NORTHWEST WELLFIELD

REPORT OF THE MIAMI-DADE COUNTY WELLFIELD TECHNICAL WORKGROUP

Prepared for Miami-Dade County

Department of Regulatory and Economic Resources'

Division of Environmental Resources Management

August 2017

Wellfield Technical Work Group
Final Report
July 2017

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Introduction

Purpose and Scope

On April 21, 2015 the Board of County Commissioners (the Board) approved Ordinance 15-25 which, among other elements, amended Section 24-43 of the Miami-Dade County Code (the Code). Section 24-43 of the Code is the County's drinking water wellfield protection regulations. This Code Section requires the Department of Regulatory and Economic Resources' Division of Environmental Resources Management (RER-DERM) to maintain maps of the areas influenced by Miami-Dade County's potable water production wells (i.e. cones of influence). The cones of influence are the basis for defining the County's wellfield protection areas. The Code provides land use restrictions for properties located within wellfield protection areas to ensure the safety of Miami-Dade County's drinking water supply.

The protection of the wellfields as a source of drinking water to meet the current and future needs of the County's residents is of paramount importance. The wellfield protection areas, which have been amended from time to time, are developed based on science and public policy. Of Miami-Dade County's 26 wellfields, the West Wellfield and the Northwest Wellfield, represent the most pristine and are therefore subject to more stringent land use restrictions.

At the time of adoption of the West Wellfield Interim Protection Area, the Code required DERM to provide for technical review of the regulations applied within this wellfield protection area and to submit to the Board recommendations necessary to protect the public's health, safety and welfare based on the technical reviews.

In fulfillment of the above-mentioned Code directive and pursuant to Resolution R-112-08, adopted by the Board on February 5, 2008, Miami-Dade County contracted with the United States Geological Survey (USGS), to develop a new groundwater/surface water model for Miami-Dade County based on current science. The USGS, a division within the U.S Department of the Interior, is nationally and internationally recognized for their expertise in groundwater and surface water hydrogeology. The first phase of scope of work for the USGS contract involved the development of a new groundwater model of the Northwest and the West Wellfield Interim Protection Areas to reflect current understanding of the hydrology of the area and to provide consistency in the assumptions and parameters used in determining the drawdown and travel times for the two wellfields.

On April 19, 2013, the USGS published USGS Open File Report 2013-1086: *Estimation of Capture Zones and Drawdown at the Northwest and West Well Fields, Miami-Dade County, Florida, Using an Unconstrained Monte Carlo Analysis: Recent (2004) and Proposed Conditions*, which presented revised travel times and groundwater draw down contours for the Northwest and West Wellfield Interim Protection Areas.

The County hosted several public workshops to present the outcome of the modeling effort and the draft of the revised wellfield protection area boundaries, and to solicit comments from the stakeholders and general public. Stakeholder's comments were addressed during the iterative report drafting process; however, some stakeholders expressed concerns with the USGS model, as presented in the final report, as well as with the draft revised boundaries for the Northwest and West Wellfield Interim Protection Areas that were developed based on the modelling results.

To address the stakeholders concerns, the Board directed county staff to further consider the stakeholders concerns and to conduct further scientific investigation of the proposed wellfield protection areas and to follow up, within twenty four months, with a recommendations to the Board for the updating and modernization of the existing protection areas.

In fulfillment of the directive from the Board, DERM established a technical work group (TWG) to evaluate the stakeholder concerns with respect to the USGS report "USGS Open File Report 2013-1086: Estimation of Capture Zones and Drawdown at the Northwest and West Well Fields, Miami-Dade County, Florida, Using an Unconstrained Monte Carlo Analysis: Recent (2004) and Proposed Conditions" and the proposed wellfield protection area boundaries. The group was tasked with providing consensus recommendations regarding options (including the need for further studies) for addressing the issues raised by the stakeholders. The technical work group consisted of experts in water resources planning and groundwater/surface water modelling and included stakeholder representatives, the academic community, and regulatory and other government entities.

The TWG held 8 meetings between March 2016 and June 2017. This report presents the workgroup's recommendations with respect to options for addressing the issues raised by the stakeholders.

