6.4 **WATER VARIABILITY: CHALLENGES WHERE THE RUBBER HITS THE ROAD**

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1.0 Introduction

Too often, the focus of water variability is on the grand scheme: global water balance, climate change, and national societal impacts. Yet, the impacts of water variability are felt primarily at the level of localities and individuals. This paper deals with one extreme of water variability; drought. Whether or not sufficient water is available for people, industry, recreation and agriculture is a balance between availability and demand. While *Mother Nature* is the primary driver on the supply side, both availability and demand depend strongly on local cultures, zoning, watershed stewardship, land use and management. At the local level, the challenges created by drought are substantial. With the continued sprawl to rural areas that has intensified over the past 50 years, local governments in newly urbanized or rural areas in transition are finding themselves without a plan of how to balance growth with water availability. As serious, elected officials are relying on established procedures and organizations that are ill equipped to deal with both development and drought. The current drought in the East, for example, has forced some counties not only to ration water, but to put a moratorium on building. Law suits have been filed to prevent such curbs, even when reservoirs and rivers were nearly dry.

The September 2002 issue of the *Bulletin of the American Meteorological Society* (Vol **83**, No 8) contains a series of articles that focuses on the issues of identifying and measuring drought. Identification and measurement is the beginning point for the communities. The next steps are planing for and managing drought in a comprehensive decision process. Help is available to plan for drought in the form of private companies and consultants, public agencies, citizen's groups, foundations, and universities. One serious challenge to professional societies is how to organize and deliver scientific advice when and where it is needed for community decision models.

2.0 Local Myths About Drought Planning

At the outset, it is important to define "drought". Drought is defined by Redmond (2002) as when water demand exceeds supply. This definition is adopted here and provides for both natural and man-made factors influencing the availability of water.

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The three different categories of drought commonly used are precipitation, agricultural and hydrologic. Long term agricultural and hydrological droughts create the greatest challenges for localities. Both relate directly to the availability of water from surface and ground sources (rivers and aquifers, respectively) for food supply, recreation, and public use. In this broad definition of drought, "average" rainfall may be experienced during a drought, but the rainfall occurs in the wrong season, in flood situations that cause rapid runoff, or is not spaced properly over time. Drought may also occur when there is historically "about normal" precipitation, but the combined demand from the natural eco-system and people's activities (e.g., agriculture, industry, and recreation) is larger than the supply from rivers, aquifers or man-made reservoirs.

Myth 1: Drought cannot be forecast. Conclusion: Why plan?

The actual prediction of the onset of precipitation or agricultural drought is not realistic beyond about a month.[1] Even then, as Redmond (2002) says, "Like twilight, drought creeps stealthily into existence..", so the onset of drought is best determined from historical records. The climatological record is clear that drought is cyclical. For long term planning, the actual month and even year of the onset of a drought is not critical.

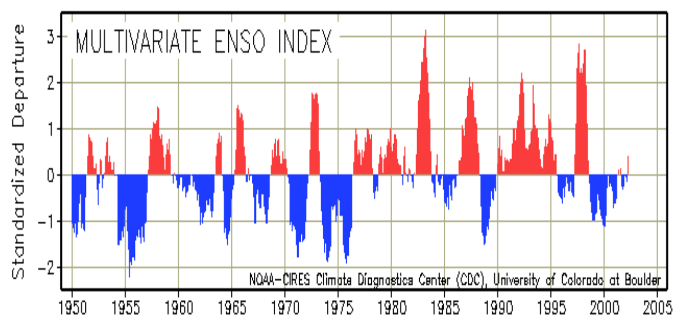

Figure 1 Fifty Years of El Nino (plus values) and La Nina

[1] Hydrologic drought represents a multi year accumulation of precipitation deficit and/or increasing demand. It is slow to develop and slow to dissipate. Because of this slow progression there are early warning signs. It is possible for decision makers and planners to anticipate hydrologic drought well in advance of it reaching its worst condition. The fact that hydrologic drought too often is not anticipated or planned for is a reflection of where communities place priorities between managing natural resources and exploiting them.

