groundwater resources for future development that have not yet been discovered.
- 2) Support and enhance current and future economic development initiatives.
- 3) Allow the Country to properly plan for population growth and/or population redistribution.
- 4) Help to address and better understand transboundary water rights issues.
- 5) Help reduce the need to build more expensive surface water dams and reservoirs through the potential discovery of substantial new groundwater resources.
- 6) Provide an opportunity for Panama to protect valuable groundwater resource areas for future generations.
- 7) Help protect and ensure the health of its people.

*The availability of groundwater is dependent upon site specific geologic conditions. No one can change the geology or groundwater favorability from one locality to another. However, Panama can alter where future activity may take place through appropriate planning and protection efforts so that groundwater resources might be used to their fullest extent now and into the future. Therefore, establishing an understanding of where all potential groundwater resources can be developed throughout the Country will serve as an outstanding tool for land use and water resource planning/protection for many years to come.*

## **Conclusion**

As you know, we cannot create water where it does not exist. We are confident, however, that applying the approach and advanced techniques proposed herein will provide Panama with the *greatest potential* to identify, and optimally characterize valuable *groundwater resources that remain available throughout the Country*.

If you have any questions regarding this proposal submission, please do not hesitate to contact me.

Best regards,



James M. Emery, P.G.  
Senior Hydrogeologist, President/CEO



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**NATIONWIDE GROUNDWATER RESOURCES ASSESSMENT  
PHASE I**

**REPUBLIC OF PANAMA**

**Proposal No. 1050**

**November 2015**

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# INTRODUCTION

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## **NATIONWIDE GROUNDWATER RESOURCES ASSESSMENT PHASE I**

### **REPUBLIC OF PANAMA**

**Proposal No. 1050**

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### **INTRODUCTION**

The National Plan of Integrated Water Resources of the Republic of Panama 2010-2030 has presented a number of concerns regarding current and future water resources existing within Panama. The Plan calls for a concerted Countrywide effort to address the following:

- To better understand the sustainability of water resources (both groundwater and surface water);
- To better understand the role of water production and development;
- To better understand the relationship between water use and society;
- To assess the vulnerability of water resources and plan for adaptation to climate change; and
- To assess institutional and water governance.

The overall objective of this Plan is to assure that water demands for human consumption, electrical power generation, agriculture, industry, and tourism, etc., can be met in the future, while at the same time protecting the environment and natural habitats of Panama. This objective will become increasingly more difficult to achieve as demands for water resources from the different water use sectors expand and potentially adverse impacts from climate change occur.

Creating a National Plan for Water Resource Management is complicated, in part, by the locally and regionally varying climatic, topographic, geologic, and hydrologic conditions within the Country. Each of these parameters has an impact on the availability of water resources, resulting in a wide variety of hydrogeologic settings throughout the Country. Understanding the potential for developing groundwater resources in each of these hydrogeologic settings is a key component in assessing the Country's overall water resources availability.

As noted in the National Plan of Integrated Water Resources of the Republic of Panama 2010-2030, information concerning groundwater resources is very limited. A 2008 study by

Empresa de Transmision Electrica, SSA (ETESA) provided a regional scale interpretation and map of the aquifer types and potential groundwater productivity of the major geologic units within Panama. Although this study forms the preliminary basis for beginning to understand groundwater resources, it does not provide sufficient detail of information needed to make both regional and *site specific* decisions about groundwater development and management. The sustainable development and protection of future groundwater resources within Panama can only be accomplished by identifying those areas within the Country where the hydrogeologic characteristics are favorable, where there is sufficient recharge to the aquifers (i.e., where high precipitation and infiltration rates exist), where the potential for groundwater contamination is low, and where existing groundwater extractions are not already exhausting the available water resources<sup>1</sup>.

The identification, characterization, and development of new groundwater resources within Panama can be accomplished through a series of Phases, gradually focusing work efforts from a regional “National” scale down to selected site-specific drilling locations. Phase I of the study will focus on the identification of hydrogeologic settings throughout the Country which have the greatest potential for yielding safe, clean, and sustainable groundwater resources.

Due to the size of Panama (75,516 km<sup>2</sup>), Phase I will be accomplished through the compilation and analyses of existing GIS databases. EGGI proposes to conduct this Phase I investigation in a similar manner to the Groundwater Development Potential Assessment performed for the Dominican Republic. In this study, the potential to develop groundwater resources was determined on a Countrywide basis (an area of 48,730 km<sup>2</sup>) and for each of the 31 Provinces within the Dominican Republic. This was accomplished by assessing which hydrogeologic settings were most favorable (and suitable) for groundwater development based upon recharge, bedrock type, fracturing characteristics of the bedrock, and the presence of transmissive unconsolidated deposits. In addition, areas where future groundwater development was not recommended were also highlighted based on the identification of existing and potential contaminant threats to groundwater quality, including the potential for salt water intrusion.

Phase I methods of investigation that will be used to evaluate the overall hydrogeologic favorability and *Groundwater Development Potential* within Panama are presented herein.

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<sup>1</sup> It is important to note that, in order to maximize the productive use of the Country’s water resources, the development of new groundwater resources will need to be combined with the preservation and restoration of existing groundwater resources through a concerted, nationwide effort to reduce pollution, initiate conservation measures, and reduce water use waste/loss from existing water systems.



## **TECHNICAL WORK SCOPE – PHASE I**

### **PHASE I -- ASSESSMENT OF POTENTIAL GROUNDWATER AVAILABILITY – CONSTRUCTION OF REGIONAL “GROUNDWATER DEVELOPMENT POTENTIAL” MAPS BASED ON NUMERICAL MODEL**

The objectives of this Phase of investigation are to collect, compile, and analyze an assortment of existing hydrogeologic datasets and to develop additional regional datasets regarding groundwater resources. These datasets will be used to assess the overall “Groundwater Development Potential” for all areas throughout the Republic of Panama (Figure 1). This will lead to the identification of sub-regions considered favorable for conducting more detailed groundwater exploration and development investigations (Phase II). As discussed in the cover letter and introduction, establishing an understanding of where potential groundwater resources can be developed throughout the Country will serve as an outstanding tool for land use and water resource planning/protection for generations to come.

#### **Task 1 -- Establishment of Project Databases, Compilation and Review of Existing Data, and Preliminary Production of Base Maps**

In order to minimize the redundancy of pursuing previously accomplished efforts, EGGI will begin this project with a comprehensive, systematic search of available technical information that is pertinent to the hydrogeologic settings of Panama. This Task will also include the production of initial base maps, which will then serve as a basis for all future data collection activities over the course of the entire project. During this Task, these maps will initially include several layers of information including: topography and geographic features, bedrock and surficial geology, land uses, slope of ground surface, watersheds, well data, groundwater withdrawal information, recharge characteristics, and potential sources of contamination. EGGI will work closely with IDAAN officials to obtain all needed information.

Available information that will likely be reviewed would include, but is not limited to, the following:

- Bedrock geology maps and associated bedrock structure information;
- Surficial geology maps;
- Digital elevation models (DEM);
- High- and low-altitude aerial photography;
- Precipitation records, evapotranspiration, streamflow, and other climatic information;
- Pertinent national and municipal reports and publications regarding groundwater use, availability, and quality;
- Reports from local, municipal, and regional planning agencies;
- Well records and groundwater withdrawal studies that can be obtained from IDAAN and other in-Country sources;
- The results of pertinent public and private consulting studies previously completed within Panama;

- Existing land use maps available throughout specific key areas within Panama;
- Information available from National health/sanitation officials relative to known groundwater quality concerns throughout the Country; and
- Available hydrogeologic data from internet and online sources.

**Task 1 – Product:** Hydrogeological data collected from the aforementioned sources will form a sound database that will be expanded throughout the project and will collectively provide a valuable information source, which subsequent Phases and Tasks of the Investigation will fully utilize. Computer digitized base maps will be prepared for field mapping purposes and for final report submittals. Since the maps will be computer generated and GIS based, the scale of maps can be changed to accommodate most any need of the project and the Client.

**Task 2 -- Assessment of Potential Hydrogeologic Favorability of Unconsolidated Deposits and Bedrock Types for Groundwater Development (includes Preliminary in-Country Site Visits/Reviews)**

*Unconsolidated Deposits*

Groundwater resources within Panama exist within unconsolidated (alluvial, fluvial, and volcanic deposits) *and* bedrock aquifers. The productivities of these aquifers are largely dependent on the primary and secondary hydrologic characteristics of the aquifer materials and the availability of recharge from precipitation.

Within Panama, there are numerous unconsolidated deposits overlying sedimentary and igneous rocks of various types and ages. The complex tectonic history of the region has resulted in a complicated geologic setting. Each of the units has distinct and different hydrogeologic characteristics that influence the development of groundwater resources.

Groundwater in unconsolidated aquifers is stored within, and flows through, openings within the sediments in the aquifer. Therefore, the productivity of unconsolidated aquifers depends on:

- 1) Grain size (*e.g.*, coarser sediments are more transmissive to groundwater flow and therefore are more productive);
- 2) Lateral distribution of the deposits; *and*
- 3) Thickness of the saturated unconsolidated sediments (the thickness of sediments below the groundwater table).

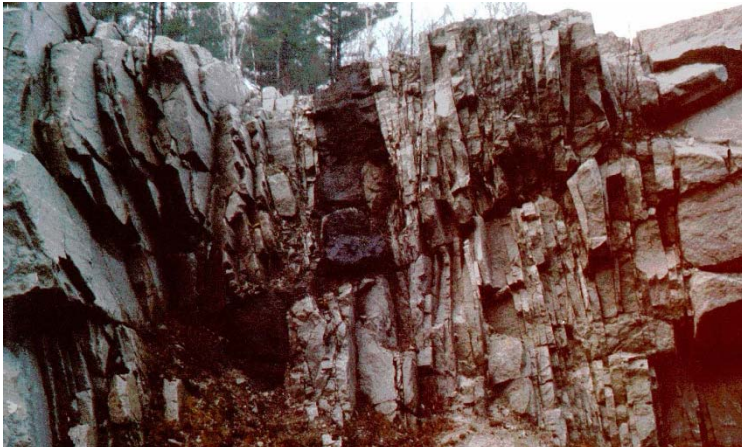


**Paleo-channel deposit in western Panama**



### ***Bedrock Lithologies***

Groundwater development within sedimentary, metamorphic, and igneous rocks is dominantly controlled by the presence of fracture features. These features typically develop along bedding and secondary discontinuities such as fractures and faults. The quality and quantity of groundwater that can be extracted from bedrock systems is directly influenced by the



**Example of bedrock fractures and bedrock fault zone system that can serve as a bedrock aquifer. A well drilled on this feature yielded 500,000 gallons per day.**

bedrock's chemical and physical characteristics. The control of bedrock type on well yield has been well documented and it is, therefore, extremely important to determine and evaluate in any groundwater exploration program (Mabee, 1994; Adamski, 1991).

As part of EGGI's investigation, we will investigate six aspects of bedrock lithologies that we have consistently demonstrated to heavily influence the groundwater development potential at any specific location.

Five of these factors influence the overall yield potential and one influences groundwater quality. The five factors known to influence groundwater yield potential are:

- 1) How well the rock unit is layered and/or foliated;
- 2) What is the potential primary permeability of each rock unit?
- 3) Whether or not secondary permeability features have developed in the bedrock, such structural discontinuities (e.g., fault zones and fractures) and karst solution cavities;
- 4) How gently the layering dips; and
- 5) How well formed through-going (extensive) regional structural feature systems tend to be.

The sixth factor, known to influence groundwater quality, is the chemical composition of the rocks.

The input of the first five of these factors will be integral to the development of the Regional Numeric Groundwater Favorability Model (Task 7). Detailed rock characteristics, such as the depth of weathering, detailed bedrock fracture fabric



**Folded Columnar Basalt in Western Panama**

analyses, and determination of specific groundwater development sites will be further evaluated in subsequent Phase II investigations.

**Task 2 -- Product:** EGGI will identify the regions that are underlain by what EGGI groundwater exploration geologists consider are the most favorable unconsolidated deposits (i.e., those that are considered to be best candidates for groundwater storage and development). In addition, EGGI will assess all bedrock types/lithologies, and characterize each with regard to their overall potential favorability/capability for yielding substantial groundwater resources.

**Task 3 -- Remote Sensing Analyses of Regional Hydrogeological Environments;  
Lineament Analyses to Identify Potential Fractured Bedrock Aquifers**

The underlying key to successfully evaluating the potential to develop groundwater supplies from fractured bedrock sources is the ability for geologists to consistently and accurately delineate zones of laterally extensive bedrock fracture systems that exhibit the ability to transmit water. “Fracture trace” or photolineament analyses, in conjunction with detailed structural mapping of brittle deformation features, are applied by remote-sensing scientists as a practical method to delineate water-bearing, bedrock fracture systems. Photolineament analysis provides the first step in locating pervasive joint and fracture zones, which control groundwater flow. During this Phase I investigation, EGGI scientists are primarily concerned with regional faults and discontinuities that formed in response to tectonic and/or gravitational forces.



**Example of Fault Line**

Remote-sensing analyses of different scales of high altitude imagery will be conducted to help characterize the geologic structure and fracture fabric of the regional study area. This will be accomplished by delineating photolineaments or “fracture traces” for each set of images. A photolineament can be loosely defined as a mappable linear feature, seen on the terrain surface, whose parts are aligned in a rectilinear or curvilinear manner. Many subsurface features, such as bedrock fracture zones, bedrock discontinuities, faults and geologic contacts, have surface expression which can be detected through remote sensing analyses of photographic images.

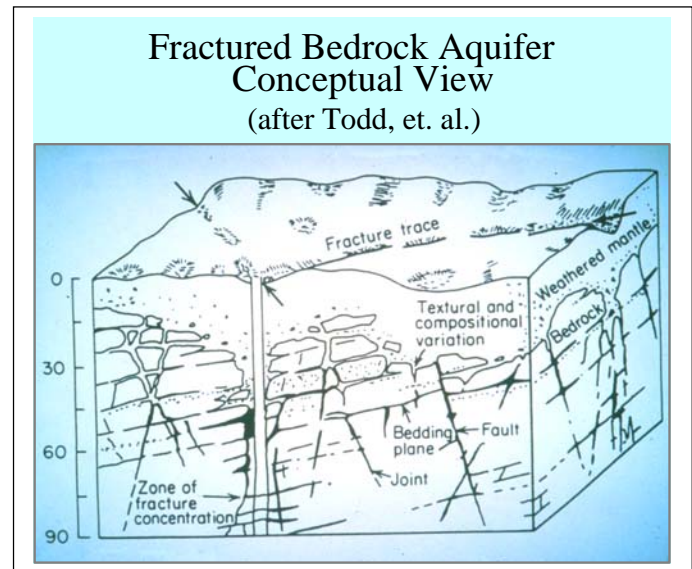
This remote sensing effort helps extend bedrock fracture features noted in the field to areas where bedrock is not exposed, including those areas overlain by unconsolidated sediments. To effectively cover the roughly 78,000 km<sup>2</sup> area of the Study Area, regional lineament analyses will be completed. The images and platforms we will use for this project will include some or all of the following<sup>2</sup>:

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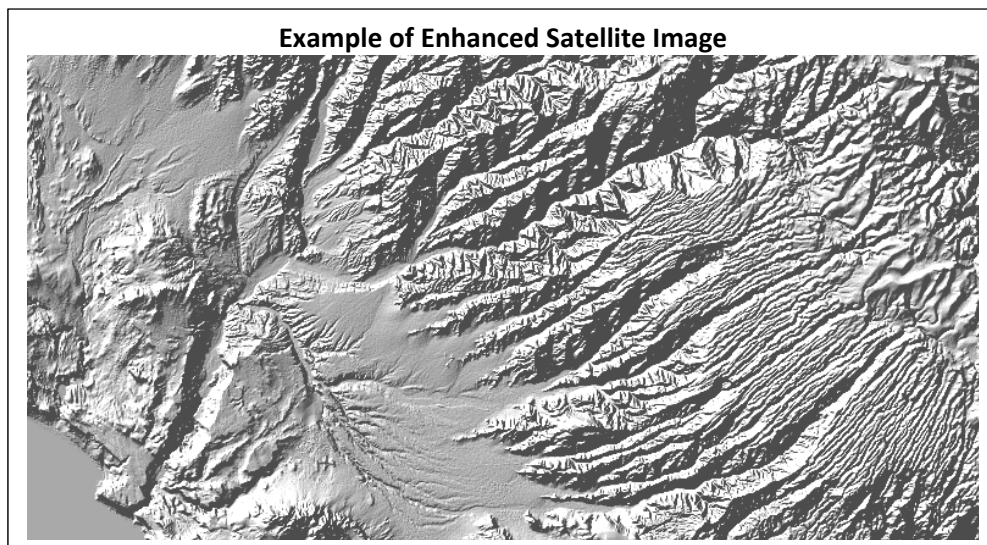
<sup>2</sup> Other platforms may also be used or substituted if deemed more appropriate by investigators after the project is initiated.

- LANDSAT 7 and 8 multi-spectral, 15-60m resolution satellite collected data
- ASTER multispectral, 15-90m resolution satellite collected data
- Digital elevation models including recently released ASTER GDEM V2 data and CATHALAC DEM
- Radar elevation data from the space shuttle (shuttle radar topography mission: SRTM)
- Hi-resolution aerial imagery

These source data sets will be digitally enhanced to create the optimal computer generated images for our remote sensing scientists to conduct lineament analyses. Computers and special software, complete with algorithms developed in-house and over many years by EGGI scientists, will be used in our analysis of photolineaments. A statistically robust and reproducible data set of the mapped photolineaments will be assembled, which will include both prominent and subtle photolineaments.

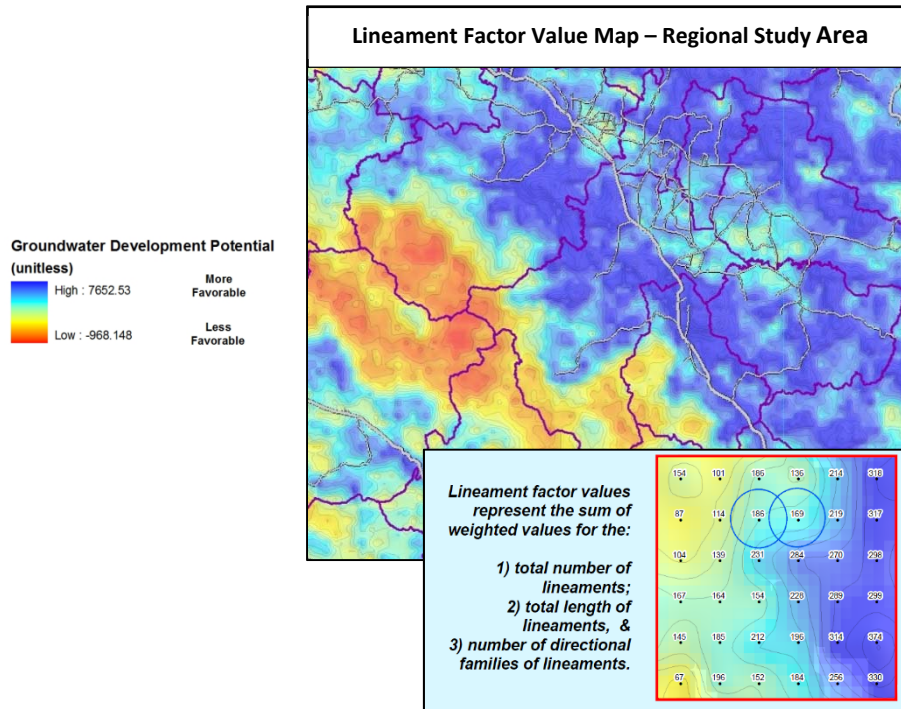


Once the lineament data have been collected, a proprietary Lineament Factor Value Map covering the entire Country will be produced. Developed by EGGI,<sup>3</sup> this method allows a quantitative assessment of the lineament data with regards to locating areas where bedrock is most likely to be fractured and, therefore, best suited for groundwater storage and transmission.



<sup>3</sup> Hardcastle, K.C., 1995, Photolineament Factor: A New Computer-Aided Method for Remotely Sensing the Degree to Which Bedrock is Fractured, *Photogrammetric Engineering and Remote Sensing*, v. 61, no. 6, pp. 739-747.

EGGI’s Lineament Factor Method calculates and normalizes three key lineament variables: lineament number, lineament length, and number of lineament directional families. The grid of Lineament Factor Values calculated during this analysis is based on the analysis of lineament data that occur within a series of circular areas (see inset to the right). The use of circular data analysis areas removes spatial biases created from the use of square analysis area grids, such as that used in commercially available software like ArcMap’s Spatial Analyst software.