The members of the TWG reviewed the individual comments received by the County in response to the USGS report and the proposed Wellfield Ordinance. The comments were summarized into fourteen main issues. The report presents the TWG's consensus recommendations/response to the individual stakeholder's comments however, for ease of reference and for clarity, the comments are presented in the body of the report in the summarized form (based on the fourteen statement areas developed by the TWG) followed by the TWG's consensus recommendation. In those cases where the consensus was not unanimous, the differing opinion(s) is presented immediately below the consensus opinion.

The full text of each stakeholders comment received by the County are provided as Attachment A.

Comment 1: Conduct further field tracer tests for improved representation of aquifer properties in the model.

Response:

Tracer tests are used to support simulations of groundwater flow and contaminant transport in heterogeneous media to obtain information about aquifer parameters. While there are many instances of using tracer tests for calibration of contaminant transport models in the literature, the TWG recognizes that the applications of such techniques in the context of the current efforts to develop wellfield protection zones in Miami-Dade County will be difficult and are unlikely to result in any significant gain. Tracer tests tend to be relatively expensive and only provide information representative of the conditions present at the specific site and during the test which limits their usefulness for generating wellfield protection maps. Tracer tests are highly influenced by hydro-meteorological conditions (e.g., rainfall, operations of flow control structures and canals, and local groundwater pumping). The USGS report already used the multiple tracer tests conducted in 2003 and 2004 near Northwest Wellfield to obtain critical aquifer parameters (see Harvey et. al., 2008; Renken et. al., 2005 and 2008; Shapiro et. al., 2008). These tests have demonstrated the significant complexity of flow patterns in the Biscayne aquifer.

Therefore, additional tracer tests conducted in a specific time are unlikely to improve the USGS predictions of travel time in the current report.

The TWG considered the nature of the modeling being used for computing travel times, complexity of the hydrogeology in the Biscayne Aquifer, boundary conditions, and the presence of large lakes in the vicinity. Groundwater modeling is the most effective tool for generating travel times, and the Monte-Carlo stochastic approach used by the USGS in the model produced many realizations of hydrogeologic parameters, (e.g., hydraulic conductivity and effective porosity), and is a reasonable and satisfactory approach for the purpose of the model.

Recommendations: With one exception, the members of the TWG agreed that additional tracer tests are not recommended. The TWG recommended remodeling using a constrained Monte Carlo approach for key model parameters such as hydraulic conductivity and effective porosity and comparing the results of the remodeling effort to the existing USGS unconstrained Monte Carlo approach in order to determine the best approach for defining the wellfield boundaries

Alternative Response (Dr. Fuentes)

Conducting field tracer tests in support of groundwater modeling, if justifiable, is an option. Field tracer tests are generally expected to support modeling development and applications, particularly in cases with insufficient or inadequate data, which does not seem to be the case of the USGS modeling herein referred to. The main purpose of field tracer tests is to increase the confidence in modeling results; nevertheless, tracer tests may also be called in into question, for instance, due to their commonly smaller scale than the prototype space to be modeled, especially for their limited level of representativeness when aquifer characteristics and processes present significant spatial variability.

Differing Recommendation: (Dr. Fuentes)

Miami-Dade County DRER should further evaluate both the available information from previous field tracer studies that were conducted within the domain of the well field protection area and then weigh the potential benefit of added knowledge from new tracer tests that could raise its confidence in any future modeling. If DRER concludes that new field tracer tests would meaningfully raise its confidence in the results of future modeling, the selection of tests, number of them and their specific objectives should be determined in terms of scale, methodology, selection of tracer(s), expected outcomes, and inherent uncertainty.

Comment 2: Account for the dispersive transport mechanism.

Response: The TWG recognizes the importance of incorporating the dispersive transport mechanism into the USGS model. However, it is not possible to incorporate such effects accurately without resorting to a model, which uses a detailed representation of subsurface heterogeneity. Also, identifying dispersivity parameter values poses a significant challenge because it is extremely difficult to measure the dispersivity in the field for large sites like NWWF and WWF. Given the limited availability of dispersivity data specific to these wellfield areas, incorporating this mechanism in the USGS model may further increase uncertainty in the model's predictions. The use of the Monte Carlo approach for simulating hydraulic conductivity fields and effective porosity indirectly accounts for the effects of dispersivity. The Monte Carlo approach is the long-established method for defining the uncertain parameter values in groundwater models. The U.S. Environmental Protection Agency (U.S. EPA) commonly uses this approach for evaluating uncertainty into delineating the wellhead protection areas (WHA).

