NUCLEAR REGULATORY COMMISSION
ATOMIC SAFETY AND LICENSING BOARD

Before Administrative Judges:
Alex S. Karlin, Chairman
Dr. Anthony J. Baratta
Dr. Randall J. Charbeneau

In the Matter of:	)	
PROGRESS ENERGY FLORIDA, INC.	)	Docket Nos. 52-029-COL,
(Levy County Nuclear Power Plant, Units 1 and 2)	)	52-030-COL

INITIAL PRE-FILED TESTIMONY OF GARETH J. DAVIES IN SUPPORT OF CONTENTION C-4 REGARDING ENVIRONMENTAL IMPACTS OF LEVY UNITS 1 AND 2 ON WATER RESOURCES AND ECOLOGY

Q.1. What is your name and your employment?

A.1. My name is Gareth J. Davies B.Sc., M.Sc., P.G., (TN, KY) and I am a consultant hydrogeologist for Cambrian Ground Water Co. In addition, I work for the Tennessee Department of Environment and Conservation in the Department of Energy Oversight Office.

Q.2. In what capacity are you testifying today and what are your qualifications to do so?

A.2. I am providing testimony as an expert on the hydrogeology of karst regions. My qualifications for this include over 40 years of interest in karst hydrogeology, beginning as a summer high-school project sampling cave waters and tracing groundwater in South Wales. I have a Master's degree in geology from the University of Southern Mississippi am a registered professional geologist. I have been involved in projects in several different countries, and been employed as a US EPA expert in tropical karst as well as working at high altitude mine sites in the US Rocky Mountains. I was a member of the

Task Group that prepared and wrote the first ASTM Standard Guide on Karst and Fractured Rocks and the first US EPA Region 4 Well-head and Spring-head protection manual. I recently conducted some of the first successful very large scale groundwater tracing done in Florida in the Wakulla Spring basin using isotopes and injected tracers. A copy of my curriculum vitae is attached as **Exhibit INT002.**

Q.3. What is the purpose of your testimony in this case?

A.3. Construction and operation of the Levy Nuclear Plant ("LNP") will cause considerable disturbance to the local groundwater and surface water flow by physically altering flow paths and withdrawing large amounts of groundwater from the Upper Floridian Aquifer. I am concerned that the FEIS does not adequately recognize that most of the flow in this area goes through preferential path-ways not through a porous medium. Because these flow paths are currently unknown I do not believe that it is possible to rely upon the predictions in the FEIS that are based upon the assumption that the aquifers behave as though the flow travels evenly through the porous medium. In reality, because of the nature of the flow paths, impacts from LNP on the flow of water could be more severe and occur further away than predicted, impacts could occur faster than expected, and freshwater springs could be cut-off. To predict the impacts more reliably I recommend mapping of some of the major preferential flow paths and use of a model that is more physically realistic.

Q.4. Is the Site of LNP made of carbonate rocks? If so, please outline their properties?

A.4. Yes, carbonate rocks underlie the LNP site. Carbonate rocks are readily soluble in weak acids such as carbonic acid (formed from precipitation + dissolved carbon dioxide, and dissolved natural organic acids, from vegetation). Sediments have bedding structures (initially sub-horizontal) which are present in all sedimentary rock sequences that can be related to the nature of their deposition. As older sediments are buried and stressed by crustal movements they become lithified (i.e. turned into rock) and become fractured. The lithified sediment also has some void space between the grains of the sediment. This space can be reduced by diagenesis (deep burial) and movement of connate water (=water formed simultaneously with surrounding rock) that has been trapped since deposition in the pore spaces: this mineralized water forms a cement. Erosion of overlying sediments and uplift of the underlying ones occurs and these rocks are then exposed to the hydrosphere and atmosphere where fractures and any open pore spaces are subjected to weathering.

Carbonate rocks are particularly prone to chemical weathering (dissolution). This is initiated at the land surface, say, at a fracture, and a positive feedback loop begins, where dissolution along the initial fracture leads to enlargement of the fracture. This leads to more water infiltration, leading to more enlargement, with eventually one pathway enlarging preferentially with respect to others until a master pathway is created from input to output. This leads to convergent flow from tributary pathways to the main pathway. This is how a master conduit (or channel) forms. The appropriate concept of such a pathway as just described is that it has an inlet and outlet and a conduit that connects the two locations. Florida currently has the longest active flowing conduit that has been mapped in the world– from Big Dismal Sink to Wakulla Spring a distance of 19.8 kilometers.

Q.5 How does water move through carbonate rocks?

A.5. Carbonate rocks can be considered to have three porosity elements: the original pore spaces, fractures and conduits. Conduits in carbonates should be considered to having been enlarged by dissolution as previously described. Although it is often assumed that conduits only form in carbonates, they are quite common in other rocks probably because at geological time scales every mineral is somewhat soluble. For example, there are well-known karst-like terrains in pure quartz sandstones in northern Minnesota (Shade, 2002) with sinking streams, caves and springs.