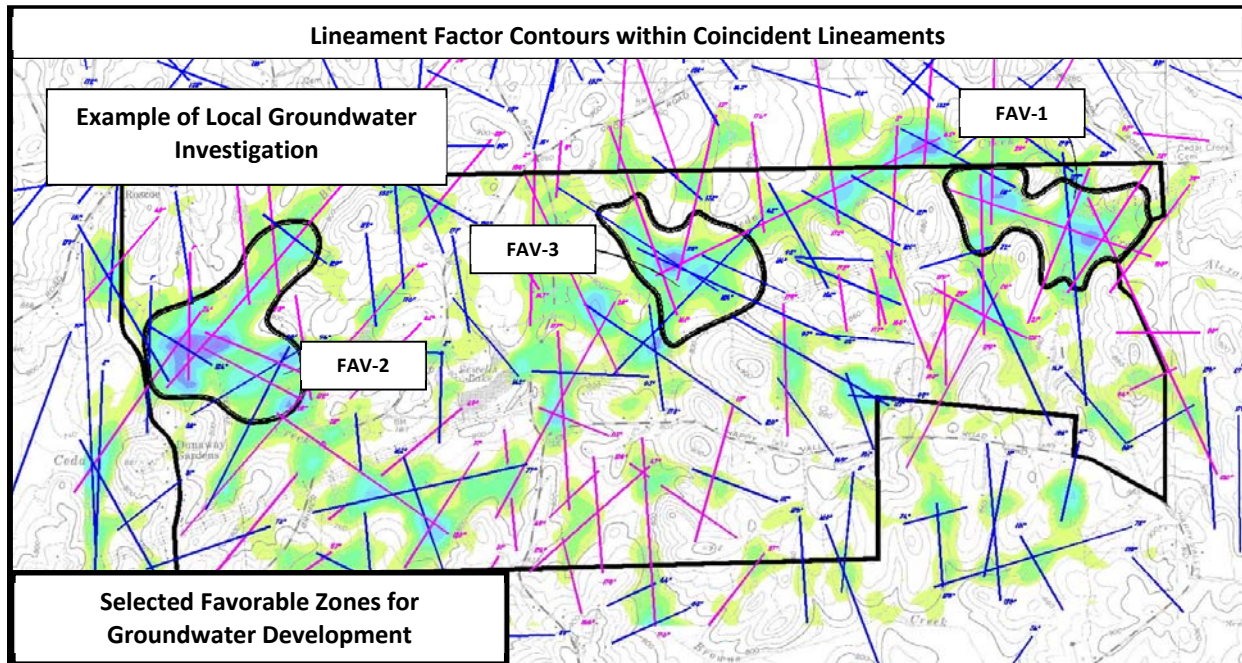


The grid of calculated Lineament Factor Value data is contoured to reveal the areas of high values that are considered to be most likely underlain by areas with enhanced groundwater productivity characteristics (see Lineament Factor Maps above). Areas shown in blue are considered more favorable for groundwater development than the areas in red. These sub-regions are considered favorable for further groundwater exploration within an integrated groundwater development program that incorporates other hydrogeologic data (such as bedrock type, nature of recharge, contaminant threats, etc.) that are key to assessing the groundwater development potential of an investigated regional area.

EGGI has created and successfully used Lineament Factor Maps many times in identifying areas considered favorable for developing new groundwater resources that require the preliminary evaluation of groundwater availability across *very large study areas*, such as exists in Panama. These data will provide a critical component to the development of EGGI’s Regional Numeric Groundwater Favorability Model (Task 7).

Accurate delineations of exposed bedrock formations and lineament systems will lead EGGI to delineate smaller sub-areas (preferred groundwater development zones) considered to have a higher potential for groundwater development (see below). Detailed investigations of

these sub-areas can be pursued as part of a subsequent “site specific” groundwater investigation and provide insights into which areas will be critical to protect as part of long-term water resource management plans (Phase II and beyond).



**Task 3 -- Product:** Lineaments can denote the location of important subsurface bedrock structures which control the storage and migration of groundwater. No known maps of such key features exist in a consistent, robust, Countrywide format in Panama. With a known geologic history of intense and complicated fracturing and faulting in the region, and only having regional geologic base maps, these data are fundamental to any groundwater resource investigation and resource management plan.<sup>4</sup>

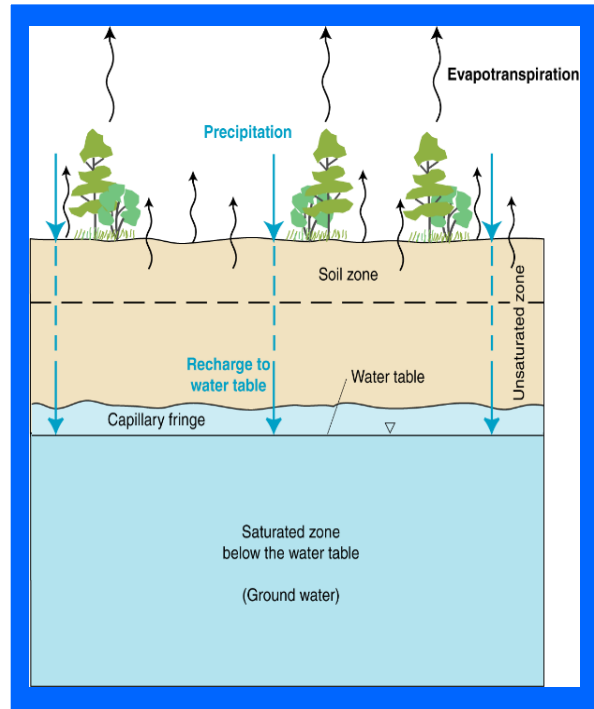
Areas having a high Lineament Factor Value will be identified and presented on a GIS base map. EGGI will prepare an enhanced Lineament Factor Map for the entirety of the Country, which will help to define areas considered favorable for new groundwater development. (In addition, the many lineaments that are drawn to determine the Lineament Factor Value Map will be available in GIS format. These lineaments can provide insights in to the underlying fracture/faults systems on a detailed site specific basis.)

<sup>4</sup> For example, a volcanic rock unit may have a moderate permeability ranking; however, where this unit is highly fractured (as can be denoted by lineaments) the permeability and groundwater yield potential can be very high. The locations of these potentially higher permeability zones are determined through mapping of lineaments.

#### **Task 4 -- Preliminary Groundwater Recharge Analyses / Hydrogeologic Review**

In order to produce dependable and sustainable supplies of groundwater, an aquifer must have a source of recharge that replenishes groundwater removed from storage. Without an adequate recharge source, groundwater will be mined from the subsurface at a rate that cannot be maintained for extended periods and, therefore, such a groundwater supply is usable for only intermittent time periods. A groundwater aquifer that does have access to a good source of recharge can be managed in a manner such that sustainable groundwater withdrawals can be used indefinitely.

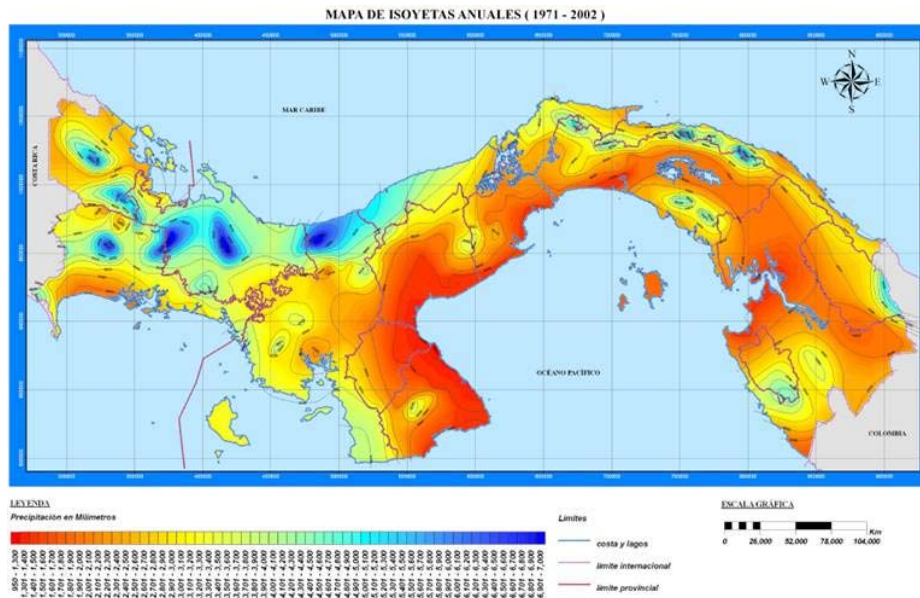
The primary source of groundwater recharge is precipitation, which infiltrates into the subsurface under natural or man-induced conditions. The amount of precipitation that becomes groundwater recharge is dependent on a large number of factors; the most important of which are the amount of precipitation, the amount of evapotranspiration, the vegetation type, the soil type, the underlying geology, and the slope of the surface topography. The impact of some of these parameters can be measured directly while others need to be estimated indirectly based on available data, including DEM and filtered multi-wavelength satellite data.



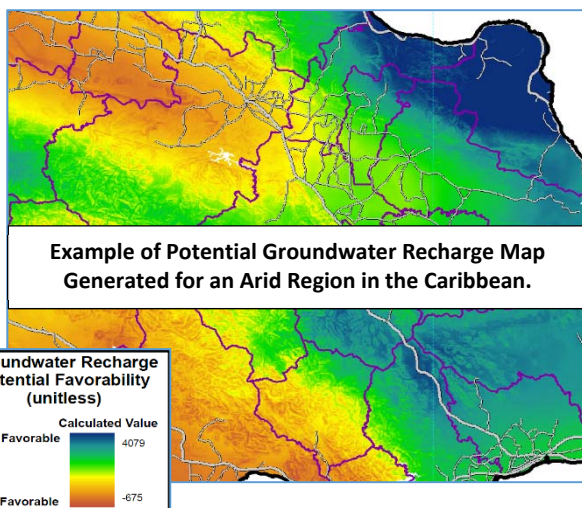
Four distinct assessments of groundwater recharge potential will be conducted during this investigation, including:

- 1) A review of the climatic data;
- 2) A review of hydrologic considerations (e.g., watershed sizes, stream flow characteristics, etc.);
- 3) A review of the geomorphologic settings throughout the Country; and
- 4) A review of the distribution of the various types and permeability of unconsolidated deposits overlying the bedrock surface.

Annual precipitation within Panama varies between approximately 1,000 mm (39 inches) and 7,000 mm (275 inches), with the driest portions of the country being located along the southern portion of the isthmus. The average annual precipitation for the Country is 2,924 mm (115.12 inches)



The percent of precipitation that becomes groundwater recharge is strongly dependent on several characteristics of a drainage basin including soils (which are related directly to geology), morphology, topography, vegetation, and other factors. Therefore, the hydrogeologic investigation will concentrate on assessing contributing watersheds above various unconsolidated deposits and bedrock types. EGGI will use digital elevation model (“DEM”) data to evaluate slope (first derivative) as part of a first step for evaluating potential recharge conditions throughout the Country. Basins with larger size, more permeable soils, shallower slopes, favorable rock types, and high Lineament Factor Values, will have relatively higher groundwater recharge rates. The higher the groundwater recharge potential of an area is, the greater the likelihood of locating high yielding wells which can *sustain* long term withdrawals. A numeric model will be developed for the recharge conditions throughout the Country and that model will comprise an integral part of the broader Regional Numeric Groundwater Favorability Model (Task 7). An example of such a groundwater recharge map taken from a numerical model and constructed for a Country in the Caribbean is provided below.



**Task 4 -- Product:** The product of the hydrogeologic investigation will be an assessment of the potential groundwater recharge throughout the Country and the development of a numeric recharge favorability model.

### **Task 5 -- Evaluation of Well Records and Pumping Records from Existing Wells**

Evaluation of existing well records is necessary and will also provide valuable information on the local subsurface geology and favorability for groundwater development. Well logs and pumping data from existing wells will be identified through available IDAAN records. These data will be utilized to help assess the general groundwater favorability.

*EGGI will work cooperatively and in partnership with professional staff at IDAAN to compile, tabulate, and review all of the available well data (estimated to exceed 4,000 datasets). The objective of this Task will include, but not be limited to, the following:*

- 1) Assess well yield versus type of well drilled, depth of well, hydrogeologic setting, diameter of well, bedrock type, and location within the Country;
- 2) Assess water quality data for each well relative to topography, hydrogeologic settings, and rock type;
- 3) Assess results of groundwater withdrawals to determine long-term yields and water quality; and
- 4) Assess, if possible, using the available data whether the mining of groundwater is occurring as a result of over pumping and/or if adverse impacts are being caused by long-term groundwater withdrawals.<sup>5</sup>

### **Task 6 -- Preliminary Assessment of Potential Contaminant Threats to Groundwater Quality and Determination of other Areas that would be Excluded from Groundwater Development**

A preliminary contaminant threats analysis will be carried-out to identify major potential sources of contamination that may threaten the quality of groundwater resources. The identification of significant threats to groundwater quality or previously contaminated groundwater may eliminate certain areas for future groundwater development consideration. The magnitude of the potential threat imposed by a certain type of contamination will be estimated and classified into different categories. Some contaminants, such as salt water intrusion, leaking underground fuel areas, or hazardous landfill areas are very serious and may totally eliminate an area as a potential zone for groundwater development, regardless of whether hydrogeologic characteristics are favorable. All potential impacts to groundwater quality, however, will be assessed in accordance with the proposed water use.

Sources of contamination will be identified by available searches through existing National and local records and internet files. EGGI will also work with officials at IDAAN to obtain pertinent information from knowledgeable local officials who can help out with this type of survey. This survey will be considered a significant first step in assessing areas that are suitable for groundwater development. Additional site specific and detailed contaminant surveys will be required as part of subsequent phases of investigation.

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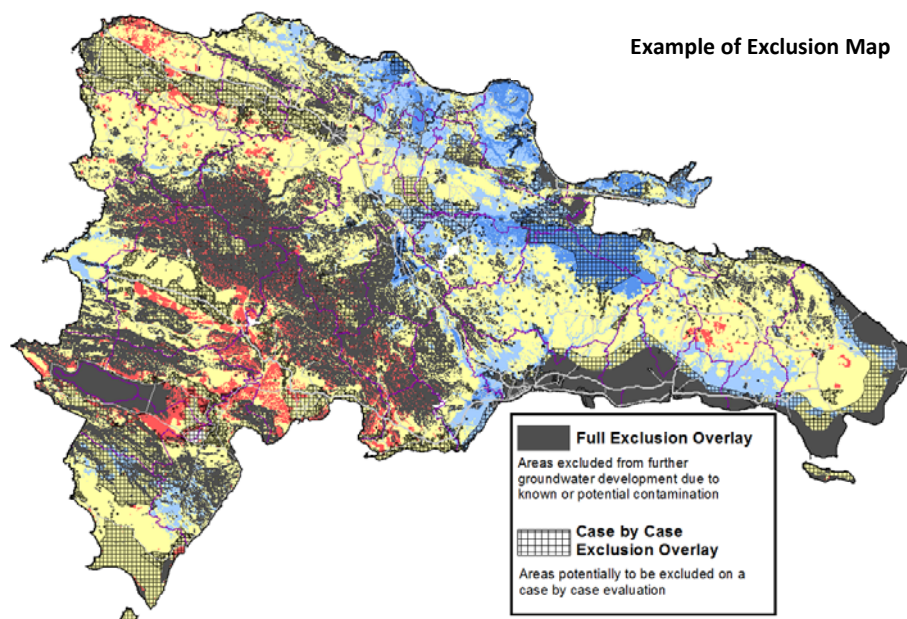
<sup>5</sup> Note: This will only be performed based upon readily available data.



In addition to identifying areas where groundwater quality might be impaired by contaminant sources, other areas will also be identified that will be excluded from groundwater development. These areas would include, but not be limited to, the following:

- 1) Areas where salt water intrusion is likely to be substantial/significant.
- 2) Protected wetlands and/or swamp areas.
- 3) Areas having steep slopes.
- 4) Densely populated areas where land use is not favorable for protecting groundwater quality.
- 5) Areas already permitted for groundwater withdrawal to meet agricultural irrigation needs.
- 6) National Parks or other protected lands.

**Task 6 -- Product:** The end result of this survey will be to construct an “*Exclusion Overlay*” Map depicting those sources of possible contamination that may present a potential threat to groundwater quality. This information will play an important role in evaluating future risk assessments relative to assessing the “Groundwater Development Potential” throughout the Country.



### **Task 7 -- Reconnaissance In-Country Mapping of Geology, Fracture Fabric, and Bedrock Structures**

In-Country field mapping in various parts of Panama will be integral to the success and quality of the groundwater resource model developed during this project. This mapping will be conducted by EGGI scientific staff in cooperation with local geologists.

Key data provided from the mapping will include:

- Direct measurements on the bedrock and surficial geology in selected regions providing important insights on the variability of the primary and secondary permeabilities of the various geologic units.
- Calibration of the spectral signature of remote sensing images at specific sites to the different ground conditions, rock/sediments types, vegetation, sediment saturation, etc. The correlations determined between physical/hydrogeologic conditions and site-specific remote sensing values can then be used to guide the interpretation of the remote sensing images throughout the Country.
- Ground-truthing of remotely sensed lineament features such as faults, fracture zones, geologic contacts, and geologic discontinuities.
- Development of a preliminary fracture fabric database.

Hydrogeologic data collected during the field visit will be incorporated into GIS databases for use in the development of the *Groundwater Development Potential Model*. In addition, these databases will be available for future use in site specific investigations.

It is anticipated that field visits by EGGI scientists will occur near the beginning, mid-portion, and conclusion of the development of the numerical model. Additional field work will be conducted, as needed, by local geologists/hydrogeologists trained to follow EGGI's protocol for bedrock fracture fabric mapping.

#### **Task 8 -- Assessment of Groundwater Availability – Construction of “Groundwater Development Potential Map”**

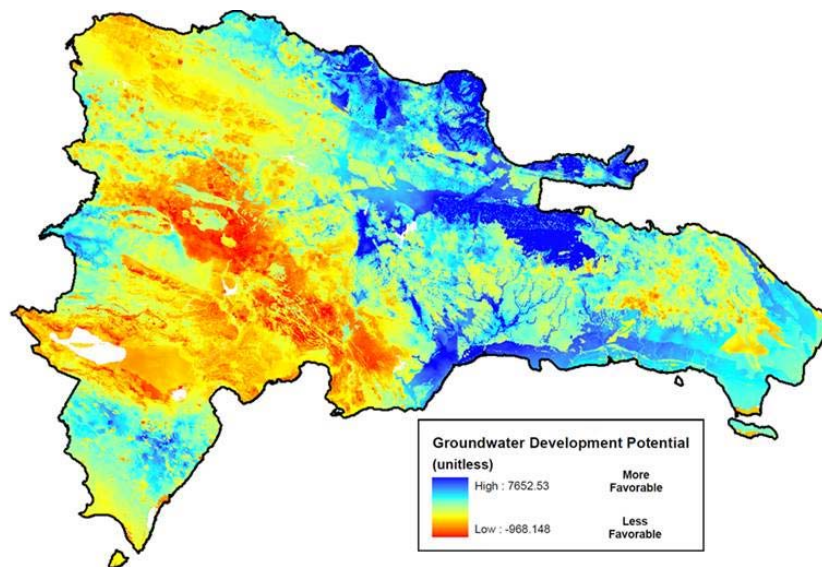
Based upon all of the hydrogeologic data collected from Tasks 1 through 6, and the additional regional datasets developed by EGGI throughout this investigation, an assessment will be made on the overall favorability for identifying new, sustainable groundwater resources within the Republic of Panama. EGGI will approach this groundwater investigation of Panama in a similar manner to that used in previous regional studies, such as the Dominican Republic study; assessing the entire Country by generating a comprehensive Numeric Model to identify those portions consider to be: a) Most Favorable; b) More Favorable; c) Moderately Favorable, and d) Not Favorable for new groundwater development.

EGGI will determine the level of favorability for groundwater development, based upon rock type, geologic setting, available groundwater recharge, presence of major contaminant threats, and other important hydrogeologic factors. A Numeric Model for the entire Country will be prepared that will serve to rank and rate each and every 100 square meters of land relative to its groundwater availability<sup>6</sup> (the “Regional Numeric Groundwater Favorability Model”). This will ultimately result in the generation of a powerful and uniquely strategic map that will provide sound technical guidance for subsequent groundwater resource development, protection, and planning efforts. An example of this map product is presented on the next pages.