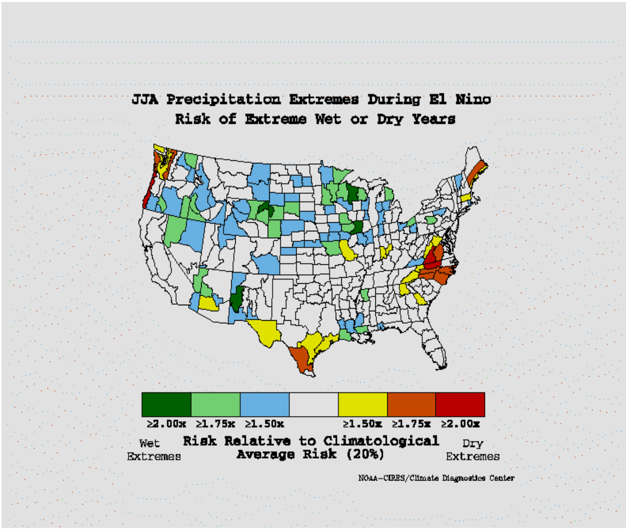

Figure 2 Precipitation Extremes During El Nino

The critical information is knowing that drought will occur, together with some sense of its frequency. Certain relationships are known between a few meteorological events and drought on time scales of months to a year or so. For the past 25 years of record, El Nino events have tended to be stronger and last longer than in the previous 25 years (Fig 1). For Frederick County, Virginia, normal or below normal rainfall is two times more likely during El Nino events than is above normal rainfall (Fig 2). By simple association, Frederick County has become more susceptible to drought. In October, 2002, Frederick County already was at least three years into a severe drought and a weak El Nino was in progress. With that information, one should not expect rapid improvement. That knowledge should be vital "predictive" information that supports planning.

The several drought indices (Heim 2002) are other pieces of information with predictive value vital to planning. The web sites for the Drought Mitigation Center and the Climate Diagnostics Center have a wealth of information including many links to other sources. (See for example, http://www.drought.unl.edu/plan/plan.htm, http://www.drought.unl.edu/links.htm, and http://www.drought.unl.edu/media.htm). In the authors' experiences, most of the indices are either poorly understood by local decision makers and planners, or totally unknown to them.

As for termination, it is possible to estimate the amount of precipitation needed to alleviate or eliminate a drought and then to give a probability of achieving that value over a period of a few months in advance. One of the products from the Climate Diagnostics Center includes that information. (Heim, 2002) While a "forecast" of drought onset or termination in the traditional sense is not possible, substantial information is available that can be critical to drought planning. So why does the myth persist?

The lack of knowledge and understanding is a major factor. The National Science Foundation's biennial report (April 2002) on the state of science understanding, found that 70 percent of Americans do not understand the scientific process. One should not be surprised that complex indicators such as the Palmer Drought Severity Index are either not understood, not used, or misused. It is much easier to just look at the rainfall deficit for any period.

State Climatologists have done an excellent job of providing information on drought and its impacts through both traditional and web-based outlets. Their work augments the national efforts of the National Weather Service and brings the information down to a local level. Unfortunately, only four of the conterminous States in the US actually encourage drought planning. Of the other 44, six emphasize mitigation (pay for the damage), two leave matters to local authorities entirely, 27 emphasize response (conserve water),and nine ignore the issue. The result of such inattention, too often, is the type of headline that appeared in the Winchester Star (Frederick County, Virginia) on September 16, 2002, *Hundreds of Virginians Cited for 'Water Crimes'*.

The authors believe that there are two fundamental reasons for the persistence of the myth: (1) too many of the decision makers, planners and business leaders do not understand science and how it can be used in the decision process, and (2) the economic impact of drought (and other environmental issues) has not yet been incorporated into the comprehensive planning process on the same footing as economic development. Particularly in an economy that has turned downward, traditional concepts of economic development take precedence over any "probabilistic forecasts" from science. One manifestation of this imbalance is Frederick County, Maryland where law suits (Summer 2002) were filed to prevent the enforcement of a moratorium on building even though severe water restrictions were in force and reservoirs were close to empty. The general belief is that the drought will soon pass, and one can "get on with business as usual". This philosophy ignores the human contribution to the drought through excessive demand. In fact, the scientific arguments about drought and its potential implications for economic development are quickly entrained into the political debate over sprawl. Too often science is dismissed for being imprecise in favor of "hard" numbers on economic development.