Davies (2008) Worthington et al. (2000) investigated the magnitude and role of the three porosity elements in various carbonates and the results are quite striking in that the conduit porosity is often, by far, the smallest porosity element and the matrix porosity the largest (Table 1) (**Exhibit INT003**). Using the calculated hydraulic conductivity (k) the relative proportions of groundwater flux in each porosity element can be calculated (Table 2) (**Exhibit INT004**). Note that even though conduits have the smallest porosity, they always carry by far the largest flux of groundwater (>94%).

Q.6. What is a Karst Aquifer?

A.6. Karst is a term that refers to the geomorphology of an area/region, but also implicitly assumes both the surface and subsurface waters are inter-connected because caves, springs and sinking streams are included. Many professionals prefer not to use the term *karst aquifer*, because it combines two terms from both geomorphology and hydrogeology, so *karstic aquifer* may be more appropriate.

Quinlan et al., (1996) saw the need to define, in relation to karst, a *triple-porosity aquifer* (with the same porosity elements as described previously), stating:

> a triple-porosity aquifer has matrix porosity where flow is Darcian (follows Darcy's Law) and laminar, fissure porosity where flow is assumed to be laminar, and macrofissure or conduit porosity where flow is commonly turbulent...

and defining a *karst aquifer* as:

> ….. a triple-porosity aquifer in carbonate rocks or other readily soluble rocks with macrofissures or conduits that typically have hydraulic radii at least as large as a few millimeters.

From this definition of a karst aquifer, a conduit can be defined as:

> a fissure or channel from as small as a few millimeters in diameter that can sustain turbulent flow at minimal traced velocities in karst (1 mm/s).

N.B., very large conduits are known (tens of meters in diameter, in Florida) so no upper size limit is implied and should not be, within reason.

The definition of a conduit (or channel) should clearly include openings of a few millimeters, because flow can be turbulent at a velocity of more than 0.001 m/s. This is therefore a reasonable low limit of traced groundwater velocity in conduits worldwide (Worthington et al., 2000). Many cave streams, and flooded caves, are known to have conduits tens of meters in diameter (large sections of dry conduits of more than 300 m in diameter are known. Traced groundwater velocities as high as 1 - 2 m/s (Worthington et al., 2000), are documented. This means that karst aquifers can respond much more rapidly than standard porous aquifers to changes in pumping or recharge quantity or quality.

It should be stressed that a terrain need not look like a karst terrain to have an underlying karstic aquifer and have conduits (Davies and Quinlan, 1993). This would also be the case for the major aquifers of Great Britain, the Jurassic Great Oolite, Inferior Oolite and the Cretaceous Chalk. These aquifers contain only a few small caves (i.e., the Chalk) but many springs and sinking streams, collapses and other features recognized as being present in all karst settings. Well bores reveal numerous small conduits of a few cm in size. Traced velocities between wells and springs compare with those in classical karst regions (McDonald et al., 1998).

Davies and Quinlan (1993) rationalize that because of the inevitable dissolution and weathering process, any unconfined carbonate rock in a moist climate must have an underlying karstic aquifer that has conduits.

Q.7. How does recharge and discharge occur in karst aquifers?

A.7. A key recharge characteristic of karst aquifer is sinking streams, also referred to as swallets or ponors. Dissolution is significant in carbonates, in the classical karst regions of Slovenia and its surrounds and many other regions, even large rivers completely disappear into their own beds. Swallets collect and rapidly discharge such large volumes of surface water into the ground that they must be directly connected to conduits. Using nominal porosity numbers it is possible to transmit only a limited volume of water per unit time through narrow fractures and the rock matrix, so dissolutionally enlarged conduits are major components in such aquifers. Physical evidence (injected tracing) from carbonates all over the world proves that swallets lead to conduits that discharge at springs.

Q.8. How does the hydrogeology of karst differ from that of normal porous media?

A.8. Quantitative hydrogeology dates back to 1856 in France, where Henry Darcy began working on getting a water supply to the City of Dijon (Simmons, 2008). He concluded that the fountains (springs) were fed by conduits (Worthington and Gunn, 2004). He also did many other hydrological experiments, some using sand from which he derived the fundamental equations of groundwater flow and that related a parameter called *hydraulic conductivity* to the discharge of water through the sand, sand-filled pipes and open pipes and channels (Simmons, 2008). Since many of Darcy's experiments involved flow through sand, it is referred to as an (ideal) porous medium.

There are major differences between a karstic/carbonate aquifer or setting and an ideal porous medium as shown in Figure 2 **(Exhibit INT0005)** and Table 1 (**Exhibit INT003)**. There are also significant differences in measured parameters in an ideal porous medium aquifer and a typical carbonate aquifer. It should be noted that in Figure 2 the ideal porous medium model depicted is entirely theoretical, but the carbonate aquifer model depicted is based upon real data. In "conventional" hydrogeology, i.e., not carbonate/karst, fractured-rock hydrology, it is implicitly assumed that there is a porous medium and thereafter many simplifying assumptions are made.

Generally speaking, the porous medium assumes: only areal (distributed) recharge through the pore spaces and fractures, laminar (i.e., not turbulent) flow and, discharge from the entire face of the aquifer (no springs). The porous medium works best with materials such as unconsolidated sand. When using the porous medium model, lithified rocks and fractures are accommodated by assuming if there are enough fractures or open pores and a large enough volume of aquifer is investigated, the aquifer should behave like a porous medium. Other approaches involve assuming discrete flow in individual fractures, but often the fractures are not assumed to be continuously connected. These approaches might work at small scales but do not function well at karstic scales of investigation.