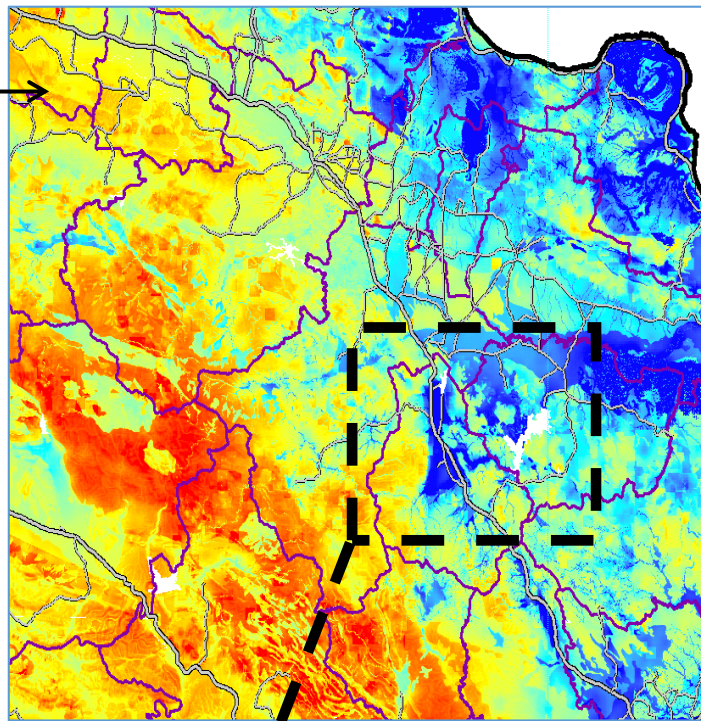
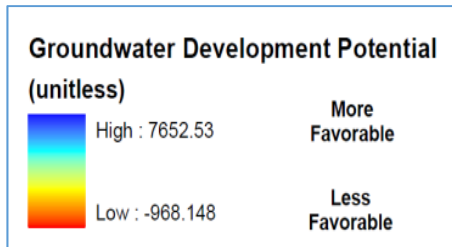
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<sup>6</sup> The final grid size of the Groundwater Favorability Model will be dependent on the level of detail of available datasets.

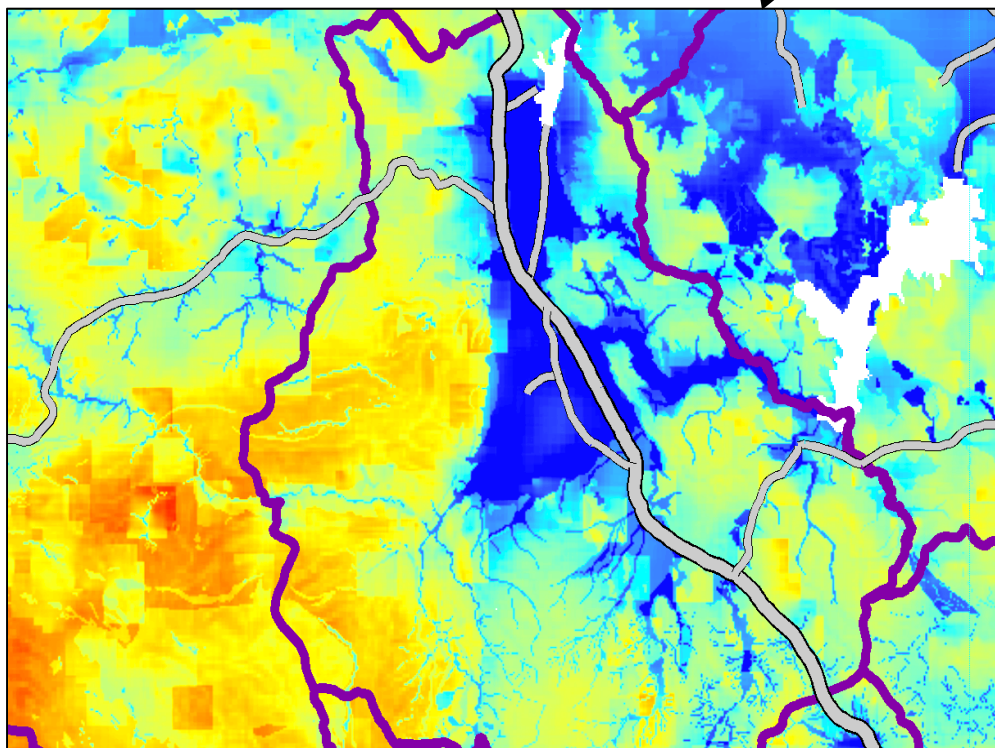
**Task 8 -- Product:** All of our data will be assembled into a computerized geographical information system (GIS). The various data layers will all be made available in an organized collection. Attributed polygons, lines, points, and rasterized data will include: geology, lineaments, lineament factor values, well data, potential contaminant threats, recharge, hydrography, topography, enhanced satellite imagery, as well as the hydrogeologic favorability, recharge favorability, and groundwater development potential models. The results of this Task will be the presentation of the Nationwide *Groundwater Development Potential Map* based on the Regional Numeric Groundwater Favorability Model, and a report that discusses the contents of the Model and which ranks areas in accordance with their overall groundwater development potential. Key datasets can also be organized on portable devices for in-field use to provide enhanced functionality.



**Example of Numerical  
Model of Regional  
Groundwater Development**



160 kilometers



58 kilometers

## **LIMITATIONS**

This investigation creates a numerical model that generates *Groundwater Development Potential Maps* and is considered the first Phase of several that will be required prior to developing groundwater resources. The level of accuracy of the numerical model is, in part, dependent upon the level of detail of the available geologic and hydrogeologic databases. Subsequent on-site investigations that include detailed geologic mapping, geophysical surveys, exploratory drilling, and groundwater withdrawal testing will be required to confirm groundwater resource availability. However, it has been demonstrated that these methods of investigation, as presented herein (as Phase I), have been extremely valuable and successful in assessing groundwater resources development potential on a regional basis.

## **REFERENCES**

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- Hardcastle, K.C., 1995, Photolineament Factor: A New Computer-Aided Method for Remotely Sensing the Degree to Which Bedrock is Fractured, *Photogrammetric Engineering and Remote Sensing*, v. 61, no. 6, pp. 739-747.
- Mabee, S.B., Hardcastle, K.C., and Wise, D.U., 1994, A Method of Collecting and Analyzing Lineaments for Regional-Scale Fractured-Bedrock Aquifer Studies, *Ground Water*, Vol. 21, No. 6, 884-894.

# TIMETABLE & FEES

## **TIMETABLE AND FEES**

**Timetable:** The project timetable will be approximately 18-24 months. Assuming a January 1, 2016 Project Start Date, work will be completed between July 1, 2017 and December 31, 2017.

**Project Cost:** \$1,450,000 - Lump Sum Fee (including direct expenses)<sup>7</sup>

**Fee Schedule:** All fees are quoted in U.S. dollars and all payments will be payable in U.S. dollars. Invoices will be submitted monthly and will include a brief correspondence outlining the work performed during the month. Invoices will be based on % completion each month with 30 day payment terms. Late fee charges will be assessed at an annual rate of 10% and accrue on a monthly basis for payment not received within 30 days of invoice.

**Retainer:** An initial retainer of \$15,000 will be required by EGGI to start work on this project.<sup>8</sup>

**Reimbursable Expenses:** The following documented expenses are included in the total cost shown above. Total direct expenses, however, shall not exceed \$50,000.<sup>9</sup>

- The costs of relevant (agency and non-agency) hydrologic, geologic and other data, reports and maps, mailings, shipping, courier, plotting, aerial photography, satellite imagery, copying, and all other direct expenses will be considered reimbursable expenses.
- This proposal assumes that the majority of work is performed strictly at EGGI's offices located in the USA. Specific trips (estimated to be a maximum total of three field excursions), determined to be critical to the success of the project, will be paid for out of the project cost fee shown above.

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<sup>7</sup> It is calculated into this fee that \$100,000 U.S. will be paid back to IDAAN for the purposes of collaboration and partnership with in-Country geologists, hydrogeologists, and other scientists to obtain existing GIS data maps, well data compilations, and other in-Country assistant service. It will also be used to train in-Country geologists to collect limited geologic structure data.

<sup>8</sup> This is a negotiable item.

<sup>9</sup> If additional direct expenses are warranted, EGGI will make a formal request for such additional funds to pay for that data. It is understood that the funding agency for this project will have the right to approve or deny any additional requests for funds as it relates to requested additional direct expenses.

# STUDY AREA MAP

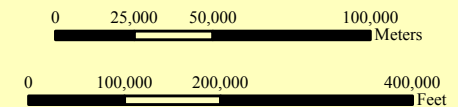


**FIGURE 1**  
Proposal for  
Nationwide Groundwater  
Resources Assessment  
Republic of Panama

Raised Relief Map



Scale is 1:2,400,000  
1 inch = 200,000 feet



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Content may not reflect National Geographic's current map policy. Sources: National Geographic, Esri, DeLorme, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P Corp.



## **POSSIBLE “NEXT STEPS” / SUBSEQUENT PHASES OF INVESTIGATION**

It has been demonstrated that the methods outlined for this investigation (as presented herein as Phase I) have been extremely valuable and successful in assessing groundwater resource development potential on a regional basis. However, the numerical model and Groundwater Development Potential Maps created during this study should be considered *the first Phase of several* that will be required in order to develop groundwater resources at specific locations within Panama. Subsequent on-site investigations that include detailed geologic mapping, geophysical surveys, exploratory drilling, groundwater withdrawal testing, and water quality analyses will be required to confirm groundwater resource availability within specific areas of interest within the Country.

It is recommended that appropriated parties/agencies within the Country select areas in which the Most Favorable Groundwater development Potential coincides with where the development of new groundwater resources would best serve the interests of the Country. Additional work Phases could then be completed to develop new groundwater resources.

The “*Next Steps*” associated with proceeding with the assessment of the overall yield potential of groundwater resources within Panama should include the following subsequent Phases of work:

### **Phase II: Select Drilling Targets for Exploratory Test Wells – Detailed Geologic Mapping/Geophysical Surveys**

*Subsequent work tasks may include but not be limited to the following:*

1. Identify, select, and evaluate specific strategic areas for groundwater development where needed.
2. Obtain detailed and additional information for site specific areas of interest, including:
  - a. Types and volumes of potential water use;
  - b. Additional local well data (depth, yields, types of construction); and
  - c. A detailed inventory of known and potential Contaminant threats.
3. Conduct detailed on-site “*on the ground*” geologic mapping in preferred selected areas to further the investigation of groundwater resources.
4. Assess drilling requirements and needed drilling equipment for selected geologic settings.
5. Interview personnel from drilling companies to assess the availability of various drilling techniques and obtain costs of various types of available drilling methods.

6. Review additional high resolution aerial photography (low altitude) and multi-spectral data to enhance the groundwater assessment at the local scale and at specific groundwater investigation areas.
7. Obtain permission to access private property to conduct field surveys
8. Conduct reconnaissance and detailed geophysical surveys to investigate subsurface geologic discontinuities that will potentially yield substantial volumes of groundwater. This task will include the collection and analyses of all geophysical data. The purpose of this investigation will be the staking of well sites in the field where the drilling of exploratory test wells is recommended.
9. Prioritize specific sites for drilling exploratory test wells based on the results of the geophysical analyses and the data generated in Phases I and II of the study.
10. Prepare summary report of Phase II investigation.

**Phase III: Conduct Exploratory Test Well Drilling and Preliminary Yield and Water Quality Testing**

1. Obtain permission from property owners to drill on private or public lands.
2. Obtain necessary permits to drill wells.
3. Drill exploratory wells at sites selected within each investigation area.
4. Coordinate and supervise all drilling effort, evaluate hydrologic characteristics of rock at depth, assess well yield, and collect water quality samples after each water-bearing zone is intercepted. Prepare hydrogeologic logs for each well by a professional geologist.
5. Conduct short-term pumping tests to provide a preliminary assessment of the yield and quality of each exploratory well drilled.
6. Select wells with sufficient yield for conversion/construction to production wells.

**Phase IV: Production Well Drilling**

1. Convert selected exploratory test well(s) into larger diameter production well(s).
2. Complete well construction to provide appropriate sanitary seal.
3. Log each well and conduct detailed water quality analyses.

**Phase V: Testing of Long-term Sustainable Yield and Water Quality of Production Well**

1. Install monitoring wells as and conduct environmental impact assessments as needed. Conduct long-term pumping tests to assess potential yield of production well(s).

2. Collect extended groundwater quality samples throughout the pumping test period to evaluate potential water treatment requirements for use as a potable water supply.
3. Evaluate recovery of well and aquifer to define sustainability of groundwater supply.

#### **Phase VI: Completion of Summary Report and Permitting of Groundwater Withdrawals**

The work efforts as outlined above provide a limited summary of the work to be performed. A more detailed work scope will be prepared upon request. These work efforts are designed to provide a systematic “stepped” approach to completing a comprehensive groundwater development program. The information collected to be during this program will serve to determine if groundwater resources can be used as a long-term viable source of water supply at any a specific site, or in a particular area of interest. It is intended that the proposed “Phased” investigation process will result in a cost-effective and efficient means for developing groundwater resources in those areas selected for further investigations.

EGGI is excited about proceeding ahead with the assessment of the potential to develop new groundwater resources within Panama for meeting potable and non-potable water demands. The numerical model of Groundwater Development Potential to be created during the investigation will be a powerful tool for conducting groundwater assessments on both a regional and local scale and provides substantive guidance as to where to focus future work efforts towards the development, withdrawal, and protection of groundwater resources.

# SENIOR TEAM RESUMES

## **SENIOR TEAM RESUMES**

### **JAMES M. EMERY, P.G.**

*President and Chief Executive Officer*

James Emery is a nationally recognized leader in the creation of successful groundwater resource assessment, development and protection techniques and has served as President and Chief Executive Officer of EGGI since founding the firm in 1989. He is a highly experienced exploration hydrogeologist, groundwater development, and well field design specialist and has participated in or supervised over 1,500 successful groundwater development and protection programs for major municipal and private water development projects throughout the eastern United States. In addition, James has been involved in several international projects, including advanced groundwater development programs in Somalia, Sudan, South Africa and the Dominican Republic.



Under his direction, EGGI has become well known for its expertise in groundwater exploration, development, monitoring, management, and protection. The firm has earned a reputation in the groundwater industry for unraveling very complex hydrogeological problems and providing clear, scientifically based solutions. EGGI is professionally recognized by the EPA, the United States Geological Survey (USGS), the Geological Society of America (GSA), and the National Association of Groundwater Scientists and Engineers (AGWSE) as a leader in groundwater resource investigations and groundwater protection for public water supplies.

Mr. Emery has prepared numerous policies and standards for use by a variety of public agencies for groundwater protection and development programs. He has served as an appointed member of the Loudoun County Water Resources Technical Advisory Committee (WRTAC), Loudoun County, Virginia, for a period of 14 years; and, formerly served as Chairman of the Groundwater subcommittee for WRTAC. He has also served on several groundwater advisory committees for numerous South Atlantic, Mid-Atlantic, and New England organizations. James was a member of the Massachusetts Department of Environmental Quality Engineering Rock Well Study Committee which determined state guidelines for municipal rock wells. Additionally, he has provided expert testimony for a wide range of technical issues associated with groundwater rights, groundwater protection, and groundwater contamination.

**JAMES M. EMERY, P.G. (continued)**

Education

B.S. Geology (cum laude) (minor: hydrology), University of New Hampshire.

Special Studies:

Geologic Field Mapping and Strata Correlation -- Northern Arizona State University

Water Well Hydraulics -- University of Wisconsin

Environmental Education Enterprises Institute, “Practical Karst Hydrogeology with Emphasis on Ground-Water Monitoring,” Cave City, Kentucky, May, 1993.

Professional History

1989-Present President of Emery & Garrett Groundwater, Inc.

1988-1989 Senior Vice President and Technical Operations Manager,  
BCI Geonetics, Inc. (an international groundwater exploration and development  
company)

1986-1988 Vice President and Senior Technical Advisor, BCI Geonetics, Inc.

1984-1986 Manager of Hydrogeology Department, BCI Geonetics, Inc.

1980-1984 Hydrogeologist, BCI Geonetics, Inc.

1979-1980 Assistant to New Hampshire State Geologist

1977-1978 Assistant Driller, Layne, New York, Inc.

Affiliations

Member – National Association of Groundwater Scientists and Engineers

Member – American Water Resources Association

Member – American Water Works Association

Member – Georgia Groundwater Association

Member – Connecticut Groundwater Association

Member – Virginia Groundwater Association

Member – Virginia Water Resources Research Center

Member – New Hampshire Society of Geologists

Papers and Honors

Emery, J.M., 2015, Assessing Groundwater Resources at a Countrywide Level, presented to World Bank, Washington, D.C., November 5, 2015.

Emery, J.M., 2015, Advanced Groundwater Development methods for assessing Bedrock Aquifers, presented at the Drought and Climate Change Conference – Drought Management and Mitigation Session, San Juan, Puerto Rico, April 23-24, 2015.



**JAMES M. EMERY, P.G. (continued)**

Emery, J.M., 2015, Groundwater Resource Protection in Karst Terrains, presented at the 26<sup>th</sup> Annual Environment Virginia Symposium – Building on Karst Workshop, Lexington, Virginia, March 31, 2015.

Emery, J.M., 2015, Moderator of the 26<sup>th</sup> Annual Environment Virginia Symposium – Building on Karst Workshop, Lexington, Virginia, March 31, 2015.

Emery, J.M., 2014, Key Note Speaker and Presenter at the **Groundwater Summit**, Fauquier County, Virginia Board of Supervisors Public Meeting, “Regional Groundwater Exploration and Development Efforts and the Benefits of Long-term Protection for Fauquier County’s Public Groundwater Supplies,” September 23, 2014.

Emery, J.M. Tinkham, D.J., and Foster, P.J., 2013, Delineation of a Wellhead Protection Area around the Lyndhurst Well, Augusta County, Virginia, presented at the 22nd Annual Maryland Ground Water Symposium, September 26, 2013.

Member of Loudoun County Water Resource Technical Advisory Committee, 2011-2015.

Foster, P. J., Emery, J.M., and Hardcastle, K.C., 2012, The Impacts of the Earthquake that Struck Near Mineral Virginia on Groundwater Resources in Northern Virginia. Oral presentation at the 61st Annual Meeting of the Southeastern Section of the Geological Society of America, Asheville, North Carolina.

Emery, J.M. and Hardcastle, K.C., 2011, Abstract, The Impacts on Groundwater Resources in Northern Virginia that were caused by the recent 5.8-Magnitude Earthquake in Mineral, Virginia.

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Brooks, J.A., and Emery, J.M., 2010, NH Water Works Association, April Technical Meeting, Presentation: Water Supply Development from Bedrock Aquifers in Newmarket, New Hampshire.

Emery, J.M., Crawford, T.J., and Karr, P.R., “Groundwater Development for Public Water Supply -- A Case Study -- Cobb County-Marietta Water Authority -- Cobb County, Georgia,” -- Proceedings of the Georgia Water Resources Conference, University of Georgia.

Emery, J.M., and Crawford, T.J., “Groundwater Exploration and Development in Cobb County for the Cobb County-Marietta Water Authority, Mountain Park Area 3” -- Georgia Geological Society 29th Annual Field Trip, Atlanta, Georgia, Guidebook Volume 14, Number 1.

**JAMES M. EMERY, P.G. (continued)**

Marts, J.M. and Emery, J.M., 2007, High Resolution Monitoring of Specific Conductivity as a Proxy for Chloride in a Valley-Fill Aquifer in Ashland, New Hampshire. Poster presentation at the 42nd Annual Meeting of the Northeastern Section of the Geological Society of America, University of New Hampshire, Durham, New Hampshire.

Tinkham, D.J., Foster, P.J., Emery, J.M., and Brooks, J.A., 2007, Implications for Aquifer Analysis from Discrete, Anisotropic Water Level Impacts Observed During Pumping Tests Performed in Fractured-Bedrock Aquifers. Oral presentation at the 42nd Annual Meeting of the Northeastern Section of the Geological Society of America, University of New Hampshire, Durham, New Hampshire.

Foster, Peter J., Hardcastle Ken C., Brooks, John A., and Emery, James M., 2006, Groundwater Exploration and Development in Sedimentary and Igneous Rocks of the Mesozoic Culpeper Basin, Fauquier County, Virginia – A Case Study; *Geo. Soc. Am., Abs. and Prog.*, v. 38, no. 3, p. 12.