Myth 2: There is little that can be done other than to build reservoirs and dig deeper wells. Conclusion: Why plan?

Building traditional reservoirs has become exceedingly difficult due to environmental concerns. Some estimates are that it takes from 20 to 30 years from concept to build a reservoir. Side channel reservoirs, those built beside the river or stream to trap flood water, are more practicable, but they are less efficient for long term water storage. Filling quarries can be a stop gap in some areas, but the volume often is limited to a few weeks or few months supply, depending on size and demand.

During the 1970s, projections were made for the demands for fresh water out to 2000. By 1990, those projections were as much as 350% too high (Fig. 3, Schilling 2002). Better engineering practices for water supply, industrial efficiencies and water recycling, and water efficient fixtures in homes and offices all contributed to the actual reduction in consumption when a rapid rise had been projected. More can be done. Some countries in Europe, for example, have elegant designs for water-efficient buildings. One sees gardens with 10-15 meter high trees growing on the tops of apartment houses. Parking is underground with grass areas and gardens forming the roof. Each of these reduce runoff, and the need for air conditioning. Water permeable surfaces can be used for parking areas and roads with light traffic. If one has 36 inches of rain a year, imagine three feet of water standing on each parking lot in front of each strip mall. That is the water that cannot percolate into the ground and is lost to the aquifer. Much more remains to be done through engineering. There is concern, however, that those steps taken in the late 20th Century, and those still to be taken will not be sufficient to control the total increase in water use into the next few decades due to population growth and zoning practices. One of the main concerns

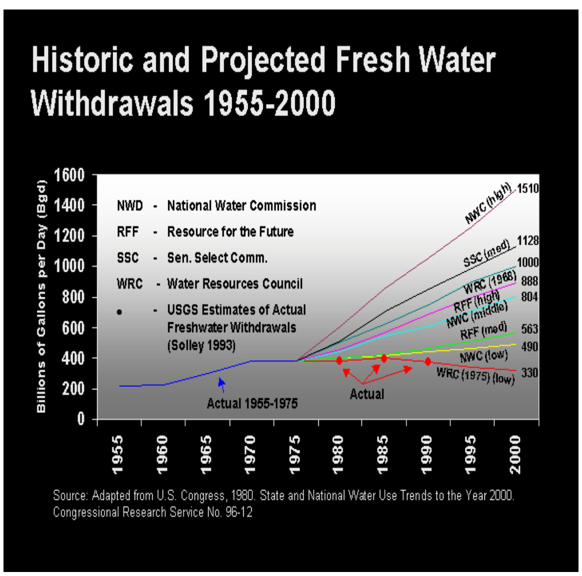

Figure 3 Historic and Projected Fresh Water Withdrawals 1995-2000

is rural sprawl.

The "water wars" of the West have moved East. These "wars" pit rural areas with shallow wells (20-200 or so feet deep) and springs as the primary water supply against rapidly growing centers just achieving the designation of Metropolitan Planning Organization (50,000 population is the break point). These latter centers often were deliberately sited on "poor" land as a way to preserve prime agricultural land from development. Unfortunately, the agricultural land often has the water and the land under the developed areas does not. That certainly is true in Frederick County, Virginia. With a national trend away from family farming, the pressure is to develop the agricultural land. Many agriculturalists see the land as their 401k for retirement. This development not only increases the rural sprawl, but puts serious demands on the available water. Both the newly urbanized areas and those developing agricultural land want the same water.

One of the primary influences on water management for many communities is control over both rural and urban sprawl. Here is where the local governments have not only the authority, but the responsibility to develop comprehensive plans and zoning practices for water management. Here is where the economic pressures to develop and the environmental realities of drought come into conflict. Many of the elected officials and county administrators in rapidly growing areas do not have the training to deal with the issues. As important, resources too often are lacking to organize environmental data bases, to conduct studies, and to train people. In Frederick County, some 65% of the annual budget is allocated to schools, and that percentage is growing. Because they are little understood, because there is the belief in Myth 2 that little can be done in any event, the environmental issues are given low priority - unless the issue is forced by regulations from above or by conditions like the drought.