Other workers have also investigated conduits; e.g., Meinzer (1927) hypothesized a conduit between River Sink (aka Kini spring/sink) and Wakulla Spring. This conduit was shown by tracing, diving and mapping decades later to connect with Wakulla Spring (Davies, 2008). Even though many workers had studied conduits, Hubbert (1940) wrote a significant paper on groundwater flow by simply conceptualizing there were no conduits present, and concentrated all his efforts on the porous medium model. This approach became standard and channels and conduits were hardly investigated except by a few karst specialists, but often not in the hydrogeological sense; most considered them rare enough to be ignored.

Unfortunately, most state and federal regulations and recommendations were written implying that settings are a porous medium. However, in 1989 USEPA sought to develop different monitoring and measuring techniques for karst settings which was published as Quinlan, (1990). The methods recommended in that document make fewer assumptions about the aquifer conditions and depend more on empirical data such as from tracer tests.

Q.9. Is the Floridan aquifer a karst aquifer?

A.9. Yes. The Floridan aquifer is an unconfined (i.e., not covered by other rocks, where groundwater is in contact with the atmosphere) in much of the Florida coastal plain. As discussed by Davies and Quinlan (1993) it is also a karst aquifer with conduits. As Table

1 shows, there is relatively high rock matrix porosity, but it is also characterized by many springs and sinking streams. This is not unusual -- the same is the case for the British Chalk (another carbonate rock), which had not been considered to be karstic even though tracing had shown rapid, turbulent groundwater velocities, that prove there are conduits present and it cannot be assumed to be a porous medium (McDonald et al., 1998). In general, there is now growing recognition that karstic properties are often found where groundwater flows through carbonate rocks.

Q.10. Would it be appropriate to use a porous medium model for the groundwater flow in the vicinity of the proposed Levy Nuclear Plant?

A.10. No. The ideal porous medium would not be an appropriate model to use in unconfined carbonates/karst (ASTM, 1995). Therefore, it should not be assumed and applied to the karst aquifer at the LNP site. Unfortunately, the FEIS does use assumptions based upon a standard a porous medium mode. That means that the site has not been properly evaluated and as a result, the FEIS probably contains many uncertain parameters, and assessments of impacts are unreliable. For example, the rapid flow in conduits in karst means that impacts can occur much faster and over much greater distances than in a standard porous medium.

Q.11. Did the FEIS recognize the presence of karst?

A.11. Yes, there is no dispute that the terrain in the area is karst. The Florida Geological Survey and other publications refer to the whole area including the LNP site a karst terrain. However, the Levy FEIS does not emphasize enough the karst landscape/aquifer at the LNP, nor does it mention the potential problems of assuming the incorrect model. The FEIS p.2-25 merely says that "some of the wetlands onsite may reflect karst development" and that "few sinkholes occur near the LNP site" and that the "regional transmissivity of the Upper Florida aquifer in the area is less than would be expected for well-developed karst (USGS 2000)." The FSAR, however, contradicts the FEIS by stating that: " Surface morphology and subsurface data indicate that there has been a long period of erosion and karst development in the site location (FSAR Subsection 2.5.1.2.1.3). The LNP site surface morphology is consistent with that of an eroded, older (paleo) karst landscape mantled by several feet to tens of feet of sand (i.e., a mantled epikarst subsurface formed over a denuded karst). (FSAR Rev. 2 p. 2.5-203) (**Exhibit INT006**).

Although the FEIS implies that the karst at the LPN site is not "well-developed," the key properties of the Upper Floridan aquifer in the area are actually very similar to well-known karst areas. In fact, the distinction between karst that is "well-developed" and other types of karst, as used above, is entirely subjective, especially because conduits – a key feature of karst development – may be relatively small but will still have a large impact on groundwater movement. There is no clear distinction between a well-developed karst setting and any other. For example, in Table 1 if we compare porosity between various carbonate aquifers, note that the values for Mammoth Cave karst and Florida karst are generally the same magnitude. Therefore there is no clear distinction between Mammoth Cave - which the longest cave in the world (~700 km) and obviously a very well-developed karst, and the Florida karst. Alternatively we can compare conduit porosity which is also similar for both settings, or the proportion of flow through that porosity element. The simple conclusion here is that there is no difference between

Mammoth Cave karst and Florida karst: in both cases, >99% of the flux is in conduits and the other parameters compare well too.

The FEIS reflects the consensus in the literature that the LNP area is karstic. It should be emphasized that Levy County and the LNP site are within an area described in many published documents as being karst (the Ocala Karst Plain or District) Bryan et al., 2008; Williams et al., (2010) and Scott, et al., (2004) are just a few examples. Quinlan et al., (1996), Davies and Quinlan (1993), and Davies (2008), provide more detail about describing karst aquifers.