Brooks, J.A. and Emery, J.M., 1999, Exploration of Groundwater Resources in Bedrock Aquifers using Surface Geophysical Methods, *Geol. Soc. Am., Abs. and Prog.*, v. 31, no. 3, p. 7.

Hardcastle, K.C., Brooks, J.A., Emery, J.M., and Tinkham, D.J., 1991, Remote Sensing of Groundwater-Controlling, Bedrock Fracture Systems: Photolineament and Magnetometer Analyses in the Culpeper Basin, Virginia, *Geol. Soc. Am., Abs. and Prog.* 23(1);41.

Emery, J.M., and Tinkham, D.J., 1992, “Groundwater Exploration and Development in Fractured Bedrock in the Piedmont,” *American Water Resources Association -- National Symposium on Groundwater Availability in the Piedmont.*

Hardcastle, K.C., Brooks, J.A., Emery, J.M., and Tinkham, D.J., Remote Sensing of Groundwater-Controlling, Bedrock Fracture Systems: Photolineament and Magnetometer Analyses in the Culpeper Basin, Virginia, *Geol. Soc. Am., Abs. and Prog.*, v. 23, no. 1, p. 41.

Emery, J.M., 1989, Decade of North America Geology Project/Geological Society of America ... *Hydrogeology of North America Volume, Chapter 21 -- Regional Synthesis of Northeast Appalachians/United States Department of Interior -- Geological Survey.*

Emery, J.M., and Cook, G.W. IV., 1986, “Determination of the Nature of Recharge to a Bedrock Fracture System,” *National Water Well Association Technical Division Eastern Regional Conference, Boston, Massachusetts.*

Selected Speaker

Keynote Speaker – “The Past, Present and the Future of Groundwater Resources in Fauquier County”, Fauquier County Water Summit, Fauquier County, Virginia.

**JAMES M. EMERY, P.G. (continued)**

Selected Speaker – “Groundwater Resource Evaluation and Implementation of Groundwater Resources Management and Groundwater Protection Practices”, Shenandoah Valley Watershed Roundtable Conference, James Madison University, Harrisonburg, Virginia.

Selected Speaker – “Groundwater Development in Fractured Bedrock Aquifers in the Georgia Piedmont”, Georgia Water and Pollution Control Association, Inc. Annual Conference and Exposition, Cobb-Galleria Center, Smyrna, Georgia.

Selected Speaker – “Groundwater Resource Evaluation of the Augusta County Region and Development of Groundwater Protection Ordinance,” Augusta County Board of Supervisors, Augusta County, Virginia.

Selected Speaker – “Groundwater Development in North Georgia – A Viable Alternative for Public Water Supply”, Georgia Rural Water Association Fall Conference, Helen, Georgia.

Selected Speaker – “Groundwater Exploration and Development in Fractured Crystalline Bedrock of the Piedmont”, United States Geological Survey, “Groundwater Exposition”, Savannah, Georgia.

Selected Speaker, Groundwater Seminar, Virginia Regional Health Department, Office of Water Supply Programs, Virginia.

Selected Speaker – “Development and Protection of Groundwater Resources in Fractured Crystalline Bedrock Aquifers”, United States Geological Survey, Stone Mountain, Georgia.

Selected Speaker – “Results of Groundwater Development in Fractured Crystalline Rock Aquifers”, Georgia Municipal Association, Jekyll Island, Georgia.

Selected Speaker – “Impact of Gravel Mining on Groundwater Quality”, Groundwater in New Hampshire's Future - A Symposium, the University of New Hampshire, Durham, New Hampshire.

Selected Speaker – Conference on Groundwater Development from Fractured Bedrock Sources in the Piedmont of the Eastern United States, United States Geological Survey, Charlotte, North Carolina.

Selected Panelist – Conference on Groundwater Development from Fractured Bedrock Sources in the Piedmont of the Eastern United States, United States Geological Survey, Charlotte, North Carolina.

Selected Guest Speaker – “Remote Sensing and How it Relates to Groundwater Exploration”, National Association of Groundwater Scientists National Convention, Baltimore, Maryland.

**JOHN BROOKS, Ph.D., P.G.**

*Vice President, Senior Project Manager, and Senior  
Scientist*

An integral EGGI team member since 1990, John Brooks is a recognized industry leader in the delineation of groundwater resources using glacial mapping technology, geophysical survey techniques, and advanced hydrogeological site characterizations. Dr. Brooks has a long track record of conducting and interpreting geophysical investigations to successfully identify favorable drilling targets for the development of high yield wells. He has supervised or been involved in over 850 groundwater exploration, development, and protection projects throughout the Eastern United States and in the Dominican Republic at EGGI, with a focus on both fractured bedrock and unconsolidated aquifers.



Dr. Brooks' experience and responsibilities include: senior project management and senior technical advisor; groundwater exploration and development in both fractured bedrock and unconsolidated aquifers; supervision of the geophysical department; development of geophysical protocols for groundwater exploration and development; modeling of geophysical data; mapping and interpretation of bedrock lithology and structural discontinuities; mapping and interpretation of glacial geomorphology; design, installation, and development of monitoring and production wells; organization, design, and management of aquifer testing programs; and aquifer and well field analysis.

His analytical and technical skills include the collection and analysis of magnetic data, electromagnetic data, resistivity data, single and multi-channel seismic refraction, ground penetrating radar and side scan sonar data; and field geology/structural analysis. His skills also include the use of X-ray fluorescence, instrumental neutron activation, solid source mass-spectrometry, and electron and scanning microprobe.

Education

Ph.D. University of New Hampshire, Durham, New Hampshire.  
Geophysics/Igneous Petrology-Dissertation.

Masters (M.S.) University of New Hampshire, Durham, New Hampshire.  
Geophysics/Metamorphic Petrology.

Bachelors (B.A.) Boston University, Boston, Massachusetts. Geology.

Professional Certifications and Memberships

New Hampshire Certified Professional Geologist No. 255  
Georgia Certified Professional Geologist No. 1114

**JOHN BROOKS, Ph.D., P.G. (continued)**

Virginia Certified Professional Geologist No. 1391  
Society of Exploration Geophysicists  
Geological Society of America  
New Hampshire Geological Society  
Sigma XI  
American Geophysical Union

Environmental and Engineering Geophysical Society

Papers and Honors

Brooks, J.A. and Tinkham, D.J., 2015, Surficial Geology of the Melvin Village Quadrangle, Carroll and Belknap Counties, New Hampshire, scale 1:24,000, NH Geologic Survey Surficial Geologic Map Open-File Series GEO-099-02400-SMOF.

Talon, A., Metcalf, M., and Brooks, J.A., 2015, Durham's Spruce Hole Groundwater Supply and Artificial Recharge Facility-Diversifying Supplies in a Combined Surface and Groundwater System, Presented at the NH Water Works Association Technical Meeting at Ashworth by the Sea, Hampton, NH, April 16, 2015.

Hussey II, A.M. and Brooks, J.A., 2014, Bedrock Geology of the York Harbor Quadrangle, Maine, Scale 1:24,000, Maine Geologic Survey open file map.

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Tinkham, D.J., Brooks, J.A., and Marts, J.M., 2014, Application of Long-term Water Level Monitoring to Assess Sustainability, Presentation at the New Hampshire Water & Watershed Conference.

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Brooks, J.A., 2013, Proto-Winnepesaukee and Squam: Deglaciation of the Winnepesaukee Basin, New Hampshire Geological Survey's Annual Geologic Mapping Workshop 2013, April 16, 2013, NHDES, Concord, New Hampshire.

**JOHN BROOKS, Ph.D., P.G. (continued)**

Brooks, J.A. and Emery, J.M., 2011, Evaluating Recharge Sources for Bedrock and Sand & Gravel Production Wells, The 2011 New Hampshire Water and Watershed Conference, March 25-26, 2011, Plymouth State University, Plymouth, New Hampshire.

Brooks, J.A., 2010, Water Resources Management with the Aid of Modeling. Presentation given at the New Hampshire Water Works Association Operators' Training Session, "Groundwater Issues," NHDES Auditorium, Concord, New Hampshire.

Tinkham, D.J., and Brooks, J.A. 2010, Surficial Geology of the Holderness, 7.5 minute Quadrangle, Belknap, Grafton, and Carroll Counties, New Hampshire, scale 1:24,000, NH Geologic Survey open file report.

Brooks, J.A., and Emery, J.M., 2010, NH Water Works Association, April Technical Meeting, Presentation: Water Supply Development from Bedrock Aquifers in Newmarket, New Hampshire.

Brooks, J.A. and Tinkham, D.J., 2009, Surficial Geology of the Bristol, 7.5 minute Quadrangle, Grafton County, New Hampshire, scale 1:24,000, NH Geologic Survey open file report.

Brooks, J.A. and Tinkham, D.J., 2008, Surficial Geology of the Wolfeboro, 7.5 minute Quadrangle, Carroll County, New Hampshire, scale 1:24,000, NH Geologic Survey open file report.

Brooks, J.A. and Tinkham, D.J., 2007, Surficial Geology of the Great East Lake, 7.5 minute Quadrangle, Carroll County, New Hampshire, scale 1:24,000, NH Geologic Survey open file report.

Brooks, J.A. and Tinkham, D.J., 2007, Insights into the Wisconsin Deglaciation of the Lakes Region, New Hampshire. Poster presentation at the 42nd Annual Meeting of the Northeastern Section of the Geological Society of America, University of New Hampshire, Durham, New Hampshire.

Tinkham, D.J., Foster, P.J., Emery, J.M., and Brooks, J.A., 2007, Implications for Aquifer Analysis from Discrete, Anisotropic Water Level Impacts Observed During Pumping Tests Performed in Fractured-Bedrock Aquifers. Oral presentation at the 42nd Annual Meeting of the Northeastern Section of the Geological Society of America, University of New Hampshire, Durham, New Hampshire.

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Guest Speaker, “The Development of Additional Resources at the Penacook-Boscawen Water Precinct County Farm Site,” NH Water Works Association Meeting, September 2005.

Brooks, J.A. and Tinkham, D.J., 2005, Surficial Geology of the Great East Lake, 7.5 minute Quadrangle, Carroll and Strafford Counties, New Hampshire, scale 1:24,000, NH Geologic Survey open file report.

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**JOHN BROOKS, Ph.D., P.G. (continued)**

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Brooks, J.A., and Bothner, W.A., 1989, Late(?) Alleghanian Dextral Transpression and Terrane Accretion within Coastal New England and Western Gulf of Maine as Interpreted from Regional Aeromagnetic and Gravity Maps. AGU Eos Trans 70(15);462.

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Brooks, J.A., Gust, D.A., and Hussey, A.M., 1989, Geology and Geochemistry of the Mt. Agamenticus Complex, York, Maine. In Guidebook for Field Trips in Southern and West-Central Maine. NEIGC 81st Annual Meeting, pp 1-24.

Bothner, W.A., Brooks, J.A., and Eusden, J.D., 1988, Geology and Geophysics of the Messabesic, Merrimack, and Rye "Zones" in central coastal New England. Geol. Soc. Am: Programs with Abstracts 20(1); 9.



**DANIEL TINKHAM, M.S., P.G.**  
*Vice President, Senior Project Manager, and Senior  
Scientist*

An integral EGGI team member since 1989, Dan Tinkham is a highly experienced hydrogeologist expert in groundwater protection, recharge, and modeling, as well as aquifer safe yield calculations. He has managed or been involved in over 850 groundwater resource investigation and supply projects throughout the Eastern United States and in the Dominican Republic at EGGI.

Dan has a particularly advanced understanding of: organization, design, and management of aquifer testing and groundwater monitoring programs; aquifer and well field analysis; calculation of recharge rates to groundwater systems; application of analytical and numerical groundwater models; volumetric water budgets for watersheds; mapping and interpretation of glacial geomorphology; implementation of groundwater quality monitoring programs; design, installation, and development of monitoring and production wells; and groundwater exploration and development in both fractured bedrock and unconsolidated aquifers.



Education

M.S., Hydrology, University of New Hampshire

B.S., Environmental Sciences, Keene State College  
Concentration in Geology and Chemistry

Professional Certifications and Memberships

Registered Professional Geologist New Hampshire No. 380  
National Ground Water Association (Association of Groundwater Scientists and Engineers)  
American Geophysical Union  
American Water Resources Association  
Geological Society of New Hampshire

Papers and Honors

Brooks, J.A. and Tinkham, D.J., 2015, Surficial Geology of the Melvin Village Quadrangle, Carroll and Belknap Counties, New Hampshire, scale 1:24,000, NH Geologic Survey Surficial Geologic Map Open-File Series GEO-099-02400-SMOF.

**DANIEL TINKHAM, M.S., P.G. (continued)**

Tinkham, D.J., Brooks, J.A., and Marts, J.M., 2014, Application of Long-term Water Level Monitoring to Assess Sustainability, Presentation at the New Hampshire Water & Watershed Conference.

Emery, J.M. Tinkham, D.J. and Foster, P.J., 2013, Delineation of a Wellhead Protection Area around the Lyndhurst Well, Augusta County, Virginia, presented at the 22nd Annual Maryland Ground Water Symposium, September 26, 2013.

Brooks, J.A. and Tinkham, D.J., Bedrock and Surficial Geology of the Lakes Region of Central New Hampshire, Geological Society of New Hampshire 2013 Summer Field Trip Guide.

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Brooks, J.A. and Tinkham, D.J., 2008, Surficial Geology of the Wolfeboro, 7.5 minute Quadrangle, Carroll County, New Hampshire, scale 1:24,000, NH Geologic Survey open file report.

Marts, Jeffrey M. and Tinkham, D.J., 2007, Mitigating the Effects of Elevated Chloride Concentrations in a Valley-fill Aquifer. Oral presentation given at the Meeting of the New England Water Well Association October 2006. Published in Journal NEWWA, December 2007, p. 286-294.

Tinkham, D.J., Foster, P.J., Emery, J.M., and Brooks, J.A., 2007, Implications for Aquifer Analysis from Discrete, Anisotropic Water Level Impacts Observed During Pumping Tests

**DANIEL TINKHAM, M.S., P.G. (continued)**

Performed in Fractured-Bedrock Aquifers. Oral presentation at the 42nd Annual Meeting of the Northeastern Section of the Geological Society of America, University of New Hampshire, Durham, New Hampshire.

Hardcastle, K.C., Brooks, J.A., and Tinkham, D.J., 2007, DEM Analysis for Surficial Mapping in the Lakes Region, New Hampshire. Poster presentation at the 42nd Annual Meeting of the Northeastern Section of the Geological Society of America, University of New Hampshire, Durham, New Hampshire.

Brooks, J.A. and Tinkham, D.J., 2007, Insights into the Wisconsin Deglaciation of the Lakes Region, New Hampshire. Poster presentation at the 42nd Annual Meeting of the Northeastern Section of the Geological Society of America, University of New Hampshire, Durham, New Hampshire.

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Brooks, J.A., 2004, Surficial Geology of the Northwood, 7.5 minute Quadrangle, Strafford and Rockingham Counties, New Hampshire, scale 1:24,000, NH Geologic Survey open file report.

Tinkham, D.J. and Brooks, J.A., 2003, Surficial Geology of the Northfield, 7.5 minute Quadrangle, Merrimack County, New Hampshire, scale 1:24,000, NH Geologic Survey open file report.

Brooks, J.A. and Tinkham, D.J., 2002, Surficial Geology of the Laconia, 7.5 minute Quadrangle, Belknap County, New Hampshire, scale 1:24,000, NH Geologic Survey open file report.

Emery, J.M., and Tinkham, D.J., 1992, “Groundwater Exploration and Development in Fractured Bedrock in the Piedmont,” American Water Resources Association -- National Symposium on “Future Availability of Groundwater Resources”.

Hardcastle, K.C., Brooks, J.A., Emery, J.M., and Tinkham, D.J., 1991, Remote Sensing of Groundwater-Controlling, Bedrock Fracture Systems: Photolineament and Magnetometer Analyses in the Culpeper Basin, Virginia, Geol. Soc. Am., Abs. and Prog., v. 23, no. 1, p. 41.

**DANIEL TINKHAM, M.S., P.G. (continued)**

Tinkham, Daniel J., Taylor, Keith R., Olafsen-Lackey, Susan, “Influence of Geomorphic Variables on the Yield of Bedrock Wells in the Northern Virginia Piedmont”, presented at “A Conference on Groundwater in the Piedmont of the Eastern U.S.”, Charlotte, NC (October 1989).

Selected speaker, Short Course on Ground Water Protection, Antioch College, Keene, NH, March, 1992.

Selected guest speaker on river dynamics at a meeting of the Pemigewasset Wild and Scenic River Study Committee, February, 1992.

**KEN HARDCASTLE, Ph.D., P.G.**  
*Senior Project Manager and Senior Scientist*

An integral EGGI team member since 1989, Ken Hardcastle is an experienced senior structural geologist who has focused his technical career on groundwater exploration and development. He is a recognized leading expert in utilizing satellite images and aerial photography in conjunction with detailed geologic mapping. Dr. Hardcastle's contribution to the delineation of favorable groundwater development sites has been instrumental in identifying high yield wells suitable for use as public supplies and/or commercial purposes. He has supervised or participated in over 800 groundwater investigations throughout the Eastern United States and the Dominican Republic at EGGI.



Dr. Hardcastle has an advanced understanding of: Senior Project Management; Regional (large-scale) groundwater exploration and development projects; remote sensing analysis, imagery manipulation and enhancement; geologic mapping with emphasis on brittle crust and fluid flow evaluations; mapping and interpretation of bedrock structural features; geophysical surveys (collection and analyses of data); development of software for the analysis of geophysical, lineament, fracture, and brittle fault data; design of protocols/templates for use with AutoCad and GIS software; database design, development, management and integration with GIS; and computer network design, management, and utilization.

Education

Doctoral (Ph.D.) in Structural Geology, University of Massachusetts, Amherst. “Analysis of faults and fracture-fillings along a cross section of the New England Appalachians: Clues to the later, brittle evolution of an orogenic belt.”

Dissertation directed by Dr. Don Wise, pioneer of lineament and fracture analysis methods.

Masters (M.S.) in Geology, Queens College of the City, University of New York. “Rb/Sr and Sm/Nd geochemical constraints on the age and evolution of the Irumide and Zambezi mobile belts, Zambia, Africa.”

M.S. research at Lamont Doherty Geological Observatory of Columbia University, New York.  
Bachelors (A.B.) in Geology, Occidental College, Los Angeles, California.

Specialty Studies:

University of Wisconsin-Madison, College of Engineering, “Groundwater Flow Through Fractured Media,” March, 1992.

**KEN HARDCASTLE, Ph.D., P.G. (continued)**

Quantitative Interpretation of Joints and Faults, Annual Meeting of the Geological Society of America, November, 1989.

Professional Certifications, Memberships, and Contributions to the Professional Advancement of Geology/Hydrogeology

Peer Reviewer of Scientific Manuscripts for the Professional Journal, “Ground Water,” published by the Association of Groundwater Scientists and Engineers – A division of the National Groundwater Association

Co-Chair at Symposium on Joints and Other Discontinuities at the National Meeting of the Geological Society of America, 2000

Chair at Symposium on Practical Methods for Evaluation of Groundwater In Fractured Bedrock at the Northeast Section Meeting of the Geological Society of America, 1993

Georgia Certified Professional Geologist No. 1154  
Virginia Certified Professional Geologist No. 990  
Geological Society of America  
National Groundwater Association  
New Hampshire Geological Society

Papers and Honors

Foster, P.J., Emery, J.M., and Hardcastle, K.C., 2012, The Impacts of the Earthquake that Struck Near Mineral Virginia on Groundwater Resources in Northern Virginia. Oral presentation at the 61st Annual Meeting of the Southeastern Section of the Geological Society of America, Asheville, North Carolina.

Emery, J.M. and Hardcastle, K.C., 2011, Abstract, The Impacts on Groundwater Resources in Northern Virginia that were caused by the recent 5.8-Magnitude Earthquake in Mineral, Virginia.

Hardcastle, K.C., Brooks, J.A., and Tinkham, D.J., 2007, DEM Analysis for Surficial Mapping in the Lakes Region, New Hampshire. Poster presentation at the 42nd Annual Meeting of the Northeastern Section of the Geological Society of America, University of New Hampshire, Durham, New Hampshire.

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**KEN HARDCASTLE, Ph.D., P.G. (continued)**

Wise, D.U., Mabee, S.B., and Hardcastle, K.C., 2003, Preliminary geology and assessment of groundwater potential at Cresta de Sacramento, Palpa, Peru, presented to the Mayor of Cresta de Sacramento, Peru.