3.0 Case Study

As part of an educational campaign, the authors organized a presentation to the Frederick County Board of Supervisors on the status of the drought and gave a case study of what can happen when too much emphasis is placed on apparently "hard" numbers. It also illustrates the need for local administrators to seek "second opinions" before they act on critical environmental decisions.

The case study concerns the Stephens City quarries that are an important source of water provided through the Frederick County Sanitation Authority (FCSA) to roughly 40% of the county residents. (The North Fork of the Shenandoah is the main source of water for the FCSA.) The quarries were purchased by Stephens City in 1983 and engineering studies were conducted in 1988 to determine the safe yield. The studies included pumping 2 million gallons per day (mgpd) for 30 days to determine the impact on the water level in the quarries and in surrounding private wells. Recharge rates were calculated based on the assumed watershed area and underground terrain type. Even considering the reduced rainfall during drought years of

Figure 4 South Quarry 1995, Stevens City, VA, courtesy of J. Shull.

record, the safe yield was determined to be about 3 mgpd.

In 1991, rights were contracted to the FCSA to withdraw on average 2.2 mgpd. One of the local papers declared "Independence Day", because there was at last a reliable source of the water for the foreseeable future. At the start of the commercial pumping in 1994 the three quarries contained a total of about 566 million gallons of water, or about 2300 acre feet (Fig 4). (Without recharge, that volume would represent only about 80 days total supply of water (roughly 8 mgpd) needed in 2002 by the Winchester City and Frederick County water authorities) Between 1994 and mid 2001, pumping rates ranged between 1.5 to 2.5 mgpd. By early 2002, the three quarries were essentially dry (Fig 5). Although, about 0.75 to 1.25 mgpd were still being

Figure 5 South Quarry 2002, Stevens City, VA, courtesy of J. Shull. Remaining water above ground in the quarry is in the upper left corner of the photograph.

extracted from the quarries from deep wells drilled at the site. What happened to "Independence Day"?

One of the authors (T. Dean) analyzed the information on pumping rates, water levels in the quarries and surrounding wells, the geological structure of the area, and the reports prepared predicting the safe yield. Figure 6 shows that the underground geological structure runs roughly from the south-west to north-east. By July 2000, the cone of depression[2] resulting from pumping at an average of 2.2 mgpd was 3 miles long, 1.2 miles wide and 81 feet deep (Fig 7). The engineering estimate at this time was that the cone of depression would not increase; that pumping could continue reliably at the same rate. The actual cone of depression in 2002 was 4.25 miles long, 1.4 miles wide and 140 feet deep (Fig 8). There is a clear reflection of the drought in the water table record. While the drought through 2002 was severe, it approximated the situation envisioned in the worst case scenario using data from the drought year of 1999. As important as the drought, however, the watershed area assumed to provide recharge was severely truncated by the underground geology. Even though the surface watershed appears to extend out some four or so miles around the quarries, the underground structure blocks the west-east flow of

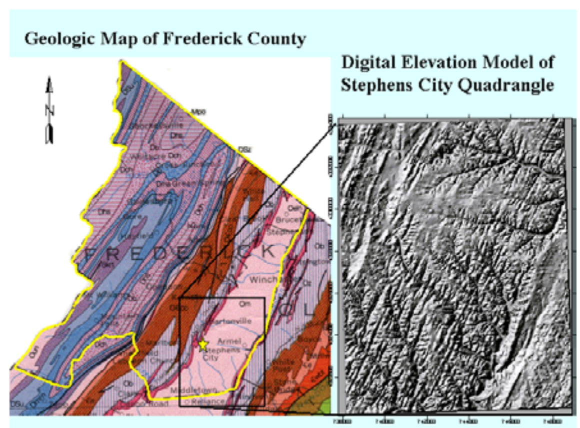

Figure 6 Geologic Map of Frederick County, VA

water so that only a small part of the surface watershed actually contributes to the underground recharge of the quarries. Not only was there a lack of precipitation, but the recharge area was significantly less than had been assumed.

The impact of a cone of depression is felt in more than just the loss of water. The geology of Stevens City is karst. Karst is broken limestone that has been eroded over the millennia by weakly acidic water seeping from above. It does have the advantage of providing pathways for water to migrate horizontally and vertically,

[2] Cone of depression is the volume in the ground where the water table has been depressed due to the extraction of water.