It is well known that it does not require that there are large conduits or caves or other macro-features for any site to exhibit karstic qualities when investigated. An excellent example is shown by McDonald et al., (1998) in the Chalk of the UK, one of the principal aquifers, and measurements show that it has many characteristics of a typical karst aquifer. Shade (2007) shows that even in non-carbonate rocks, in that case a pure quartz sandstone, with sinking streams, there is rapid turbulent flow in conduits and springs are present.

Q.12. Did the FEIS adequately characterize the water flow in the karst?

A.12. No, the investigation methods used to evaluate the hydrogeology at the LNP site, (slug tests, pumping tests) all assume that most of the water flow is through a homogeneous porous medium. Examples include references to “monitoring data from nested wells at the proposed LNP Units 1 and 2” (FEIS p2-28). The FEIS also states that: “In addition to the slug testing program, three constant-rate withdrawal (pumping) tests were conducted at the LNP site (PEF 2009d): one within the surficial aquifer (at LNP

Unit 2) and two within the Upper Floridan aquifer (LNP Units 1 and 2) (FEIS p.2-26). These tests are only useful indicators of the properties of aquifers if those properties are relatively uniform, as is assumed for ideal porous media.

Other indications that a porous medium was assumed are the numerous references to a single value hydraulic conductivity and transmissivity for each aquifer. Examples where these parameters are used as evidence in the FEIS are on page 2-26 where it somewhat confusingly states, "Hydraulic conductivities for the surficial aquifer ranged from 15 to 20 ft/d" and then on the same page different values are given for the same surficial aquifer, "Hydraulic conductivity estimates ranged from 0.9 to 28.6 ft/d in the surficial aquifer and from 2.4 to 54.4 ft/d in the Upper Floridan Aquifer, with average reported values of 9.2 and 13.9 ft/d for the surficial and Upper Floridan Aquifers respectively."

The FEIS assumes that the hydraulic conductivity will be uniform but that assumption is invalid in karstic areas. In karst, the results of individual well tests can depend on whether the well is hydraulically connected to the conduit system. Hydraulic conductivity is an important parameter in hydrogeological investigations. However, there are known scaling effects of hydraulic conductivity measurements, (or equivalent conduit velocity) (Quinlan et al. 1992). A scaling effect is where a measurement value increases as the size of the measurement volume increases. This should not happen, but does as shown in Figure 2. This is due to the increasing probability of intersecting conduits as the size of the measured volume increases. The data in the measured volume to the top right (E) in Figure 2 contains data from only conduits. The average value and large range of values of the other results (A,B,C and D) is because conduits were probably randomly included, resulting in larger values of k, or probably not included, resulting smaller values of k. It should also be noted that this does not mean that the conduits in B, C and D are master conduits, which could also result in less than maximum values being measured (Smart, 1999). Page 2-26 also refers to using the Bouwer and Rice (1976) method to analyze the slug test data. Hyder and Butler (1995) state that the Bouwer and Rice (1976) method can "introduce large errors into parameter estimates." All slug-test methods come with assumptions because they are well-based and assume a porous medium, many test wells do not comply with all the assumptions and many will never hope to, leading to misinterpretation of inaccurate measurements.

Q.13. How can karst aquifers be properly investigated?

A.13. A Standard Guide published by the American Standards for Testing and Materials (1995) was written precisely *because* carbonates, karst and fractured rocks exhibit conditions that are acknowledged by a consensus of professionals as not behaving like a porous medium. Although this Standard Guide is currently being updated, the 1995 guide gave many useful recommendations, which generally are similar to recommendations made by Quinlan (1990). Unfortunately, few, if any, of these recommendations were followed by the authors of the FEIS. The results obtained in the FEIS are therefore unreliable.

For example, on page 2-26, the FEIS states, "three constant-rate withdrawal (pumping) tests were conducted at the LNP site." Wells also cause potentially unreliable parameters to be measured, Bidaux and Drogue (1983), reveal a complicated hydrological and geochemical situation in any well, especially when there is a long open interval that is being monitored. ASTM (1995) states that when testing using wells, care must be taken to use a vertical testing interval that is of an appropriate length to represent all the flow from the formation into that well.

The FEIS p.2-25 references "a site investigation that included 118 geotechnical borings to characterize subsurface conditions at the proposed LNP Units 1 and 2." Wells and borings have a low probability of intersecting conduits (Benson and la Fountain, 1984). If they do happen to intersect a conduit, it is most often a tributary conduit and not the master conduit (Smart, 1999). Using the numbers in my attached Table 2 (**Exhibit INT004**), this means that most of the time wells, borings, and cores might only intersect tributary conduits and thus will only sample < 1% of the relevant groundwater that is moving through a system. If a master conduit is intersected by drilling and it can be confirmed, it can be assumed that it is transmitting much of the water that is flowing in the aquifer at that location and possibly the whole groundwater basin. Because it is currently impossible to know whether any of the wells that were drilled at the LNP site intersected a master conduit, we have very little knowledge about how much groundwater is really flowing.

As previously stated, Davies (2008) calculated that in the Woodville Karst Plain greater than 99% of the flux through the aquifer is in conduits; similar to Worthington et al., (2000) elsewhere in carbonates of different geological age and settings. Benson and La Fountain (1984) calculate that it would take 1,000 3-cm drill holes per acre (404 per hectare) to have 90% probability of intersecting a 1-meter solid elliptical object in the subsurface. Obviously 118 borings on a 3105 acre site (FEIS p.2-41) is less than the optimum number needed for an accurate analysis of conduits, even if they are large. .