Brooks, J.A., Hardcastle, K.C., Allen, R.P., Foster, P.J., Howard, P.E., 2002, Geophysical Investigation of Groundwater Contamination, Case Study of the Laurel Valley Landfill, Culpeper, Virginia, EEGS Proceedings of the Symposium on the Application of Geophysics to Environmental and Engineering Problems.

Mabee, S.B., Curry, P.J., and Hardcastle, K.C., 2002, Correlation of Lineaments to Groundwater Inflows in a Bedrock Tunnel, *Ground Water*, v. 40, no. 1, p. 37-43.

Williams, K.W., Mabee, S.B., Curry, P.J., and Hardcastle, K.C., 2001, Surface vs. Subsurface Fracture Characteristics along Cross Strike Transect in Eastern Massachusetts, *GSA Abstracts with Programs*, vol. 33, no. 6.

Mabee, S.B., Curry, P.J., and Hardcastle, K.C., 2001, Correlation of Lineaments to Ground Water Inflows in the MWRA Tunnel, *GSA Abstract with Programs*, vol. 33, no. 6.

Kratt, C., and Hardcastle, K.C., 2001, Mapping Reproducible Lineaments using Digital Elevation Models, *GSA Abstracts with Programs*, vol. 33, no. 6.

Williams, K.W., Curry, P.J., Mabee, S.B., and Hardcastle, K.C., 1999, Surface and Subsurface Fracture Characterization and Correlation Along a Cross-strike Transect in Eastern Massachusetts, *American Geophysical Union*, abstract H51B-04.

Curry, P.J., Hardcastle, K.C., Mabee, S.B., and Williams, K.W., 1999, Factors Influencing Groundwater Inflows in a Newly Constructed Cross-Strike Tunnel, Eastern Massachusetts: Lineaments and Subsurface Structures, *GSA Abstracts with Programs*, vol. 31, no. 7.

Hardcastle, K.C., Curry, P.J., Williams, K.W., and Mabee, S.B., 1999, Factors Influencing Groundwater Inflows in a Newly Constructed Cross-Strike Tunnel, Eastern Massachusetts: Fracture-Supported Coincident Lineaments and Subsurface Structures, *GSA Abstracts with Programs*, vol. 31, no. 7.

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Hardcastle, K.C., 1998, Lineament Fabric of Tenants Harbor, Maine, Northeast Section Geol. Soc. Am., Abs. and Prog., v. 30, no. 1.

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Mabee, S.B., and Hardcastle, K.C., 1997, Analyzing Outcrop-Scale Fracture Features to Supplement Investigations of Bedrock Aquifers, Hydrogeology Journal, v. 5, no. 4, pp. 21-36.

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Mabee, S.B. and Hardcastle, K.C., 1996, Fracture Characterization – Valuable Inputs for Modeling Groundwater Flow in Fractured Bedrock, Northeast Section Geol. Soc. Am., Abs. and Prog., v. 28, no. 3, p. 77.

Mabee, S.B., and Hardcastle, K.C., 1995, Use of Outcrop-based Observations as Indicators of Subsurface Fluid Flow in Fractured Grandiorite, Raymond, California, Geol. Soc. Am., Abs. and Prog., v. 27, no. 6, p. A-105.

Mabee, S.B., Hardcastle, K.C., and Wise, D.U., 1994, A Method of Collecting and Analyzing Lineaments for Regional-Scale Fractured-Bedrock Aquifer Studies, Ground Water, v. 21, no. 6, p. 884-894.

Hardcastle, K.C., 1995, Photolineament Factor: A New Computer-Aided Method for Remotely Sensing the Degree to Which Bedrock is Fractured, Photogrammetric Engineering and Remote Sensing, v. 61, no. 6, pp. 739-747.

Chair at Symposium on Practical Methods for Evaluation of Groundwater In Fractured Bedrock at the Northeast Section Meeting of the Geological Society of America, 1993.

Hardcastle, 1993, Fracture Fabric of the Mesozoic Culpeper Basin and Adjacent, Pre-Triassic Crystalline Rocks, invited to the Northeast Section Geol. Soc. Am., Abs. and Prog., v. 25, no. 2, pp. 21-22.

Hardcastle, K.C., 1992, Correlation of Lineaments and Fracture Fabric in the Piedmont:



**KEN HARDCASTLE, Ph.D., P.G. (continued)**

Implications for the Study of Fractured Bedrock Aquifers, *Geol. Soc. Am., Abs. and Prog.*, v. 24, no. 2, p. 19.

Brooks, J.A. and Hardcastle, K.C., 1992, Magnetics and the Detection of Sub-Surface Water-Bearing Zones, Culpeper Basin, Virginia, *Geol. Soc. Am., Abs. and Prog.*, v. 24, no. 2, p. 5.

Wise, D.U. and Hardcastle, K.C., 1992, Field Evidence for Paleo-Seismic Patterns Across New England, invited to the American Geophysical Union, v. 73, no. 14, p. 306.

Hardcastle, K.C. and Hills, L.S., 1991, BRUTE3 & SELECT: QuickBASIC 4 programs for determination of stress tensor configurations and separation of heterogeneous populations of fault-slip data, *Computers & Geoscience*, v. 17, no. 1, 23-43.

Hardcastle, K.C., Brooks, J.A., Emery, J.M., and Tinkham, D.J., 1991, Remote Sensing of Groundwater-Controlling, Bedrock Fracture Systems: Photolineament and Magnetometer Analyses in the Culpeper Basin, Virginia, *Geol. Soc. Am., Abs. and Prog.*, v. 23, no. 1, p. 41.

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## **EGGI CLIENT STATEMENTS**

*“Cobb County-Marietta Water Authority is developing groundwater to supplement our surface water supply. We went through a detailed procurement process to select an experienced groundwater consultant for identifying potential well sites in Cobb County ... Emery & Garrett Groundwater, Inc. was ranked the highest of all firms and was selected to look at the entire County for us ... We were very pleased with their product ... I highly recommend Emery & Garrett Groundwater, Inc. for any groundwater exploration and development project.”*

### **Dr. Philip R. Karr (General Manager – Cobb County-Marietta Water Authority, GA)**

*“Emery & Garrett Groundwater Investigations have demonstrated hydrogeological expertise by analyzing and resolving complex and unique hydrogeological situations ... They have been relentless in developing solutions to hydrogeological and conservation problems which require advanced or innovative applications of geologic principles ... In my opinion, their work performance is exceptional and their dedication to excellence is noteworthy. Staff has demonstrated a high degree of professionalism and have been able to communicate effectively. Both the field work and the reporting of the project have been completed in a timely manner.”*

### **Nnamdi Madakor (Project Hydrogeologist – Loudon County, VA)**

*“Fauquier County, Virginia, is the fifth largest county in the state. As such, we have an extremely diverse and complicated upland geology that makes groundwater exploration and development very difficult. The entire county’s population base is supported by groundwater ... Emery & Garrett Groundwater has been under contract with the Authority during the past year to explore and develop groundwater in various locations in the county. We have experienced groundwater system failures in older existing communities. Emery & Garrett has been contracted because of their excellent knowledge of Eastern Geology and their expertise in scientifically developing groundwater resources that take into account not only safe yields but the economics of developing the water resource ... We have found their staff to be extremely professional, knowledgeable and they have the ‘can-do’ spirit that so many companies lack. They are the type of company you can turn the project over to and sleep well at night ... I recommend Emery & Garrett to you with complete confidence. We are now using their expertise and we will continue to use them in all our groundwater management, exploration and development.”*

### **Richard E. McNear (Co. Adm. of Planning, Board of Supervisors – Fauquier County, VA)**

*“I think your presentation at the Germanna Technology Center on the status of the Countywide Groundwater Study and groundwater availability in the Triassic Basin was a tremendous success. I received numerous compliments from both staff members and the public on the quality of your presentation and your responses to questions. I think it is a testament to your professionalism and expertise of your employees.”*

### **Paul Howard (Director of Environmental Services – Culpeper County, VA)**

*“My firm has worked closely with James Emery of Emery & Garrett Groundwater since 1987... There was and continues to be much skepticism throughout our industry and at the town and county levels about the ability to identify wells in the Piedmont. Emery & Garrett has eliminated many of the myths and questions dealing with groundwater exploration and many of the biggest critics of groundwater exploration in this area are now their clients... We hold Emery & Garrett Groundwater in the highest regard due to their knowledge, professionalism and responsiveness. We can confidently recommend Mr. Emery without hesitation, and in our opinion, there is no second choice.”*

**Jerome C. O’Connell (President, Intergate, Inc. – Washington, D.C.)**

*“I have had occasion to work with James Emery of Emery and Garrett for approximately four years while he and his associates undertook extensive field investigations of the City of Keene to assist us in preparing a comprehensive groundwater drinking supply plan. Mr. Emery and Dan Tinkham provided outstanding assistance to the City, evidencing considerable technical competence. They provided a wide range of services from hydro-geologic mapping to field electromagnetic and radar surveys, to test drilling, to pump tests, to the delineation of watershed areas — primary/secondary and tertiary zones of contribution and the preparation of draft wellhead protection regulations .... For these reasons, I would not hesitate to recommend the firm of Emery and Garrett for any work associated with groundwater exploration, monitoring or protection. I would recommend them in the strongest possible terms and would be quite willing to provide anyone who might be interested with additional information.”*

**Peter C. Ryner (Planning Director – City of Keene, NH)**

*“I would like to take this opportunity to commend and thank Emery & Garrett Groundwater, Inc. for the professional guidance provided in developing a major water source in the National Forest for the Sanitary District. The complex geology presented multiple obstacles not only in the study and hydrogeological phases, but in the test wells and production well drilling phases, as well. However, your staff’s technical expertise, coupled with good old-fashioned logic and teamwork, maximized our situation by locating a well that should provide us adequate water supply for several decades. It is truly rare to have the pleasure to work with consultants that provide such a high level of professionalism ... Please be assured the Stoney Creek Sanitary District would gladly recommend Emery & Garrett Groundwater, Inc. to other municipal entities.”*

**Rodney W. McClain (General Manager – Stoney Creek Sanitary District, Basye, VA)**

*“Thanks to your expertise and skills, we’ve saved our water source ... While others in the area continue to dig wells producing poor quality water, your studies have led us to several high quality, high production sources ... We’re now convinced that the geologic studies are more than worthwhile, they’re essential.”*

**Gary W. Weaver (President, Trifam Systems, Inc. – Oakton, VA)**

*“I want to commend you on the quality of the study you did for the Clinton Water District. In it, you have organized a remarkable body of scientific knowledge into a readily understandable policy instrument ... the study not only describes convincingly Clinton’s groundwater sources and water quality, but lays to rest often heard concerns about feared contamination the data does not support ... The findings and recommendations are presented in understandable terms. It is clear that public input was valued throughout the data collection process. It seems rare to find a consultant who so clearly grasps both scientific and political realities ... Please feel free to use my name as a reference.”*

**Peter Nielsen (Town Manager – Town of Clinton, ME)**

*“Your professionalism and ability to present complex technical details are very impressive. Your staff shares your commitment to go beyond the normal and expected tasks. I look forward to the next time that the DEP selects EGGI to work on a High-Priority Oil Remediation Project.”*

**Tom Benn (Project Manager – Department of Environmental Protection, State of ME)**

*“Never in my twenty plus years (as a County Administrator) have I had the pleasure of being responsible for a contract that was accomplished in such professional, conscientious and timely manner. Your knowledge, technical expertise and public forum abilities are a true credit to your profession.”*

**Richard E. McNear (Co. Adm. of Planning, Board of Supervisors – Fauquier County, VA)**

*“This letter is to express my great appreciation for the work you performed on our Piedmont golf course project. Your staff was always cooperative in problem solving and the hydrogeologic data/map exhibits supplied to me were very impressive. Furthermore, and most importantly, you achieved the required high yield output from selected well sites on time and within budget. It was a pleasure working with you and I look forward to our continuing relationship.”*

**Michael F. Johnson (Project Manager, KSI Services, Inc. – Vienna, VA)**

*“Thank you for all the effort and time you have given us so far in our quest to protect and understand our aquifer. Your presentation at the Planning Board meeting was excellent. We look forward to working with you on the completion of this project.”*

**Donna Woodward (Fryeburg Aquifer Research Committee – Fryeburg, ME)**

*“I’d like to call particular attention to the report itself. Seldom in the paper industry do we see a technical report as well written. It leaves no questions unanswered, as it takes us methodically through the entire process of problem description to recommendations. I’ve last seen such well-written reports dating back to technical writing courses and my early career in the aircraft industry. Congratulations.”*

**W.S. Bridges (Madison Paper Industries – Madison, ME)**

*“EGGI has done many hydrogeologic investigations for private land development proposals over the past several years which have been well prepared and reported and which have reflected the very high education and experience level of EGGI staff. I believe them to a top notch firm ... We have been very pleased with their performance ... I have found James Emery and his staff to be very good to work with due to an up front and honest style and a ‘can do’ professional attitude. I recommend the firm highly.”*

**Robert F. Montgomery (Deputy Director, Dept. of Env. Resources – Loudon County, VA)**

*“During my six years plus, working with Jamie and EGGI, I have seen only the finest quality of hydrogeological services. Their exceptional communication skills keep everyone on the same page as projects move forward. Reports are presented in a timely and understandable manner which allows for a clear picture of each phase of the project and possible future issues that may need to be addressed. EGGI’s overall professionalism and work efforts are unquestionable. Their services should be seriously considered by anyone who has the need for hydrogeologic work.”*

**James A. McSweeney (Superintendent – Merrimack Village District, NH)**

*“In this day and time it seems that most of the focus is directed toward negative issues rather than the positive ones. I feel that it is important to recognize the efforts that are made .... therefore, both Don Moyers (ACSA Water Superintendent) and I feel it is appropriate that you be made aware of the exceptional effort Mr. Dan Tinkham put forth during our recent well pumping tests. Mr. Tinkham was charged with a testing schedule that would have been considered ambitious under the best of conditions .... Mr. Tinkham provided a very valuable service in the way he treated and talked to the local residents. Mr. Tinkham should be commended for his poise and professionalism under extremely arduous conditions. It has been a pleasure working with Dan on this project, and we hope to be able to work with him on future projects.”*

**George J. Gross (Project Engineer – Augusta County Service Authority, VA)**

*“Dear Jamie ... I want to express how much I appreciated your efforts on behalf of the project. You always do an outstanding job. In the end, your abilities, coupled with the proven success of the technologies you incorporate, always provide the necessary assurance decision-makers need in order to protect the best interests of their constituents. I feel strongly that without your efforts on behalf of the application it would never have been approved.”*

**Bruce DeAtley (Development Consultant – Herndon, VA)**





# Emery & Garrett

## Groundwater Investigations

ABBREVIATED COMPANY PROFILE



Recognized Leaders in  
Groundwater Exploration, Development, Management & Protection  
Since 1989

*Solving Water Supply Challenges with the Lowest-Cost, Lowest-Impact Solutions*

### Core Company Focus

Emery & Garrett Groundwater Investigations (EGGI) is a highly specialized and very unique company. Unlike the vast majority of organizations that perform groundwater services globally, we are not an 'engineering', 'general environmental services', or 'drilling' firm. Instead, as our name implies, we are strictly a technical groundwater services company. Since our founding in 1989, our entire corporate focus has been on the exploration, development, protection, sustainable management and enhancement of renewable groundwater resources across a wide variety of hydrogeologic settings.



### Proven Track Record

To our knowledge, no other firm has conducted more successful groundwater exploration and development programs in crystalline rocks, limestone regions, and unconsolidated deposits. Having successfully completed over 1,500 groundwater investigations and developed over 100 million gallons per day of fresh, sustainable drinking water, we are widely considered the most respected and sought after groundwater experts in the Eastern United States.



In over 90% of the cases where groundwater exploration programs have been fully pursued, EGGI has successfully developed groundwater resources sufficient to satisfy our clients' water supply needs. In over 75% of those cases we have actively discovered and developed renewable groundwater supplies from previously unknown and undocumented aquifers.

### Unrivaled Technical Expertise

EGGI's senior team has developed numerous proprietary exploration algorithms over the years, which have continuously proven to be instrumental to our success. One hundred percent (100%) of our senior team has worked together on groundwater exploration programs for the past 25+ years. Collectively, we possess over 150 years of groundwater exploration and development experience amongst us. Our professional staff is highly trained in geology, geochemistry, geophysics, hydrology, remote sensing, and groundwater hydrogeology, and maintain Masters or Ph.D. degrees in their respective scientific disciplines.



### **Regions with Inconsistent & Low Average Yields**

Despite strong aquifer recharge potential, conventional theory holds that groundwater resources in many regions cannot support withdrawals for local industrial, utility and agricultural needs due to challenging hydrogeologic characteristics and low average yields.

### **High-Yielding Wells from Fractured Rock Aquifers**

Despite low average yields, high-yielding wells are feasible when developed within productive bedrock aquifers. The capacity of bedrock to be water-bearing depends to varying degrees on the natural occurrence of laterally extensive fractures, faults, and other bedrock discontinuities, which provide avenues for the storage and transmission of groundwater.

### **Consistent Delineation of Fracture Zones is Critical**

Characterizing these types of aquifers is very complex however, and the ability to predictably identify and develop high-yielding wells from them requires sophisticated groundwater exploration methods and a highly experienced technical team capable of accurately delineating productive features.

### **EGGI Scientists are Experts at Identifying Water-Bearing Fracture Zones**

Since 1989, Emery & Garrett Groundwater Investigations has frequently re-written local groundwater availability theory by predictably identifying favorable drilling targets for high-yield wells. Our success as a groundwater services company is based on an ability to locate high-yielding bedrock wells using proven, low cost, and effective methods, which have saved our clients millions of dollars in avoided infrastructure and future water utility expense.



### **Variable Project Sizes**

Our projects vary considerably in size. Successful hydrogeologic investigations have ranged from large, regional assessments greater than 15,000 square miles, to smaller site-specific projects.

### **Variable Geographies**

While we have focused most of our efforts in the U.S. historically, team members have worked with great success throughout the world, including Africa, South America, and the Caribbean.

## Broad Application of Modern Exploration Technologies

EGGI's scientific program includes the use of satellite imagery, multiple platforms of aerial photography, geologic mapping, bedrock fracture fabric data, geophysical analysis (including aerial, ground surface, and borehole methods), existing well data, statistical analysis, and in situ hydrogeologic testing.

## Enhanced Remote Sensing Assessments

“Fracture trace” or lineament analyses, in conjunction with detailed structural mapping of brittle deformation features, are routinely applied by remote-sensing scientists as practical methods to delineate water-bearing bedrock systems. EGGI's remote sensing scientists utilize specialized software for the enhancement of aerial imagery, multispectral satellite, and digital elevation data (USGS, ASTER, and LiDAR). Unique spectral band combinations, mathematical stretches, artificial lighting from different directions and angles, and hybrid images (combining different types of imagery), are created to best reveal important features otherwise not obvious on topographic maps or standard aerial photographs.

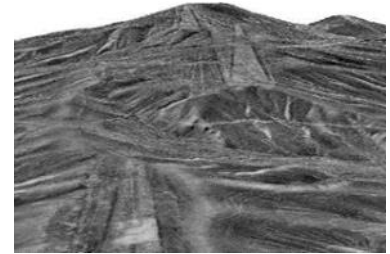
## Key Features Digitally Overlaid & Evaluated

Important geologic, geothermal, structural, karst, and other geomorphic features are then mapped on the imagery created. These features are organized in a digital database for evaluation and processing. Analyses of the data are aided by specialized software developed by EGGI, leading to the identification of lineament factor values, coincident lineaments, rose diagrams, lineament density, etc. These analyses form a key component to any thorough hydrogeologic investigation.

## Geologic Mapping at Local Scale

EGGI scientists have also developed proprietary mapping methods that focus on the identification of geologic features favorable for the development of groundwater resources in fractured bedrock aquifers. Study areas are always mapped at the local scale to refine favorable zones.