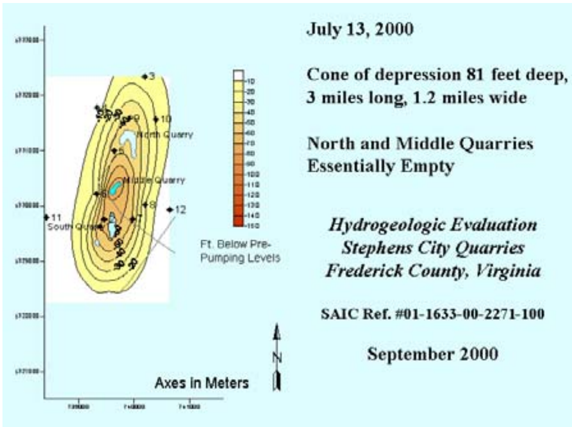

Figure 7 Cone of Depression Around Stevens City Quarries After Six Years of Pumping (Dean 2002)

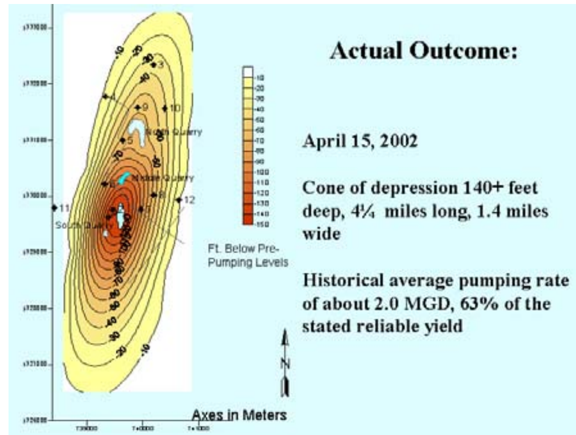

Figure 8 Cone of Depression Around Stevens City Quarries After Eight Years of Pumping (Dean 2002)

and is a good place for wells. Karst has the disadvantage of being riddled by caverns (some spectacular ones in the area have been tourist attractions for well over one hundred years). Caverns can lead to sinkholes when the underground water is removed leaving the surface overburden unsupported.

Frederick County has many hundreds of such sinkholes. Some have formed under major buildings causing collapse. In September 2002, one swallowed about 200 meters of a stream flowing through Winchester, Virginia. The pathways mean that springs and wells for several miles may be connected and will run dry when cones of depression are created by major water extractions. The pathways also mean that contaminants can travel long distances. All of these aspects have a significant impact on planning for development and industry.

Several conclusions can be drawn from this case study. First, the reliable estimation of safe yield is far from simple. Second, the inability to predict the impact of pumping the quarries has severe impacts throughout the area and has major implications for economic planning. Third, and probably the most important, is that there was no long term strategy in the event of a major drought that left both the quarries and the Shenandoah essentially dry. The Shenandoah River was running as low as 15% of normal (the average was about 1/3rd of normal) during the Summer of 2002.

A basic assumption on the part of the decision makers was that the original estimates of safe yield from the quarries were “hard” engineering numbers that could be “taken to the bank”. They were not. While the FCSA has not had to enforce severe water restrictions, voluntary ones have reduced the overall demand by some 400,000 gallons per day. The real impact of the drought has been on the roughly 60% of the residents in the county not serviced by FCSA who were suffering from dry wells and springs, and ruined crops.[3] Many people blamed production wells operated by the FCSA for unnecessarily drawing down their private wells. Others were mounting major citizen’s efforts to stop the FCSA from drilling additional test wells in agricultural areas that would eventually become production wells. Some of these test wells are on land ripe for development. So the debate over rural sprawl and water availability is well joined.

The story of the quarries continues. A second set of quarries in the northern part of the county (Clearbrook) has just been added (July 2002) as a water source for the FCSA. The same engineering methods have been applied to the estimation of safe yield from these quarries. Based on the assurances of water, the Frederick county board of Supervisors added some 4,000 new acres to the FCSA sewer and water service area in July 2002. Citizen’s in the Clearbrook area are looking at the case study for the Stephens City quarries and are asking the question, “Is my well next?” Each of these vignettes is a manifestation of the importance of water and the impact of water variability when adequate management plans are missing.