Q.14. What are the consequences of failing to recognize the karstic nature of the aquifers?

A.14. Using inappropriate assumptions about how groundwater flow is occurring can result in unpleasant surprises . In several large projects at major DOE facilities, e.g., the WIPP (Waste Isolation Pilot Plant), Yucca Mountain, and an investigation done at Los Alamos National Laboratory, and other non-DOE sites (Bredehoeft, 2007), shows how flawed conceptual models led to "surprise"– mostly hydrogeological, long after large sums of money have been expended. Given the vulnerability of the water resources at the LNP, it is clear that only if empirical tests and minimal assumptions about aquifer characteristics are used, can any predictions approaching reliability be made. As yet at the LNP none of this has been done. This has happened even though guidance on how to properly evaluate carbonate settings like at the LNP have been in print for more than two decades (Quinlan, 1990; USEPA, 1997; ASTM, 1995).

It is vital that correct assumptions be made when attempting to plan any hydrogeological actions, such as dewatering or any pumping operations. It is well established that these projects can change groundwater pathways and change ground water discharge characteristics. In aquifer settings where springs have been known to flow for centuries (Downing et al., 1993), water being abstracted for consumption can cause any spring downgradient to cease discharging. Similar situations have already been documented in Florida (Bengtsson, 1987).

Assuming an ideal porous medium also leads to an underestimate of groundwater flow velocity compared to the actual situation. Groundwater velocity is typically orders of magnitude greater in conduits in the karst than an assumed porous medium. What is also often the problem is that porous medium parameters cannot estimate an accurate magnitude of discharge. This is because the hydraulic conductivity of carbonates increases downgradient in a basin (Table 3); in a porous medium it is assumed to be constant. Also, hydraulic gradients flatten downgradient in carbonates, where in a porous medium they would steepen (Table 3 **(Exhibit INT007)**, Figure 1 **(Exhibit INT008)**).

This would mean that either: (1) more water could be dewatered than predicted, or (2) a larger area could be affected than was predicted. Conduits mean that locations where changes happen can be specific and the changes of large magnitude and abrupt. Other surprises can result; spring flows can cease completely, or can be shifted downstream because of underflow caused by a change in hydraulic gradient. In short there is huge uncertainty to such predictions. Predicting where conduits occur in the subsurface can be done to some degree, but it requires large amounts of empirical data on hydraulic head variation, groundwater velocity and geochemistry.

When conduit locations are known to some degree, better estimates can be made. Davies (2008) modeled surface water and groundwater mixing using natural uranium in the Floridan aquifer south of Tallahassee that concurred with the results of numerous injected tracing experiments using fluorescent dyes.

Prediction of a 20 mile geographic area of interest either for cumulative impacts from surface water impacts (FEISp.7-10) or groundwater impacts (FEIS p.7-13) is therefore highly uncertain. Given the vulnerability of the water resources at the LNP, and the complicated hydrogeology, that has not been taken into account, it is clear that only if empirical tests are performed and minimal assumptions are used, could any reliable predictions be made. These tests and correct assumptions are missing in the Levy FEIS. As a result, the FEIS' predictions about the impacts of the pumping system are not reliable to a reasonable degree of scientific certainty.

Q. 15. Why do you believe that an area larger than 20 miles from the proposed LNP should be evaluated?

A.15. If estimated fluid transport parameters are compared for an ideal porous medium using a Darcy velocity, and traced velocities in conduits in a carbonate (karstic) setting, the contrast is clear. Groundwater velocity, and thus transported contaminant velocity, where it applies, is typically orders of magnitude higher in conduits than in an assumed porous medium (e.g., the differences in velocity or k in Figure 2). Therefore the FEIS' assumption of a 20 mile geographic area of interest either for cumulative impacts from surface water impacts (FEIS p.7-10) or groundwater impacts (FEIS p.7-13) cannot be relied upon for velocity or in fact distance. Recent and previous work (Davies, 2008; Loper et al., 2005) done in the Woodville Karst Plain south of Tallahassee connects conduits from a sink to Wakulla Spring and south of there to coastal, estuary springs (the Spring Creek group of springs) over a distance of greater than 55 km (34 miles), and there is evidence that even that distance is a fraction of the total extent of the basin.

The coastal karst plains of Florida are extensive, but the underlying groundwater basins are far larger. For example, recently in the Woodville Karst Plain south of Tallahassee a tracer test being conducted by this witness (data are still being collected) connects conduits over distance of more than 50 km inland. The sinkhole into which the tracer was injected lies just north of Interstate 10 east of Tallahassee, and is known to respond to tidal fluctuations. The tracer was recovered at several large springs in the Woodville Karst Plain to the south and west with the peak concentration passing through the largest spring about 50 days after injection, an average velocity of about 700 m/day. Figure 3 **(Exhibit INT009)** compares this and range of velocities from there (Davies, 2008) with the k values that are quoted from the LNP site. Flow path distances there, as compared to distances used at the LNP site, show it is imprudent to assume that cumulative effects from dewatering can be arbitrarily relegated to the relatively small (given the extent of the coastal karst plain previously described) distance of 20 miles. Based upon discharge values and the documented large conduits, the larger Florida springs could have basins as large as 4,000 km2.