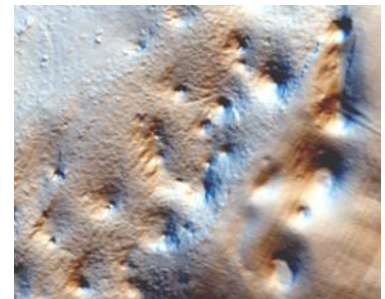
*Terrain Analysis*



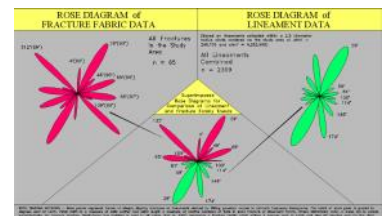
*Lineament Analysis*



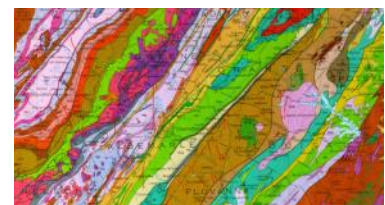
*Sinkhole Assessment*



*Fracture-Fabric Analysis*

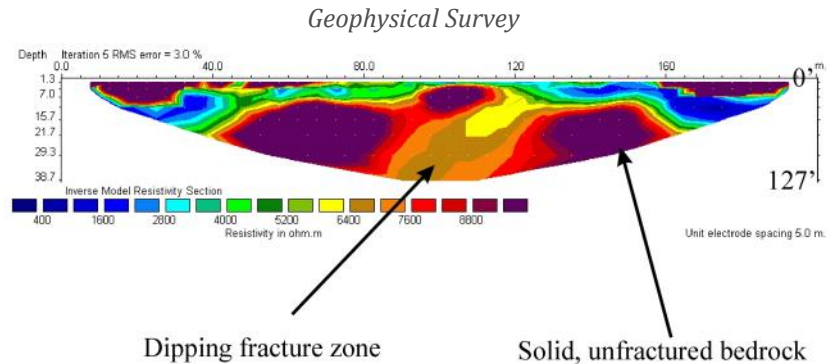


*Geologic Mapping*



## Geophysical Surveying On-Site

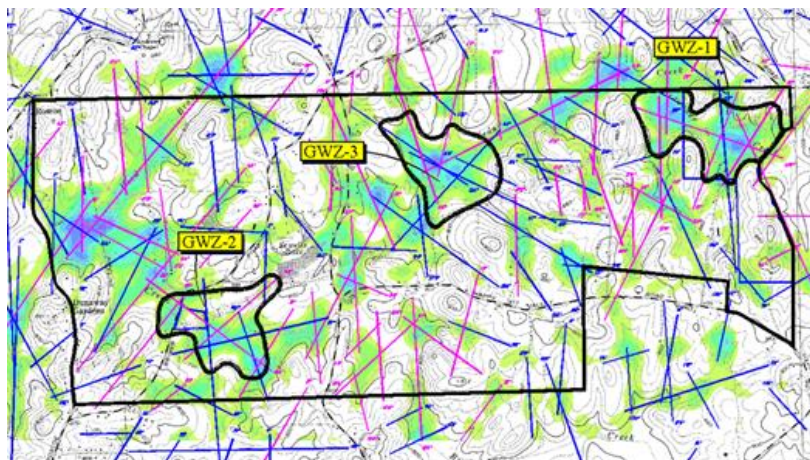
Geologic contacts, fractures, faults, and other bedrock discontinuities commonly cause changes in the physical characteristics of bedrock that can be detected remotely using geophysical instruments. Variations in the magnetic characteristics of rocks, caused by such geologic discontinuities, result in measureable deflections in the earth's magnetic field. Similarly, local variations in the electrical resistivity of the bedrock (and the overlying unconsolidated regolith) create measurable deviations in electromagnetic fields that propagate from VLF radio transmitters. Changes in bedrock resistivity can also be measured using electrical resistivity methods. EGGI routinely conducts a wide range of advanced geophysical surveys to help define the depth to the water table, depth to bedrock, and type of subsurface material (e.g., unconsolidated sediment, saprolite, competent bedrock, and fractured bedrock).



## Compilation of All Gathered Data Enables Identification of Favorable Drilling Targets

Utilizing an overlay of these data sources, EGGI has been very successful in identifying and developing high yield bedrock wells for use by public water authorities, agriculture, power plants, golf courses, residential developments, and other industrial/public entities. In fact, EGGI has successfully developed *hundreds* of high-yielding bedrock wells, which individually produce 100,000 to 1,600,000 gallons per day (gpd) for *hundreds* of public and private clients.

*Favorable Zone Identification*



### No Local Groundwater Withdrawal Impacts

EGGI is committed to only developing private water sources in situations where it is clear that such withdrawals will not adversely impact other existing water users and/or other environmental concerns.

### Groundwater Withdrawal Permitting

EGGI has successfully obtained hundreds of groundwater withdrawal permits as a result of our comprehensive technical investigations, data collection, and full environmental assessments. In all instances, EGGI provides scientific evidence that the withdrawal rates permitted are sustainable, and do not negatively impact the surrounding environment. All of EGGI's wells are designed and developed according to regulatory guidelines.

### Enhancement of Groundwater Yields Using Artificial Recharge

EGGI is a leader in the use of artificial recharge in sand and gravel aquifers, having successfully executed and permitted the very first project of its kind in New England.

Artificial recharge is a process that involves enhancing the natural replenishment of groundwater and has widespread global applicability. Projects are designed to actively induce supplemental infiltration of surface water into aquifers – during periods of excess flow – through dedicated recharge basins. When properly implemented, artificial recharge offers the unique ability to reverse aquifer depletion while storing vast new quantities of freshwater for later use.

As future water supplies become increasingly variable due to climate volatility and prolonged drought, water managers will need incremental storage capacity to balance short-term or long-term disparities in water availability – particularly when new sources of water cannot be secured, are not affordable, or cannot be consistently relied upon. Given the growing environmental challenges, extreme financial and social costs, and long permitting timelines faced by the development of new surface water sources, the use of artificial recharge to enhance existing groundwater supply systems represents an excellent tool that has enormous potential to aid water suppliers in the future.



## EGGI's Core Mission

Existing and prior clients for whom EGGI has conducted groundwater investigations have become our best professional references. To our knowledge, there are no existing or former clients that would choose another technical groundwater firm after having worked with EGGI. This continues to be *Our Mission*. We regularly receive letters from them stating how pleased they are with our services, and we are currently working with dozens of water utilities and others who have contracted us for 15 or more consecutive years.



## Professional Recognition of EGGI

EGGI's promotion of sound scientific solutions to groundwater investigations and water resource protection has resulted in local, state, national, and international recognition for excellence. Over the years, we have been recognized by the U.S. Geological Survey (USGS), the U.S. Environmental Protection Agency (EPA), the U.S. National Ground Water Association (NGWA), the U.S. Geological Society of America, and the World Bank for providing pioneering technical leadership in the field of exploration, development, and management of groundwater resources from fractured bedrock aquifers. Collectively, our team has published over 100 recognized scientific professional papers in this field; many of which continue to be referenced by other scientists conducting research in bedrock hydrogeology globally.





**Jamie Emery, P.G.**

**President and Chief Executive Officer**

- Founder and Principal of EGGI since 1989.
- Supervised or participated in over 1,500 groundwater resource investigations.
- Nationally recognized leader in developing successful groundwater resource assessment and protection techniques.
- Has prepared policies/standards for use by a variety of public agencies for groundwater protection/development programs.
- B.Sc. Geology and Hydrology.



**Peter Garrett, Ph.D., P.G., M.C.G., C.G.W.P.**

**Senior Project Scientist and Senior Scientific Advisor**

- National and international reputation for his contributions to groundwater exploration, development and protection, the fate of MTBE in groundwater, the study of oil spills in groundwater, stormwater as a resource, and the use of artificial recharge of aquifers.
- Featured on the national CBS news program “60 Minutes” regarding MTBE as a groundwater contaminant.
- Ph.D. Geology Geochemistry.



**John Brooks, Ph.D., P.G.**

**Vice President and Senior Project Manager**

- EGGI team member since 1990.
- Industry leader in the delineation of groundwater resources using glacial mapping technology, geophysical survey techniques, and hydrogeological site characterizations.
- Long track record conducting and interpreting geophysical investigations to successfully identify favorable drilling targets for the development of high yield wells.
- Involved in over 800 groundwater investigations with a focus on both fractured bedrock aquifers and unconsolidated aquifers.
- Ph.D. Geophysics.





**Dan Tinkham, M.S., P.G.**

**Vice President and Senior Project Manager**

- EGGI team member since 1989.
- Expert in groundwater protection, recharge, and modeling, as well as aquifer safe yield calculations.
- Involved in over 800 groundwater resource projects investigating groundwater resources.
- M.S. Hydrogeology.



**Ken Hardcastle, Ph.D., P.G.**

**Senior Project Manager**

- EGGI team member since 1989.
- Expert in satellite imagery and aerial photography utilization in conjunction with detailed geologic mapping to delineate favorable groundwater development sites.
- Remote sensing contributions have been instrumental to EGGI's groundwater investigations for large regional studies.
- Has participated in over 800 groundwater investigations with a particular focus on fractured bedrock aquifers.
- Ph.D. Structural Geology and MSc Geology.



**Jeff Marts, B.S., P.G.**

**Hydrogeologist**

- EGGI team member since 1996.
- Expertise includes geologic mapping, pump test analysis, and geophysical investigations.
- Involved in over 700 projects exploring for and/or investigating groundwater resources.
- B.S. Geology.



**Mark Wingsted, M.S., P.G.**

**Hydrogeologist and Geologist**

- EGGI team member since 1997.
- Expertise includes geologic mapping, bedrock fracture fabric analyses, field assessments and geophysical investigations.
- Involved in over 650 projects investigating groundwater resources.
- M.S. Geology.



**Peter Foster, M.S.**

**Hydrogeologist**

- EGGI team member since 2000.
- Expertise includes coordinating groundwater testing programs, groundwater modeling, and coordination and supervision of hydrogeologic field investigations.
- Involved in over 500 projects investigating groundwater resources.
- M.S. Hydrology.



**Mike O'Brien, B.S.**

**Geologist**

- EGGI team member since 2005.
- Expertise includes geologic mapping, geophysical surveys, and planning and performing pumping tests to assess aquifer yield and quality.
- Participated in or managed over 100 water supply projects investigating groundwater resources.
- B.S. Geology.



**Emery & Garrett**  
**Groundwater Investigations, LLC**

56 Main Street  
Meredith, NH 03253

James M. Emery  
Phone: (603) 279-4425  
Email: [jme@eggi.com](mailto:jme@eggi.com)

# PROJECT DESCRIPTIONS

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***Fax +1 (603) 279-8717***

**EXAMPLE ADVANCED REGIONAL  
GROUNDWATER AVAILABILITY ASSESSMENTS**

**(PARTIAL LIST)**



## Countrywide Advanced Groundwater Resources Assessment – Dominican Republic



Portions of the Dominican Republic (“DR”) are arid and the Country’s water supply situation is increasingly dire. New supplies of affordable, fresh and sustainable water are needed. Groundwater resources have been overlooked and under-investigated; in many regions far more renewable groundwater than previously realized can be utilized to meet current and future demands. These critical resources must be better understood to enable their sustainable utilization, and to help ensure their protection for future generations.

EGGI was selected by a \$6 billion international consortium – with extensive interests throughout the DR – to design and complete a *first-of-its-kind* countrywide advanced groundwater resources assessment. The Client was seeking an accurate, forward-looking assessment of the Country’s groundwater supplies in light of existing water supply challenges, anticipated increased shortages, and the time delays and costs associated with developing new surface water supplies. The client’s specific motivations for commissioning the study included desires to:

- Ensure adequate on-going water supplies to maintain and expand its existing core operations (including agriculture, mining and real estate concerns);
- Uncover compelling new opportunities for development in areas throughout the Country *previously deemed* to lack sufficient renewable water supplies; and
- *Facilitate national sustainable groundwater management efforts*, to help preserve the DR’s increasingly precious groundwater supplies for future generations.

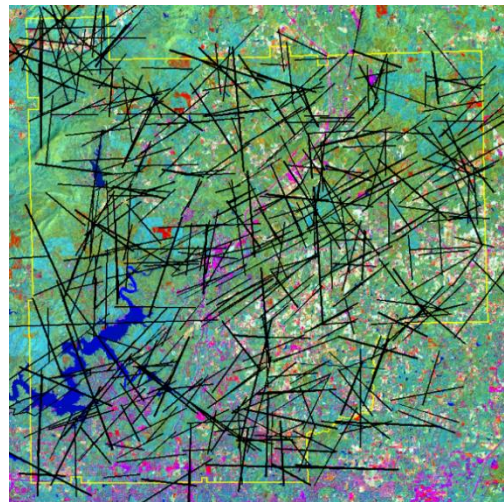
EGGI evaluated the potential to sustainably develop new groundwater resources – for both potable and non-potable use – across the *entire* Country; a Study Area of roughly 48,000 km<sup>2</sup>. EGGI applied a numerical model approach to determine which hydrogeologic settings were most favorable for groundwater development, and incorporated data sets covering (i) groundwater recharge favorability (including rainfall, aridity, drainage density, etc.) and (ii) hydrogeologic favorability (incorporating bedrock type and structure, nature of unconsolidated deposits, occurrence and trend of remotely sensed lineaments, etc.).

## Countrywide Advanced Groundwater Resources Assessment – Dominican Republic (continued)

As part of the comprehensive resource investigation, EGGI scientists assessed all of the hydrogeologic settings within the DR, including unconsolidated deposits, karst, and fractured bedrock aquifers; identified and analyzed, using proprietary EGGI software programs, a total of 79,857 lineaments; and created the *first ever* consistent countrywide permeability ranking of all described geologic units within the DR.

The ultimate Regional Numeric Groundwater Favorability Model, incorporating insights gained through EGGI's rigorous evaluation, numerically categorized and objectively ranked each and every 100 square meters in the DR relative to that location's potential to obtain sufficient recharge and produce significant new groundwater resources. **The model formed the basis for the creation of National and Province-based Regional Groundwater Favorability Contour Maps, enabling the assessment of relative groundwater resource development potential at any given location, anywhere in the Country.**

- In several cases, arid regions widely assumed *not* to possess any meaningful levels of renewable groundwater resources were rated Moderately Favorable to More Favorable for new groundwater development potential.
- **Opportunities to meet unmet critical demands with low-cost, sustainable groundwater development were uncovered in areas where groundwater was previously not thought to be a viable supply.**
- Areas were identified where *proactive* sustainable groundwater management efforts are necessary to prevent fresh resources from being lost forever.





Emery & Garrett  
GROUNDWATER INVESTIGATIONS

Consulting Hydrogeologists Since 1989

**Countrywide Advanced Groundwater Resources Assessment – Dominican Republic**

*(continued)*

**Relevance to the Groundwater Resources Assessment for the Panama Project:**

- Delineation of potential groundwater aquifers, and their distribution across the DR, enhanced knowledge of potential groundwater resource occurrence throughout the Country.
- Assessed all of the varying hydrogeologic settings within the DR, including unconsolidated deposits, karst, and fractured bedrock aquifers.
- Assessed bedrock geology, bedrock fracture fabric (remote sensing lineament analysis), groundwater recharge, and potential contaminant threats that could impact groundwater quality.
- Prepared summary hydrogeologic report which included digital geologic and hydrogeological maps of the entire country.
- Public water agencies actively exploring opportunities to use the maps – in coordination with other socio-economic data – to determine optimal areas for specific *follow-on* groundwater development projects.



## Regional Advanced Groundwater Resources Assessment – Atlanta Regional Planning Commission, Georgia



The Atlanta Regional Commission (ARC) is the regional planning and intergovernmental coordination agency for the 10-County area surrounding the City of Atlanta, Georgia. With the State experiencing rapid population growth, and increased incidence and severity of drought, the ARC thought it prudent to evaluate the groundwater resources available in their region.

After a competitive review, EGGI was selected to complete a detailed GIS-based analysis of the entire 10-County region, comprising a roughly 8,000 km<sup>2</sup> Study Area. EGGI determined what regional areas were favorable based upon a detailed evaluation of rock type, geologic setting, presence of major contaminant threats, and other important hydrogeological factors. Land masses in each County that were deemed to be unfavorable for groundwater development were subsequently

excluded from further consideration. Each County was objectively ranked in terms of its overall Favorability for new groundwater development. During later phases of investigation, Favorable sub-areas within each county were identified for specific groundwater development activities.

***EGGI's regional investigation determined that over 100 MGD of previously undetected renewable groundwater resources could be sustainably developed within the 10-County region.*** EGGI has identified nearly 15 MGD of new groundwater resources at site-specific locations within three of the ten Counties to-date, and continues to consistently identify and develop *new*, high-yield groundwater resources throughout the hydrogeologically complex northern Georgia region.

### Relevance to the Groundwater Resources Assessment for the Panama Project:

- Ranking of hydrogeologic favorability of various rock units throughout the ARC-area; enhanced knowledge of potential groundwater resources occurrence across 10 Counties.
- Assessment of geology, groundwater recharge, and potential contaminant threats that could impact groundwater quality.
- Made conclusions regarding the availability and development potential of groundwater resources in the ten Counties.
- Prepared digital geologic and hydrogeological maps of the entire 10-County area.



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GROUNDWATER INVESTIGATIONS

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## **Regional Advanced Groundwater Resources Assessment – Noble Energy & CONSOL Energy, Marcellus Shale, Pennsylvania & West Virginia**

As the unconventional Gas industry continues to expand, access to local, low-cost, sustainable and dependable water sources is becoming a growing challenge to Operators throughout the Marcellus Shale play. While costs and permitting timelines for surface water supplies continue to increase, groundwater sourcing by the industry remains *highly limited* given some of the U.S. Eastern Seaboard’s *most challenging* hydrogeological terrains.

After completing a rigorous competitive review, the joint venture between Noble Energy & CONSOL Energy – *two of the largest and most active Operators in the region* – selected EGGI to conduct an advanced regional groundwater investigation across roughly 225 square miles of the companies’ combined land positions. The stated project goal was to find and source *new* high-yield, sustainable groundwater supplies local to the Clients’ existing well pads and centralized water infrastructure. While announcing the contract award, the Clients noted “*after having vetted every possibility, **we’re confident there’s no one else in the industry looking at groundwater resources the way EGGI is. We believe you give us the best chance for success.***”

As a result of the first phase of EGGI’s assessment, 23 potential Groundwater Development Zones (GDZs) were selected that are considered to be hydrogeologically preferred for further investigation relative to developing new groundwater resources. These Zones were based upon the evaluation of both geologic and hydrogeologic factors, including:

- Detailed geologic mapping;
- Remote sensing analysis of different maps, images, and platforms (a total of eight platforms);
- Bedrock fracture fabric analysis;
- Preliminary contaminant threats analysis;
- Preliminary groundwater recharge potential; and
- Geophysical surveys.

This project is on-going. Based upon the hydrogeologic data collected to date, EGGI believes that it may be possible to develop new groundwater resources to meet a significant portion of their water needs – in areas previously deemed *not* capable of producing meaningful groundwater supplies –from a series of wells drilled in selected Groundwater Development Zones.

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## GROUNDWATER INVESTIGATIONS

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### Regional Advanced Groundwater Resources Assessment – Noble Energy & CONSOL Energy, Marcellus Shale, Pennsylvania & West Virginia (*continued*)



#### Relevance to the Groundwater Resources Assessment for the Panama Project:

- Delineated potential groundwater aquifers and their distribution within a 225 square mile Study Area, enhanced knowledge of regional groundwater resources occurrence.
- Evaluation of potential groundwater availability from local fractured bedrock aquifer sources.
- Assessment of regional geology, detailed bedrock fracture fabric, groundwater recharge, and potential contaminant threats that could impact groundwater quality.
- Conducted geophysical surveys throughout “*priority ranked*” sub-areas that were identified as favorable for groundwater development (per Phase I hydrogeologic investigation).
- Selected and “*priority ranked*” exploratory test well drilling targets throughout the Study Area.
- Prepared detailed summary report which included digital geologic and hydrogeological maps of the entire Study Area.

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## GROUNDWATER INVESTIGATIONS

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### Countywide Advanced Groundwater Resources Assessment – Cobb County- Marietta Water Authority, Georgia



After a comprehensive competitive bid review, EGGI was selected to conduct a Countywide (365 mi<sup>2</sup>) groundwater resources investigation for the Cobb County-Marietta Water Authority (CCMWA), *the second largest water purveyor in the State of Georgia*. EGGI was hired to assess and map the occurrence and distribution of *all* groundwater resources throughout the County, including conducting a bedrock aquifer exploration and development program.

EGGI synthesized hydrogeologic parameters based on detailed field investigations to locate 11 primary subareas within the County considered favorable for potable groundwater resource development. Based upon geotechnical data collected, including photolineament analysis, bedrock mapping, bedrock fracture fabric analysis, and geophysical surveys, **a total of 10-15 million gallons per day was projected to be available for groundwater supply development from bedrock aquifers**. All sites selected had an extensive contaminant threat review to assure that wellhead protection measures could be implemented.

EGGI's detailed report and analysis of the County's groundwater resources received high acclaim from the Georgia Geological Survey, United States Geological Survey (USGS), and the Cobb County-Marietta Water Authority.