4.0 Challenges

Changes are occurring which have the potential for dramatically improving the ability of communities to plan for drought; in fact to be able to use effectively all kinds of scientific information. The advent of reasonably priced geographical information systems (GIS), the hiring of full time planning staff even for small counties, the increased emphasis on environmental studies in local universities and Community Colleges, the increased interest by foundations in local issues, and the establishment of well informed citizen’s groups, are

[3] From 1993 to 2001, drought had caused $193 million damage to agriculture in Frederick County. (Source: National Climatic Data Center)

all providing a resource base that local decision makers did not have 10 or 15 years ago. Those resources are being used with increasing success in some localities. But, the myths remain.

As stated earlier, the authors believe that there are two fundamental reasons for the persistence of these myths: (1) too many of the decision makers, planners and business leaders do not understand science and how it can be used in the decision process, and (2) the economic impact of drought (and some other environmental issues) has not yet been incorporated into the comprehensive planning process on the same footing as economic development.

Decision makers at the local level rely heavily on what they believe to be hard engineering numbers on environmental issues such as the availability of water, impact on the eco-system and air quality. While these numbers seem to support relatively black and white decisions, the real scientific information needed for decision making remains untapped. The direct analogy within meteorology is the shift away from deterministic forecasts to probabilistic ones, such as the ensembles used in numerical weather prediction. The "hard" engineering numbers and projections are, in reality, deterministic. Complex decision models and risk analyses need ranges of possibilities (ensembles), hence the need for the probabilistic approach.

That will be a "hard" sell to most local leaders. Not only is there tradition to support deterministic approaches, but there is "political" comfort in definitive numbers in a report prepared by an "expert". "If our expert says it is so, it is so." In effect, the verbatim use of deterministic information transfers the responsibility from the decision maker to the expert. A range of possibilities with attendant probabilities may be difficult to understand at first, but it does return the responsibility to the decision maker.

In all of this, the authors see both a challenge and an opportunity for professional societies. Professional economic planners are on the staffs of every city council and county government to ensure that the economic issues are well understood and articulated. Local Chambers of Commerce and Economic Development Commissions actively develop programs and models for economic development. Science does not have that kind of grass roots organization. As people in scientific professions, we should not be surprised, then, that environmental issues often are secondary considerations until some crisis erupts.

The challenge to professional societies is to begin the process that would bring a "professional science planner" to every community. The cadre of people and local organizations mentioned above already exist and are trying to carry science into the decision process, with some limited success. State and federal governmental agencies have professional staff available for specific issues. Unfortunately, these people too often are involved primarily with enforcement of regulations and are not part of the political process. What seems to be lacking is the catalyst to put a "professional science planner" on the staff of every local government and every regional planning commission.

How to start? There has to be a "think in" by the professional societies that science and politics have to cohabitate at the local level if science is to be brought into the decision process.[4] If that "think in" is positive, a first step would be to organize support for the local people. One could start with a few pilot projects to try out ideas and to scope the issues. Part of that support could be a virtual resource center including a library and a register of funding sources cutting across disciplines. A corps of "science advocates" could be trained in how to work at the local level, drawing support from the "resource center". One might develop a series of distance learning courses much as was done under COMET[5] to assist the national weather services to survive the extensive modernization of the 1980s and 1990s. Eventually, one would hope that colleges and universities would offer courses in something called "Science for Politics" leading to a "Science Advocate" degree.

Science professionals too often feel that they should not become involved with politics: that the objective nature of the science is lost if one becomes a partisan. That partisanship normally leads to head-to-head confrontations between advocates of science and those for economic development; as if the two were natural enemies. The idea is not to become a scientific partisan, but a science advisor for politicians. That mix of science and politics at the local level is essential if environmental policies are truly to be effective where the rubber hits the road.

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[4] The effort by the American Meteorological Society to entrain the professional meteorological TV broadcasters into the public education process is one important step along this path.

[5] Cooperative Program for Operational Meteorology, Education, and Training

Environment and Water Resources Institute, American Society of Civil Engineers, Roanoke, Virginia, May 19-22.