Velocities of hundreds of meters or kilometers per day are normal in conduits (Worthington et al., 2000; Davies 2008). Previous tracing has connected most of the dived and mapped flooded caves to the Spring Creek Group of springs on the Gulf Coast. As previously stated this cave system contains the longest known actively flowing and mapped continuous pathway of 19.8 km, between Big Dismal Sink and Wakulla Spring. Others compare; Padirac cave in France 19 km, and the Rio Encatado cave in Puerto Rico, 14 km (Dr. Stephen R.H. Worthington, person communication). Hydrogeological effects could be far reaching.

Q.16. How do saline and fresh water interact in the vicinity of LNP?

A.16. The great distance in this pathway and the large conduit system connected to it also reveals the potential extent of fresh water /saline water interaction inland. Systems like this behave in a very complicated way, with layered interfaces of saline and fresh waters–some warm, some much cooler (Woodville Karst Plain Project, unpublished data). The complex nature of the interaction is partially because the coastal karst landscape and aquifer have seen much modification through the last 5 -10 ma (1 ma = 1 million years) and possibly hundreds of episodes of fluctuating sea level.

During the tropical storm season in 2004 a rapid response from a tropical storm at the coast along a conduit was gauged and documented between the large group of springs vents at Spring Creek and Wakulla Spring (Loper at al., 2005). As stated previously this is not unlike the complicated nature of the interaction in the Yucatan caves, Mexico (Beddows, 2004), and on the Mediterranean coast (Drogue and Bidaux, 1986). In addition, there is also decoupled fresh water moving next to saline water 1,100 meters below the water table in the San Antonio segment of the Edwards Aquifer (Lindgren et al., 2006). In coastal Florida there are also documented very large active conduit tiers that carry active flow up to 100 m below the present water table elevation (Werner, 2001).

The situation in Florida is most complicated because it is a karst landscape that probably formed during Miocene or older times (> 5 ma) and was exposed by a drop in sea level of -140 m 20 ka ago (Simms et al., 2007), only to be drowned again by higher sea level at its present level (today's level is at zero when 20 ka ago it was –140 m). There is a regular cycle of fluctuation in sea level as continental ice is formed and melts caused by oscillations in the planet's orbit around the sun. Based upon a comparison of sea level changes ~400,000 years ago, and similar earth orbital and spin precession, sea level is projected to rise naturally about 7 m in the next 60 ka years (see discussion in Bowen, 2010). The FEIS acknowledges sea level rise may already be contributing to wetland losses (FEIS 7-22) without analyzing how or predicting how future sea level rise will impact the Floridan aquifer. The interaction of saline and fresh water means that sea level fluctuation should also be considered when evaluating the impacts of dewatering in a karst environment, because in conduits removal of fresh water will mean more saline water entering.

Q.17. How could quarry and excavation dewatering affect groundwater flow in the vicinity of the proposed LNP site?

A.17. Quarrying operations often involve reducing the water-level in the excavation, as is proposed at the LNP, "The current conceptual foundation design calls for substantial dewatering of each nuclear island area to depths of approximately 100 ft. below existing grade" (FEIS p.3-13). This can have significant effects on the flow system as shown by Edwards et al., (1992), Smart et al., (1991).

They describe a quarrying situation in the Mendip Hills, Somerset, Great Britain, where previous tracing experiments had connected sinking streams with springs several kilometers the other side of a quarry. After deepening the quarry, the flow from a conduit was diverted by the de-watering <u>even though a conduit was not actually intercepted,</u> and that flow did not thereafter reach one of the springs that it had been traced to previously. This also caused water flowing in other conduits to now discharge at the quarry. Blasting and excavating in the quarry significantly increased the hydraulic conductivity in the quarry floor, in one case, almost an order of magnitude higher than values obtained for undisturbed rocks in the same setting (Smart et al., 1992). Simulations done in this quarry case suggest that pre-dewatering levels would take 24 years to recover. It is important to note that this disturbance in discharge happened *despite* investigatory tracings having been done. No such tracings to evaluate the flow pathways are mentioned in the Levy FEIS, so even greater uncertainty about predictions exists here.

Q.18. Why does regional groundwater extraction matter?

A.18. The withdrawal of groundwater for consumption upgradient of any coastal area can encourage saline intrusion inland. Appropriate numerical models in the Woodville Karst Plain show that extensive removal of groundwater for irrigation and drinking water becomes the most likely reason that water quality and groundwater quantity at Wakulla spring and in Wakulla County are declining. This shows that comparably, even without dewatering at the LNP site, there is probably a depletion of fresh groundwater occurring. David Still's testimony also provides more examples of saline intrusion problems being experienced. Given the currently stressed nature of the aquifer, all significant current and proposed groundwater extractions should be included in the modeling of the regional groundwater resources.

Q.19. Can excavations, mines and quarries affect the flow paths in karstic aquifers?