EGGI's discoveries enabled the CCMWA to make important decisions regarding available water resources. **Nearly 1 million gallons per day were developed from just the first two wells drilled into crystalline rocks of the Georgia Piedmont province**. Additional high yield bedrock wells were drilled around the County, some yielding as much as **600 gpm (0.9 MGD)**. Assessments of off-site impacts to groundwater withdrawals from these bedrock aquifers was required as part of this investigation.



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GROUNDWATER INVESTIGATIONS

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### **Countywide Advanced Groundwater Resources Assessment – Cobb County-Marietta Water Authority, Georgia (*continued*)**

*"Cobb County-Marietta Water Authority is developing groundwater to supplement our surface water supply. We went through a process at the end of 1990 to select an experienced groundwater consultant for identifying potential well sites in Cobb County ... Emery & Garrett Groundwater, Inc. was selected to look at the entire County for us ... We were very pleased with their product ... I highly recommend Emery & Garrett."*

- Dr. Philip Carr, General Manager, Cobb County-Marietta Water Authority, Georgia

#### **Relevance to the Groundwater Resources Assessment for the Panama Project:**

- Regional delineation of potential groundwater aquifers and their distribution across 365 square miles; discovered and successfully developed material new groundwater supplies; enhanced knowledge of regional groundwater resources occurrence.
- Evaluation of groundwater availability from local fractured bedrock aquifer sources.
- Assessment of regional geology, detailed bedrock fracture fabric, groundwater recharge, and potential contaminant threats that could impact groundwater quality.
- Conducted geophysical surveys throughout "***priority ranked***" sub-areas that were identified as favorable for groundwater development (per Phase I hydrogeologic investigation).
- Selected and "***priority ranked***" exploratory test well drilling targets within Cobb County.
- Prepared summary hydrogeological report which included digital geologic and hydrogeological maps of the entire County.

## Countywide Advanced Groundwater Resources Assessment – Douglas County, Douglasville-Douglas County Water & Sanitation Authority, Georgia

EGGI was selected, after a competitive review, to assess and map the occurrence and distribution of groundwater resources for Douglas County on behalf of the Douglasville-Douglas County Water and Sanitation Authority (DDCWSA). Due to the increased demand for water resources throughout northern Georgia – and the overall uncertainties of surface water availability in the future from water sources that require obtaining permits from the US Army Corp – Douglas County chose to investigate the potential to identify and develop new groundwater resources.



EGGI proceeded with a phased approach to groundwater exploration and development. This study resulted in the identification and **“priority ranking”** of 24 Favorable Groundwater Development Zones (Phase I); it was determined/estimated that **in excess of 5 million gallons per day of new previously undiscovered groundwater sources could be developed**. Phase II geophysical surveys were completed in the six Most Favorable Groundwater Development Areas and resulted in the identification of 69

favorable exploratory test well sites. All drilling targets were **“priority ranked”** according to their favorability to produce wells of high yield.

### Relevance to the Groundwater Resources Assessment for the Panama Project:

- Delineation of potential groundwater aquifers and their distribution throughout a large Regional Study Area.
- Evaluation, characterization, and mapping of groundwater availability from local bedrock aquifers.
- Assessment of regional geology, bedrock fracture fabric, groundwater recharge, and potential contaminant threats that could impact groundwater quality and availability.
- Prepared summary reports with digital geologic and hydrogeological maps of the Regional Study Area.
- The results of the study highlighted areas where detailed geologic mapping, geophysical surveys, and exploratory test well drilling should be conducted for the development of significant groundwater resources.

## Countywide Advanced Groundwater Resources Assessment – Etowah Water & Sewer Authority, Dawson County, Georgia



Planning for the future, the Etowah Water & Sewer Authority selected EGGI to assess and map the occurrence and distribution of groundwater resources throughout the entirety of Dawson County.

EGGI's groundwater investigation efforts included detailed bedrock mapping, remote sensing studies to map potentially water-bearing bedrock structures, analyses of newly created hybrid images based on digital elevation model data, assessment of available groundwater recharge data, and the evaluation of potential threats to groundwater quality.

Products of this Phase I investigation included the identification of Groundwater Development Zones (sub-areas within the County) that overlie high-yield bedrock aquifers. Each of these Zones were priority ranked according to their favorability for developing substantial groundwater resources. Groundwater Development Zones were then selected for further investigation through the use of geophysical surveys. Geophysical surveys were carried out with the sole purpose of investigating the subsurface geology in order to select exploratory drilling targets.



A number of very favorable exploratory test well drilling targets have been identified and “*priority ranked*” based on the analysis of the geophysical and hydrogeologic data collected during the investigation. This project is ongoing.

### Relevance to the Groundwater Resources Assessment for the Panama Project:

- Delineation of potential groundwater aquifers and their distribution across a large Regional Study Area, enhancing knowledge of groundwater resource occurrence.
- Assessment of regional geology, bedrock fracture fabric, groundwater recharge, and potential contaminant threats that could impact groundwater quality.
- Identified and “*priority ranked*” exploratory test well drilling targets within the County.
- Prepared summary report with digital geologic and hydrogeological maps of the County.

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## GROUNDWATER INVESTIGATIONS

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### Countywide Advanced Groundwater Resources Assessment – Forsyth County Department of Water & Sewer Authority, Georgia



The Forsyth County Water and Sewer Authority contracted EGGI to assess and map the occurrence of groundwater resources from fractured bedrock aquifers throughout the entire 225 square mile area of the County. Underlain by a complex assemblage of crystalline bedrock geologic units, EGGI geologists and remote sensing scientists conducted a comprehensive groundwater exploration and development program that included a series of investigation phases. The results of the Phase I investigation led to the delineation of favorable

Groundwater Development Zones. Phase II geophysical surveys were then completed within 29 selected zones, resulting in the identification of 157 exploratory test well sites. These test well sites were “*priority ranked*” in the order of geologic favorability. EGGI has completed Phases I and II of this multi-phase exploration program. In preparation for Phase III test well drilling, permits for selected Primary exploratory test well sites have been obtained from the EPD and permission has also been obtained from private landowners to drill a significant number of the selected sites.

#### Relevance to the Groundwater Resources Assessment for the Panama Project:

- Identified potential groundwater aquifers and their distribution across a large Regional Study Area, enhancing knowledge of groundwater resource occurrence.
- Assessment of regional geology, bedrock fracture fabric, groundwater recharge, and potential contaminant threats that could impact groundwater quality.
- Conducted geophysical surveys throughout “*priority ranked*” sub-areas that were identified as favorable for groundwater development (per Phase I hydrogeologic investigation).
- Identified and “*priority ranked*” exploratory test well drilling targets within the County.





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## GROUNDWATER INVESTIGATIONS

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### Countywide Advanced Groundwater Resources Assessment – Cherokee County Water & Sewer Authority, Georgia



In light of anticipated water demand increases throughout Cherokee County, the expanding competition for surface water resources, and the time delays and costs associated with developing new surface water supplies, the Cherokee County Water and Sewer Authority (CCWSA) felt it prudent to investigate the availability of groundwater resources within Cherokee County. Groundwater resource developed within the County will be used to meet peak water supply demands and to supplement existing surface water sources. With this goal in mind, EGGI was selected by the Authority to conduct a Countywide groundwater exploration and development program.

EGGI has successfully completed its rigorous Phases I and II of this Countywide study and has identified Groundwater Development Zones (sub-areas) and exploratory drilling targets throughout the County. Drilling has been recommended for the fifty (50) most favorable (*“priority ranked”*) exploratory test well sites selected during the study. This project is ongoing.

#### Relevance to the Groundwater Resources Assessment for the Panama Project:

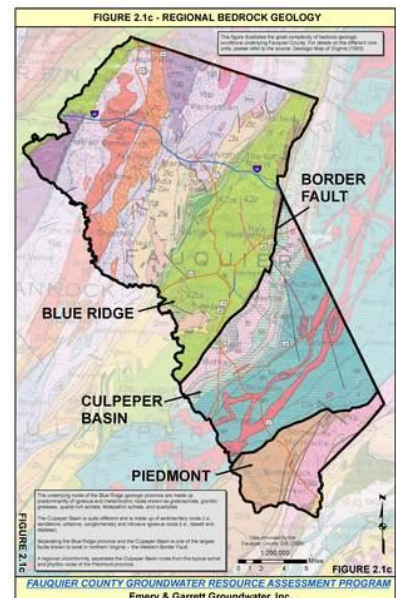
- Identified potential groundwater aquifers and their distribution across a large Regional Study Area, enhancing knowledge of regional groundwater resource occurrence.
- Assessment of regional geology, bedrock fracture fabric, groundwater recharge, and potential contaminant threats that could impact groundwater quality.
- Conducted geophysical surveys throughout *“priority ranked”* sub-areas that were identified as favorable for groundwater development (per Phase I hydrogeologic investigation).
- Selected and *“priority ranked”* exploratory test well drilling targets within Cherokee County.
- Prepared summary report with digital geologic and hydrogeological maps of the County.



## Countywide Advanced Groundwater Resources Assessment – Fauquier County Water & Sanitation Authority, Virginia

After a qualifications review of 15 firms, EGGI was selected jointly by the County of Fauquier and Fauquier County Water & Sanitation Authority (FCWSA) to conduct a Countywide groundwater investigation. The objective of the groundwater study was to assess the availability and protectability of new sources of groundwater from bedrock aquifers within specific County-designated areas. New water sources developed would replace existing supplies currently servicing the FCWSA. The County had struggled for nearly 20 years with insufficient water supplies and lack of a groundwater development plan.

**EGGI's comprehensive investigation has resulted in the discovery of over 2.5 million gallons per day of new water sources from fractured bedrock aquifers to serve the needs of the FCWSA.** Individual wells drilled in these fractured bedrock aquifers have yielded as much as 350 gallons per minute. Unlike regional surface supplies, severe drought conditions experienced in northern Virginia during the past decade have not adversely impacted the groundwater sources developed by EGGI for the FCWSA. Information gained from these groundwater investigations has been incorporated into the County's revision of FCWSA's Comprehensive Master Plan, as well as their overall Water Utility Plan. Furthermore, policy standards for the development of individual subdivision water supplies were prepared by EGGI and are currently being used by the Fauquier County Planning Agencies. EGGI has successfully worked for both the County and the FCWSA for the past 20+ years.



### Relevance to the Groundwater Resources Assessment for the Panama Project:

- Delineated potential groundwater aquifers and their distribution across a large Regional Study Area; discovered new supplies and enhanced knowledge of regional groundwater resource occurrence.
- Assessment of regional geology, bedrock fracture fabric, groundwater recharge, and potential contaminant threats that could impact groundwater quality.
- Conducted geophysical surveys throughout “*priority ranked*” sub-areas that were identified as favorable for groundwater development (per Phase I hydrogeologic investigation).
- Identified and “*priority ranked*” exploratory test well drilling targets within the County.
- Prepared summary reports which included digital geologic and hydrogeological maps of the entire County.

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## GROUNDWATER INVESTIGATIONS

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### Countywide Advanced Groundwater Resources Assessment – Augusta County Service Authority, Virginia



EGGI was selected by the Augusta County Service Authority (ACSA), after a competitive qualifications review of over 12 firms, to investigate the potential to develop additional groundwater resources and to evaluate the protectability of new sources of water supply. This project included Countywide groundwater investigations, geophysical investigations, exploratory test well drilling and testing, and the implementation of detailed groundwater protection programs.

**EGGI's groundwater investigation throughout the County has resulted in the development of in excess of 4 million gallons per day (4+ MGD).** The water

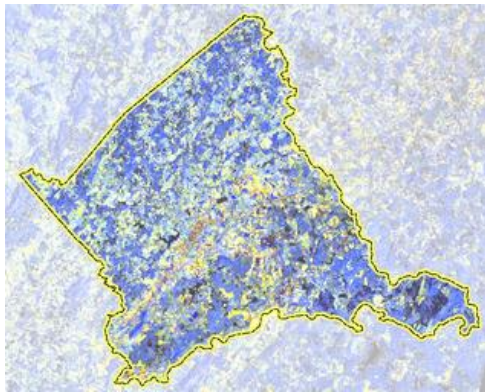
quality is excellent and meets all EPA Primary and Secondary Drinking Water Standards. The development of this water supply has substantially improved the overall water supply system capacity for meeting the Augusta County Service Authority's overall water supply needs.

#### Relevance to the Groundwater Resources Assessment for the Panama Project:

- Identified potential groundwater aquifers and their distribution across the County; discovered new supplies and enhanced knowledge of regional groundwater resource occurrence.
- Assessment of regional geology, bedrock fracture fabric, groundwater recharge, and potential contaminant threats that could impact groundwater quality and yield.
- Conducted geophysical surveys throughout “*priority ranked*” sub-areas that were identified as favorable for groundwater development (per Phase I hydrogeologic investigation).
- Identified “*priority ranked*” exploratory test well drilling targets within the County.
- Prepared summary reports with digital geologic and hydrogeological maps of the entire County.



## Countywide Advanced Groundwater Resources Assessment – Culpeper County, Virginia



EGGI was contracted, after a comprehensive qualifications review, to investigate the availability and protectability of groundwater resources in eight regional service areas spread throughout Culpeper County. Initial investigations focused on evaluating geologic and hydrogeologic data, remote sensing information, and contaminant threats to groundwater quality. **EGGI identified several significant, *new* bedrock aquifers – capable of yielding several million gallons per day – that had not previously been discovered or accessed.**

**Information gained from these groundwater investigations is being used to develop a Countywide water resource development plan along with a long-term groundwater protection program.** Project results were highly regarded by both County staff and the County Board of Supervisors, and the Project has received many accolades.

*"Your presentation (James Emery's) at the Germanna Technology Center on the status of the Countywide Groundwater Study and groundwater availability in the Triassic Basin was a tremendous success. I received numerous compliments from both staff members and the public on the quality of your presentation and your responses to questions. I think it is a testament to your professionalism and expertise of your employees."* – Paul Howard, Director of Environmental Services, Culpeper County

### Relevance to the Groundwater Resources Assessment for the Panama Project:

- Identified potential groundwater aquifers and their distribution across a large Regional Study Area, discovered material new supplies and enhanced knowledge of regional groundwater resources occurrence.
- Evaluation of groundwater availability from local fractured bedrock aquifer sources.
- Assessment of regional geology, bedrock fracture fabric, groundwater recharge, and potential contaminant threats that could impact groundwater quality and yield.
- Conducted geophysical surveys throughout "***priority ranked***" sub-areas that were identified as favorable for groundwater development (per Phase I hydrogeologic investigation).
- Identified "***priority ranked***" exploratory test well drilling targets throughout the County.

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GROUNDWATER INVESTIGATIONS

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## EXAMPLE ADVANCED GROUNDWATER EXPLORATION AND DEVELOPMENT PROJECTS

(PARTIAL LIST)



## Advanced Groundwater Exploration and Development – Coweta County Water & Sewer Department, Georgia

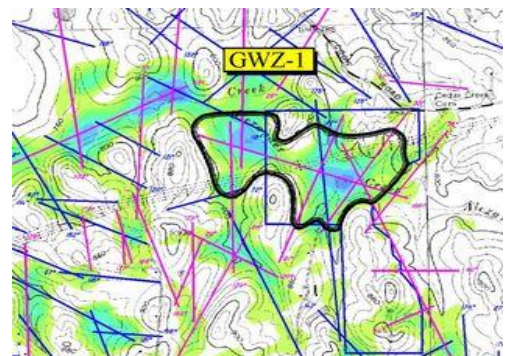


Looking to augment their surface water supplies, and to provide some water supply diversity to their water system, the Coweta County Water & Sewer Department selected EGGI to investigate the availability of groundwater resources in a northern section of this Georgia County. Application of EGGI's proven exploration and development program resulted in the delineation of three Groundwater Development Zones, one of which was later discovered to contain a potentially high-yielding domestic well. Preliminary well testing and negotiations with the homeowner led the County to purchase the well lot. The existing well was then converted into a larger-diameter public water supply Production Well. EGGI proceeded with the testing of the yield and quality of the well. EGGI successfully completed the development process for the well and received all necessary groundwater withdrawal permits for the public use of this groundwater source.

**The well is currently on line, supplying more than 0.5 MGD (500,000 gpd) of 'sweet water' directly into the County's water supply system;** 'sweet water' being what the commissioners called it after it was brought on line.

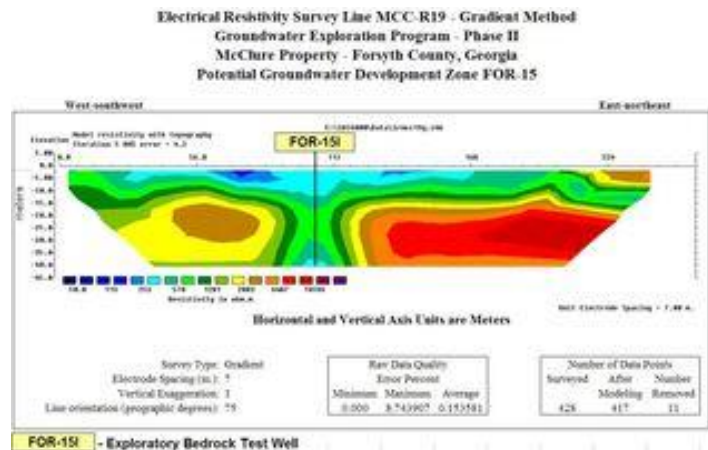
### Relevance to the Groundwater Resources Assessment for the Panama Project:

- Identified potential groundwater aquifers and their distribution across the northern part of the County, enhancing knowledge of groundwater resource occurrence.
- Evaluation of groundwater availability from local fractured bedrock aquifer sources.
- Assessment of bedrock geology, bedrock fracture fabric, groundwater recharge, and potential contaminant threats that could impact groundwater quality and yield.
- Conducted geophysical surveys throughout “*priority ranked*” sub-areas that were identified as favorable for groundwater development (per Phase I hydrogeologic investigation).
- Successfully identified, drilled and developed high-yield well within the County.



## Advanced Groundwater Exploration and Development – McClure Property, Forsyth County Department of Water & Sewer, Georgia

As a result of its highly-successful and *fully-proven* groundwater exploration program within complex hydrogeological terrains, EGGI was contracted by the Forsyth County Water and Sewer Authority (FCWSA) to evaluate and develop new groundwater resources. The crystalline bedrock that underlies Forsyth County is commonly *not* thought of as a highly productive aquifer, however, properly located wells can tap specific, highly fractured bedrock features and achieve high yields. EGGI utilized its proprietary exploratory method and identified a number of drilling targets.



**Exploratory test wells drilled at this site produced a combined airlift yield of nearly 700 gallons per minute (1 million gallons per day).** This project was funded using GEFA monies and is being used as an example for other communities who might be seeking lower cost options for developing additional water supply sources. A groundwater testing program is currently being performed to assess the long term sustainable yield. The intent is to develop a series of high yielding wells in a single well field.

### Relevance to the Groundwater Resources Assessment for the Panama Project:

- Delineated potential groundwater aquifers and their distribution throughout the County, enhancing knowledge and understanding of groundwater resource occurrence.
- Evaluation of groundwater availability from local fractured bedrock aquifer sources.
- Assessment of regional geology, bedrock fracture fabric, groundwater recharge, and potential contaminant threats that could impact groundwater quality and yield.
- Conducted geophysical surveys throughout “*priority ranked*” sub-areas that were identified as favorable for groundwater development (per Phase I hydrogeologic investigation).
- Successfully identified and developed high-yield wells within the County.

## Advanced Groundwater Exploration and Development – City of Woodstock, Georgia

The City of Woodstock is dependent upon Cherokee County as its water supply source. For diversity, the City is investigating its own water supply source options. As it is underlain by crystalline bedrock of the Piedmont Geologic Province, they contacted the experts, EGGI to investigate the potential of their fractured bedrock aquifers.



Phase I resulted in the “priority ranking” of 13 Potential Groundwater Development Zones. Phase II geophysical investigations were conducted in order to locate the optimal sites for exploratory test well drilling. **EGGI completed over 35 miles of magnetic and VLF electromagnetic geophysical survey lines as well as nearly 10 miles of electrical resistivity surveys.**

A total of fifty-nine (59) proposed exploratory test well sites have been identified and “priority ranked” in the 13 Groundwater Development Zones. Eleven exploratory test wells were drilled in Phase III, and four converted to potential Production Wells (Phase IV), with a combined **airlift yield of 660 gallons per minute.**

Recent long-term pumping tests and water quality analyses indicate that the sustainable, total yield is 360,000 gallons per day and that treatment will be required for some, but not all, of the water produced. Efforts are underway to drill additional exploratory test wells.