A.19. Yes, blasting can have dramatic effects on flow paths in karst. The resulting alterations in hydraulic conductivity from blasting at that nearby Tarmac site mine should be more fully explored in the FEIS in order that an accurate assessment of hydrological effects be made.

Q.20. Do you swear in accordance with 28 U.S.C. § 1746, under penalty of perjury, that this testimony is true and correct?

A.20. Yes I do.

Executed in accord with 10 C.F.R. § 2.304(d)

Gareth J. Davies
109 Dixie Lane,
Oak Ridge, TN 37830
865 310-6250 (cell) 865 483 7027 (land)
June 26, 2012

References Cited

Hubbert, M.K., 1940, The theory of ground water motion, Journal of Geology, 48, p. 785-944.

Davies G.J., and Quinlan, J.F., 1993, There is no such thing as a diffuse-flow carbonate aquifer if that aquifer is unconfined and subaerially-exposed, Geological Society of America Abstracts with Programs, v. 25, no. 6, p. A211.

Loper, D.E., Werner, C.L., Chicken, E., Davies, G.J., and Kincaid, T., 2005, Coastal carbonate aquifer sensitivity to sea level change, EOS, v. 86, no. 39, p. 353-364.

Shade, B.L., 2002, The Genesis and Hydrogeology of a Sandstone Karst in Pine County, Minnesota, Master of Science thesis, University of Minnesota Department of Geology and Geophysics, Minneapolis Minnesota, 171 p.

Werner, C. L., 2001, Preferential flowpaths in soluble porous media and conduit system development in the Woodville Karst Plain, Florida, Master of Science Thesis, Department of Geology, Florida State University, Tallahassee, FL., 171 p.

Drogue, C., and Bidaux, P., 1986, Simultaneous outflow of fresh water and inflow of sea water in a coastal spring. Nature, 322:361-363.

Bidaux, P., and Drogue, C., 1983, Calculation of low-range flow velocities in fractured carbonate media from borehole hydrochemical logging data comparison with thermometric results, Ground Water, 31(1) Jan-Feb 1983, p. 19-26.

McDonald, A.M., Brewerton, L.J., Allen, D. J., 1998, Evidence for rapid groundwater flow and karst-type behaviour in the Chalk of southern England, (in) Robins, N.S., (ed) Groundwater Pollution and Aquifer Recharge and Vulnerability, Geological Society Publication No. 130, The Geological Society, p. 96-106.

Hyder, Z., and J.J Butler Jr. 1995. Slug tests in unconfined formations: An assessment of the Bouwer and Rice technique. Ground Water 33, no. 1: 16–22.

Bouwer, H., and R.C. Rice. 1976. A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells. Water Resources Research 12, no. 3: 423–428.

Edwards, A.J., Hobbs, S.L., and Smart, P.L., 1992, Effects of quarry dewatering on a karstified limestone aquifer: a case study from the Mendip Hills, England, Hydrology, Ecology, Monitoring and Management of Ground Water in Karst Terranes, Conference Proceedings (3rd Nashville, Tenn.), National Ground Water Association, Dublin, Ohio, p. 77-92.

Bengtsson, T. O., 1987, The hydrologic effects from intense ground water pumpage in East-Central Hillsborough County, Florida, (in) Beck, B.F., (ed), Proceedings, 2nd Multidisciplinary Conference on Sinkholes, Their Geology, Engineering and Environmental Impact, p. 109-114.

Bryan, J.R., Scott, T.M., and Means, G.H., 2008, Roadside Geology of Florida, Mountain Press Publishing Company, Missoula, MT., 376 p.

Smart, P.L., Edwards, A.J., and Hobbs, S.L., 1992, Heterogeneity in carbonate aquifers; effects of scale, fissuration, lithology and karstification, Hydrology, Ecology, Monitoring and Management of Ground Water in Karst Terranes, Conference Proceedings (3rd Nashville, Tenn.), National Ground Water Association, Dublin, Ohio, p. 373-388.

Simms, A.R., Lambeck, K., Purcell, A., Anderson, J.B., Rodriguez, A.R., 2007, Sea-level history of the Gulf of Mexico since the Last Glacial Maximum with implications for the melting history of the Laurentide Ice Sheet, Quaternary Science Reviews, 26: 920-940.

Worthington, S.R.H., Davies, G.J., and Ford, D.C., 2000, Matrix, fracture and channel components of storage and flow in a Paleozoic limestone aquifer, p. 113-128, (in) Wicks, C.M. and Sasowsky, I.D., (eds) Groundwater Flow and Transport in Carbonate Aquifers, Balkema, Rotterdam, 193 p.

USEPA, 1997 , Guidelines for Wellhead and Springhead Protection Area Delineation in Carbonate Rocks, EPA 904-B-97-003.

ASTM, 1995, Standard Guide for the Design of Groundwater Monitoring Systems in Karst and Fractured-rock Aquifers, D5717-95, V. 04.09 (Soil and Rock), Annual Book of ASTM Standards, American Society for Testing and Materials, West Conshohocken, PA 19428, p. 451-468.

Smart, C. C., 1999, Subsidiary conduit systems: a hiatus in aquifer monitoring and modeling, (in) Palmer, A.N., Palmer, M.V., and Sasowsky, I.D., (eds) Karst Modeling, Symposium Proceedings, Charlottesville, VA, Karst Waters Institute, Special Publication No. 5., p.146-157.

Quinlan, J.F., Davies, G.J., Jones, S.W., and Huntoon, P.W., 1996, The applicability of numerical models to adequately characterize groundwater flow in karstic and other triple-porosity aquifers, (in) Ritchey, J.D, and Rumbaugh, J.O., (eds) American Society for Testing and Materials, STP 1288, American Society for Testing and Materials, West Conshohocken, PA 19428, p. 114-133.

Worthington, S.R.H., and Gunn, J., 2004, Hydrogeology of Carbonate Aquifers: A Short History, Vol.47, No. 3, Ground Water, May-June, 2009, p. 462-467.

Davies, G.J., 2008, Mixing of rapid recharge and rapid-flowing ground water : Implications to protecting municipal wells in the Woodville Karst Plain, North Florida, Geological Society of America Abstracts with Programs, vol. 40 no. 6., p.211.

Bredehoeft, J.D., 2005, Modeling:: the conceptual model problem - surprise, Hydrogeology Journal, v. 13., p 37-46.

Price , M., Downing, R.A., and Jones, G.P., 1993, The making of an aquifer, (in) Downing, R.A., Price , M., and Jones, G.P., (eds) The Hydrogeology of the Chalk of Northwest Europe, Oxford Science Publications, p. 1-13.

Lindgren, R.J., Dutton, A.R., Hovorka, S.D., Worthington, S.R.H., and Painter, S.., 2004 Conceptualization and Simulation of the Edwards Aquifer, San Antonio Region, Texas, USGS Scientific Investigations Report, SIR 2004-5277, p. 17.

Benson, R. C.,and La Fountain, L.J., 1984, Evaluation of subsidence or collapse potential due to subsurface cavities, (in) Beck, B.F., (ed) Sinkholes, their Geology, Engineering and Environmental Impact, p. 201-215.

Quinlan, J.F., 1990, Special problems of ground water monitoring in karst terranes, (in) Nielsen, D. M., and Johnson, A. I., (eds) Ground Water and Vadose Zone Monitoring, ASTM STP 1053, American Society for Testing and Materials, West Conshohocken, PA 19428, p. 275-304.

Williams, C.P., Green, R.C., Flor, A.D., Paul, D.T., Scott, T.M., and Kromhout, C., 2010, Text to accompany geologic map of the western portion of the USGS Ocala 30x60 minute quadrangle, north-central Florida, Florida Geological Survey Open File Report 94, 29 p.

Smart, P.L., Hobbs, S.L., Edwards, A.J., 1991, Dye tracing in the Beacon Hill pericline, East Mendips, Proceedings University of Bristol Spelaeological Society, Vol. 19, No. 1, p. 67-82.

Smart, P.L., Edwards, A.J., and Hobbs, S.L., 1992, Heterogeneity in carbonate aquifers; effects of scale, fissurisation, lithology and karstification, Hydrology, Ecology, Monitoring and Management of Ground Water in Karst Terranes, Conference Proceedings (3rd Nashville, Tenn.), National Ground Water Association, Dublin, Ohio, p. 373-388.

Scott, T.M., Means, G.H., Meegan, R.P., , Means, R.C., Upchurch, S.B., Copeland, R.E., Jones, J., Roberts, T., and Willet, A., 2004, Springs of Florida, Florida Geological Survey Bulletin No. 66, Florida Geological Survey, Tallahassee, FL, 377 p.

Beddows,. P.A., 2004, Groundwater Hydrology of a Coastal Carbonate Aquifer: Caribbean Coast of the Yucatán Peninsula, México, Doctor of Philosophy Thesis, School of Geographical Sciences, University of Bristol, 240 p.

Worthington, S.R.H., 2001, Depth of conduit flow in unconfined carbonate aquifers, Geology, v. 29., no. 4., p. 335-338.

Meinzer, O.E., 1927, Large Springs of the United States, USGS Water Supply Paper 557, U.S Government Printing Office O-1951, 119 p.

Werner, C.L., 2001, Preferential flowpaths in soluble porous media and conduit system development in carbonates of the Woodville Karst Plain, Florida, Master of Science Thesis, deprtment of Geosciences, Florida State University, Tallahassee, FL., 180 p.

Bowen, D.Q., 2010, Sea level 400 000 years ago (MIS 11): analogue for present and future sea-level? www.clim-past.net/6/19/2010/ Clim. Past, 6, 19–29, 2010.

Simmons, C. T., 2008, Henry Darcy (1803-1858): Immortalized by his scientific legacy, Hydrogeology Journal, 16:1023-1038. (e-mail)

Quinlan, J.F., Davies, G.J., and Worthington, S.R.H., 1992, Rationale for the design of cost-effective groundwater monitoring systems in limestone and dolomite terranes: Cost-effective as conceived is not cost-effective as built if the system design and sampling frequency inadequately consider site hydrogeology. Waste Testing and Quality Assurance Symposium (8th Washington, D.C., July 1992) Proceedings. U.S Environmental Protection Agency, Washington, D.C., p. 552-570.