### Relevance to the Groundwater Resources Assessment for the Panama Project:

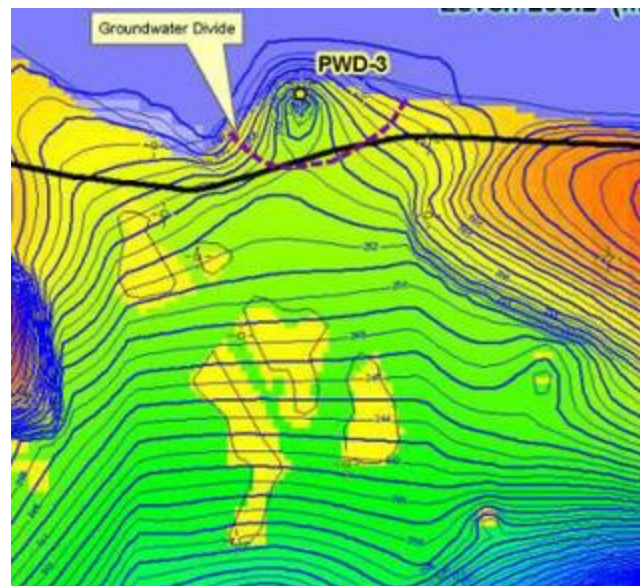
- Identified potential groundwater aquifers and their distribution throughout the City, enhancing knowledge and understanding of groundwater resources occurrence.
- Evaluation of groundwater availability from local fractured bedrock aquifer sources.
- Assessment of bedrock geology, bedrock fracture fabric, groundwater recharge, and potential contaminant threats that could impact groundwater quality and yield.
- Conducted geophysical surveys throughout “**priority ranked**” sub-areas that were identified as favorable for groundwater development (per Phase I hydrogeologic investigation).
- Successfully identified, drilled and developed high-yield wells within the City.



## Advanced Groundwater Exploration and Development – Portland Water District (PWD), City of Portland, Maine

EGGI was selected (on the basis of a competitive review) to lead a team of geologists, hydrologists, and engineers to complete a multi-phase study to conduct a groundwater exploration, development, and protection program for the City of Portland, Maine. Groundwater resources developed for the PWD will serve as an emergency backup supply and/or as a permanent supplement to their existing surface water supplies. The development of groundwater resources will also help to increase water source security.

By conducting detailed geological mapping, geophysical surveys, groundwater modeling, exploratory test drilling, pumping tests, hydraulic modeling, and detailed hydrogeological assessments **EGGI developed a new 24-inch-diameter production well capable of producing up to 2,400 gallons per minute (or 3.45 million gallons per day) of potable groundwater resources.** EGGI's investigation laid the groundwork for the groundwater withdrawal permit obtained for the well from the State of Maine.



### Relevance to the Groundwater Resources Assessment for the Panama Project:

- Evaluation of groundwater availability from local sand and gravel aquifer.
- Assessment of glacial stratigraphy, groundwater recharge, and potential contaminant threats that could impact groundwater quality and yield.
- Conducted geophysical surveys throughout the Study Area.
- Successfully identified, drilled and developed high-yield well within the Study Area.

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## GROUNDWATER INVESTIGATIONS

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### Advanced Groundwater Exploration and Development – Town of Waterville Valley, New Hampshire



After the lack of success by other consultants who, over a period of 25 years, had drilled 110+ exploratory wells with no success of finding any significant groundwater resources, EGGI was contracted by the Town of Waterville Valley to develop a new source of drinking water.

EGGI accomplished the groundwater development project through a multi-phase program of exploration and testing. The investigation included the review of geologic information generated during the drilling of 110+ test wells by "other" consulting firms, detailed geologic mapping of the glacial deposits by EGGI geologists, the collection and analysis of electrical resistivity geophysical data, and the drilling and testing of exploratory test wells.

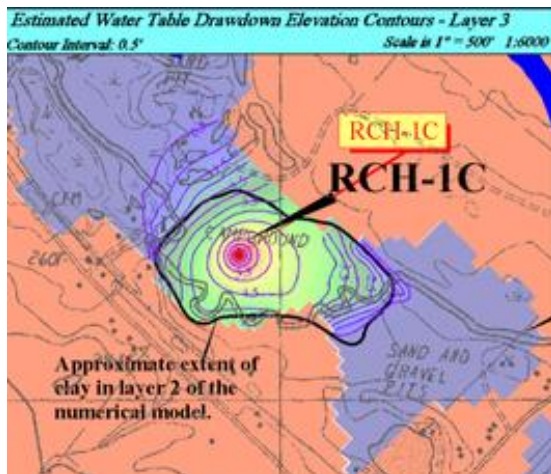
**The results of these analyses led to the successful selection of a new high-yield Production Well** site located within the White Mountain National Forest. A final hydrologic report submitted to the NHDES resulted in the permitting of a production volume of 432,000 gallons per day (300 gallons per minute) for the 12-inch-diameter gravel pack well installed at this location.



#### Relevance to the Groundwater Resources Assessment for the Panama Project:

- Mapped hydrogeologic characteristics of glacial and fluvial sediments throughout the Town, enhancing knowledge and understanding of groundwater resource occurrence.
- Discovered and developed new potable groundwater supply in unconsolidated aquifer.
- Assessment of surficial geology, groundwater recharge potential, and potential contaminant threats that could impact groundwater quality and yield.
- Conducted geophysical surveys throughout "**priority ranked**" sub-areas that were identified as favorable for groundwater development (per Phase I hydrogeologic investigation).
- Successfully identified, drilled and developed high-yield well.

## Advanced Groundwater Exploration and Development – City of Rochester, New Hampshire



EGGI conducted a City-wide groundwater exploration program designed to develop groundwater supply wells. This exploration program included numerous Phases including detailed geologic mapping, a contaminant threat assessment, geophysical surveys, exploratory drilling, pumping tests, water quality analyses, and numerical groundwater flow modeling.

The results of this study led to the identification of 13 areas (Groundwater Development Zones) within the City where groundwater resources could potentially be developed. To date, three groundwater production wells have been developed within these Groundwater Development Zones.

Pending final permit approval by the State of New Hampshire Department of Environmental Services, **each of the wells will provide up to 600 gallons per minute (gpm) of groundwater resources to the City of Rochester, for a combined yield of up to 2.6 MGD.**

A long-term wetland monitoring program was developed to enhance the protection of wetlands proximal to one of the production well sites.



### Relevance to the Groundwater Resources Assessment for the Panama Project:

- Mapped hydrogeologic characteristics of glacial and fluvial sediments throughout the City, enhancing knowledge and understanding of regional groundwater resources occurrence.
- Evaluation of groundwater availability from unconsolidated aquifer sources.
- Assessment of surficial geology, groundwater recharge, and potential contaminant threats that could impact groundwater quality and yield.
- Conducted geophysical surveys throughout “*priority ranked*” sub-areas that were identified as favorable for groundwater development (per Phase I hydrogeologic investigation).
- Successfully identified, drilled and developed high-yield wells.

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## GROUNDWATER INVESTIGATIONS

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### Advanced Groundwater Exploration and Development – Town of Culpeper, Virginia



EGGI was hired by the Town of Culpeper to use its proven groundwater resources exploratory methods to locate groundwater supplies to supplement existing surface water sources.

Results of Phase I of EGGI's investigation identified eight potential groundwater development zones. Phase II resulted in the identification of specific exploratory bedrock test well sites in these eight zones. Phase III of this investigation is focused on drilling exploratory test wells and, to-date, this drilling program has proven substantial groundwater resources can be developed at several locations.

Conversion of eight of the exploratory test wells to larger-diameter Production Wells has produced a combined estimated airlift yield (using the drill rig to evacuate water) in excess of 3,200 gallons per minute. **Extended pumping tests on the eight production wells and detailed water quality**

**analyses, served to prove a long-term, combined, sustainable yield capacity in excess of 2 million gallons million gallons per day of high quality water.**

Assuming this groundwater exploration and development program continues to proceed with success, **it is estimated that the Town could save more than \$25 million versus making improvements to existing surface water supply sources.**

#### **Relevance to the Groundwater Resources Assessment for the Panama Project:**

- Delineated potential groundwater aquifers and their distribution throughout the Town, enhancing knowledge and understanding of groundwater resource occurrence.
- Discovered and developed new potable groundwater supplies.
- Assessment of regional geology, bedrock fracture fabric, groundwater recharge, and potential contaminant threats that could impact groundwater quality and yield.
- Conducted geophysical surveys throughout "**priority ranked**" sub-areas that were identified as favorable for groundwater development (per Phase I hydrogeologic investigation).
- Successfully identified, drilled and developed high-yield wells proximal to or within the Town.

## Advanced Groundwater Exploration and Development – Howard Hughes Medical Institute, Loudoun County, Virginia



The Howard Hughes Medical Institute (HHMI) built the largest medical facility of its kind in the Nation. Due to the high expense of purchasing potable public treated water supply, it was imperative that groundwater resources be developed on site to meet their irrigation water needs. Originally, HHMI hired an engineering consultant with hydrogeologists on staff to conduct a groundwater investigation. This **previous consultant drilled a total of nine exploratory test wells; each of the nine wells yielded less than 5 gallons per minute (gpm).**

EGGI was subsequently contracted to explore for and develop groundwater resources on this 500+ acre parcel of land.

**EGGI completed its groundwater exploration and development investigation and needed to drill only one well to meet the entire water supply needs of the project.**

EGGI identified and drilled one exploratory test well that yielded 350 gallons per minute (500,000 gallons per day). The water developed on site is used to irrigate the entirety of the medical research facility. This project was considered an extraordinary success, particularly in light of the failures of others to find a satisfactory groundwater source at this site.



### Relevance to the Groundwater Resources Assessment for the Panama Project:

- Successfully discovered and developed new supply where previous ‘experts’ had failed.
- Evaluation of groundwater availability from local fractured bedrock aquifer sources.
- Assessment of bedrock geology, bedrock fracture fabric, groundwater recharge, and potential contaminant threats that could impact groundwater quality and yield.
- Conducted geophysical surveys on “*priority ranked*” sub-areas that were identified as favorable for groundwater development (per Phase I hydrogeologic investigation).
- Successfully identified, drilled and developed high-yield well *on-site*.

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## GROUNDWATER INVESTIGATIONS

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### Advanced Groundwater Exploration and Development – The Peterson Companies, Chantilly, Virginia



The Dulles Discovery Office Park, owned and developed by The Peterson Companies, consists of 2.4 million sq. ft. of government office buildings, including a data center. Following a recent interruption of its municipal water service and the costly downtime inflicted, on-site, backup water supplies were required to mitigate any future supply risks.

Given EGGI's ability to source high-yield wells in challenging terrains, and the team's track record with other large developers and Federal agencies, EGGI was hired to develop groundwater resources on this 150-acre site. The goal was to develop backup water sufficient to meet the needs of the data center, should the municipal water supply be curtailed.

**EGGI completed its comprehensive groundwater exploration and development program and successfully developed wells yielding 450 gallons per minute (gpm), exceeding the client's desired goal.**

#### Relevance to the Groundwater Resources Assessment for the Panama Project:

- Evaluation of groundwater availability from local fractured bedrock aquifer sources.
- Assessment of bedrock geology, bedrock fracture fabric, groundwater recharge, and potential contaminant threats that could impact groundwater quality and yield.
- Conducted geophysical surveys to help identify potential exploratory test well sites.
- Successfully identified, drilled and developed high-yield wells on site.

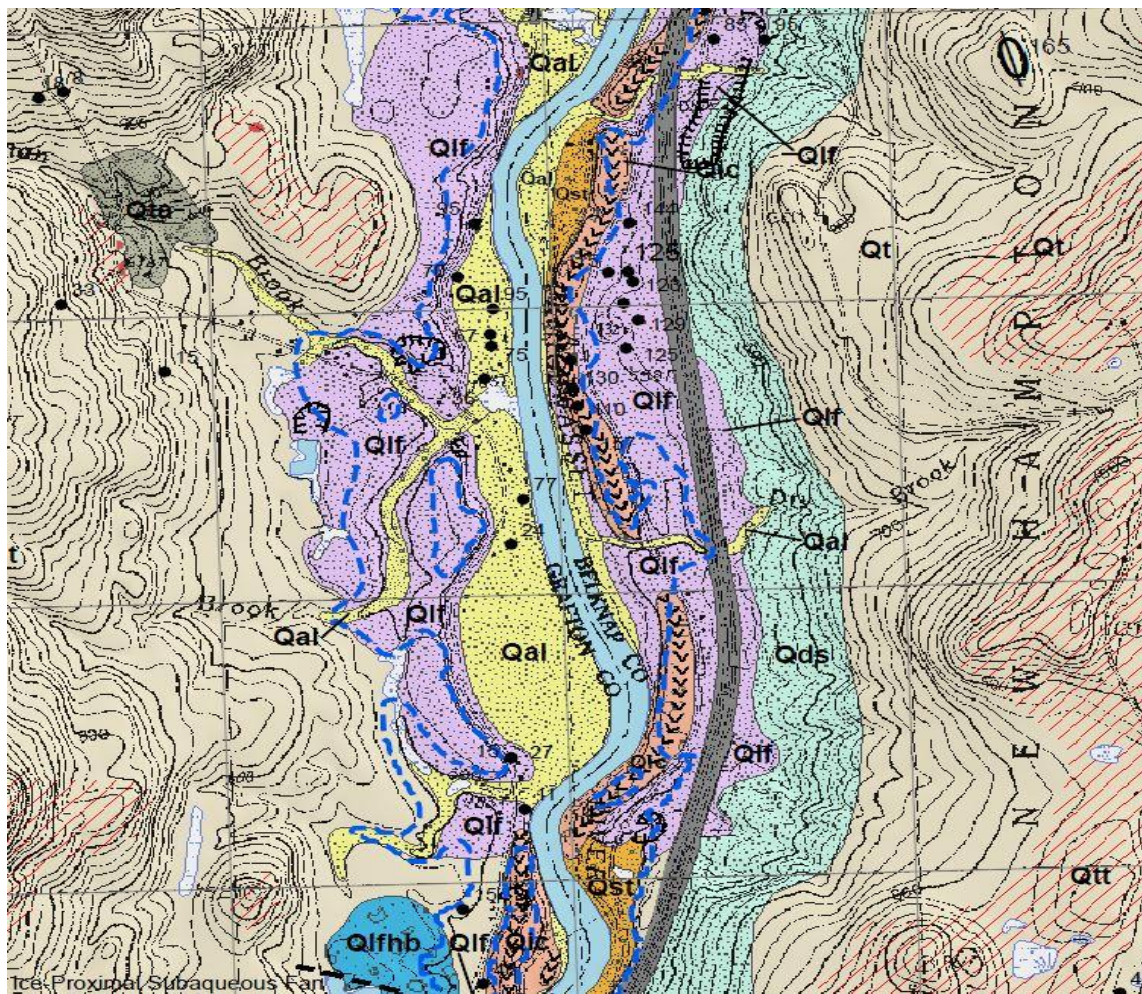
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## EXAMPLE SURFICIAL GEOLOGIC MAPPING & GIS DATABASE DEVELOPMENT PROJECT

(PARTIAL LIST)



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## GROUNDWATER INVESTIGATIONS

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### U.S. Geological Survey (USGS) – State Mapping Program – Surficial Geology of New Hampshire



The State of New Hampshire is creating a statewide coverage of surficial geologic maps as part of the NH STATEMAP program, which is funded jointly by the State of New Hampshire and the U.S. Geological Survey. **EGGI was selected as the first-ever private contractor to participate in this geological mapping program.**

Over the last 12 years, EGGI scientists have conducted detailed geologic mapping to produce the surficial maps of thirteen 7.5 minute Quadrangles. In addition, EGGI developed and tested methods for using DEM and LANDSAT data to guide and supplement the field mapping. Surficial geologic maps of the Quadrangles were produced in digital format for use in the GRANIT GIS database and GRANIT website. EGGI was instrumental in developing standards for the maps with the office of the New Hampshire State Geologist, Dr. David Wunsch.

*"John Brooks, Ph.D., P.G., (Emery & Garrett Groundwater, Inc.) has been contracted by the New Hampshire Geological Survey under my direction for the purpose of conducting surficial geological mapping for the State's STATEMAP Geological Mapping Program. STATEMAP is a federal cooperative program that requires peer review of all funding proposals, completed maps, and associated geologic descriptions and data. In addition, the completion of these products is regulated by a stringent delivery timetable each year. Dr. Brooks has completed two maps over the past two years. Our mapping program requires a robust effort in data collection, compilation, and dissemination of the final product. Dr. Brooks, d.b.a. Emery & Garrett Groundwater, have performed admirably in this regard."*

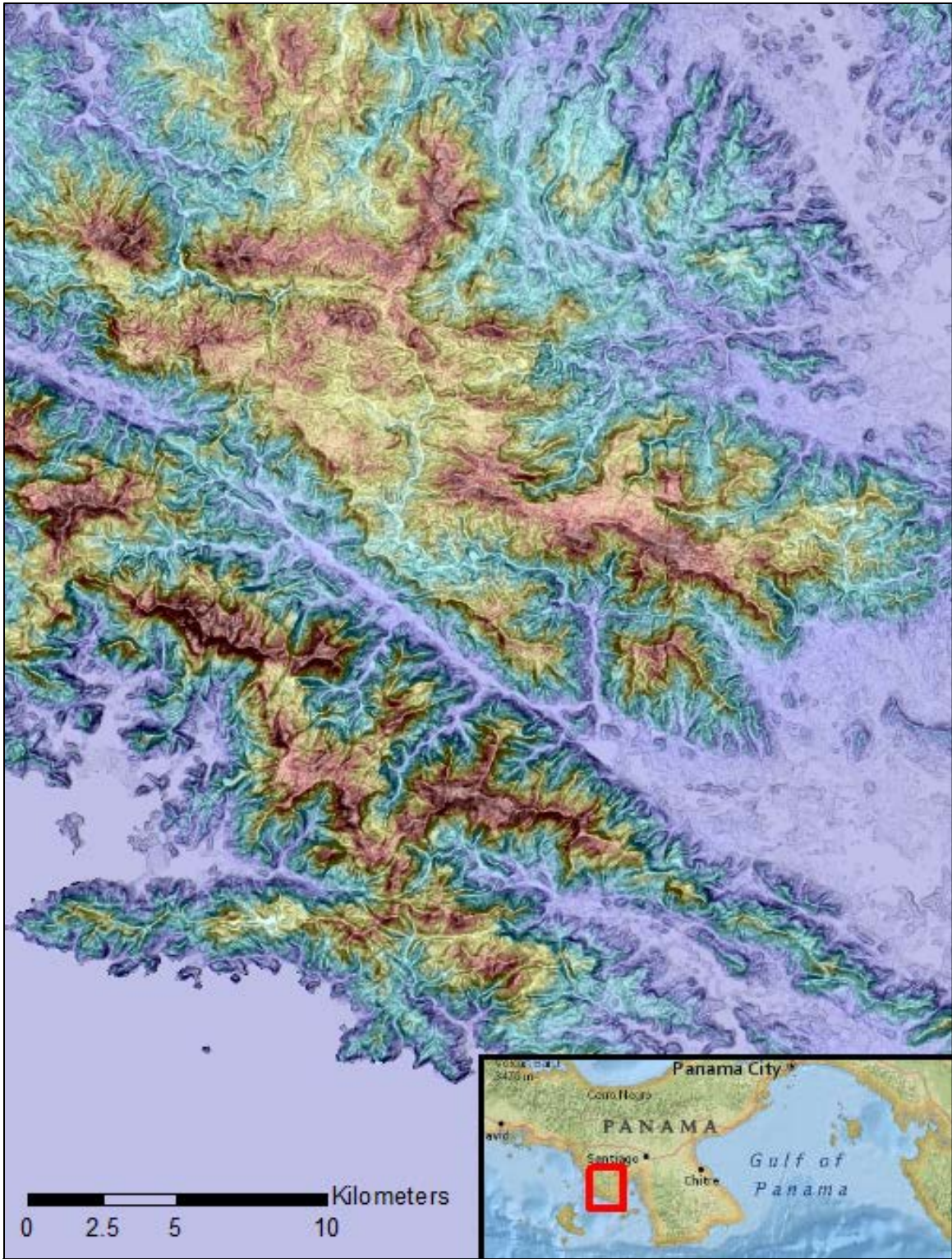


Dr. David Wunsch, Former New Hampshire State Geologist

### Relevance to the Groundwater Resources Assessment for the Panama Project:

- Demonstrated mapping skills of unconsolidated sedimentary deposits.
- Proven ability to interpret field data to create map products and conceptual geologic models.
- GIS-based map products and geo-referenced GIS database capabilities.
- Production of project specific GIS products.





Example of color contoured shaded relief elevation contour map.

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