Recommendations: The members of the TWG agree that the current modeling approach does not explicitly account for dispersion. However, all the members except one, were of the opinion that advective transport modeling with or without the Monte Carlo simulations is an acceptable practice for WPA and is adequate for this modeling effort.

Differing Response (Dr. Fuentes)

The MODFLOW-MODPATH code package that USGS used in its modeling is based on governing equations that do not mathematically account for hydrodynamic dispersion; as a result, USGS chose "advection" as the controlling physical process of flow. If dispersion was to be accounted for, the source codes of the above package would have to be modified, unless a different code (or code package) was identified to be an acceptable alternative to simultaneously simulate advection and dispersion. An example of an alternative code is MT3D-USGS, which can deterministically quantify advection and hydrodynamic dispersion. MT3D-USGS accommodates flow input from MODFOW and can simulate the flow and transport of non-reactive and reactive solutes; other codes are also available. The application of a suitable code (i.e., a computational tool) could be cost effective in assessing the role of dispersion while providing a basis to assess the effectiveness of travel time contours estimated by the "advection-controlled" USGS modeling. It is important to keep in mind that the successful use of a code is conditional to, at least, the availability of good data and an acceptable calibration. As in the case of any modeling effort, the uncertainty of any predictions should also be quantitatively estimated to best frame modeling results for decision-making.

Differing Recommendation: (Dr. Fuentes)

Miami-Dade County DRER should further evaluate the benefits gained from expanding modeling to account for the role of hydrodynamic dispersion in the determination of travel time contours.

Comment 3: Quantify the uncertainty of the residence time in the quarry lakes.

Response: The mean hydraulic residence time used by the USGS to simulate particle movement through lakes does not adequately capture the complexity and the random nature of water particle movement through the quarry lakes. Accounting for complex flow dynamics and mixing behavior is essential for accurately modeling particle travel time through the lakes.

Prior to resigning as a member of the TWG, Dr. Chin provided comments on the limitations of the USGS approach, and recommended an alternate approach to calculating the travel time through lakes. The comments are provided in Attachment B.

Unanimous Recommendation: The TWG recognizes that the USGS model does not adequately address particle movement through lakes, and therefore recommends the County investigate further refinements to the approach.

Comment 4: Use maximum withdrawal rates to delineate respective wellfield.

Response: Miami Dade County's policy is to develop wellfield protection areas based on installed capacity. This approach provides the County the flexibility to optimize wellfield operations efficiently. The County's use of installed capacity to define wellfield protection areas also protects the wellfields for long term planning. Miami-Dade Water and Sewer Department's (WASD) prepares and updates a 20-Year Water Supply Facilities Work Plan as required by Section 163.3177(6)(c)3 of the Florida Statutes, which utilizes wellfield and plant installed capacities to meet future water demands.

The wellfield protection areas (WPAs) are designed to protect the drinking water resources of Miami-Dade County based on the current and future water demands of its residents. The current USGS groundwater modeling approach for the re-establishment of the WPAs (i.e. West Wellfield (WWF) and Northwest Wellfield (NWWF)) utilizes the installed capacity of the existing infrastructure, as opposed to the current permitted groundwater withdrawal limitation of the wellfield authorized by the South Florida Water Management District Water Use Permit 13-00017-W (25 MGD vs. 15 MGD for the WWF and 225 MGD vs. 97 MGD for the NWWF). Utilizing the above approach accounts for the following:

1. The groundwater withdrawal rate is defined in the water use permit and is based on the future water supply needs of Miami-Dade County; additional flow allocations from the wellfields may be requested.

2. In the event that a wellfield in the County is partially or completely shut down (i.e. contamination issues, infrastructure problems, etc.), the withdrawal from other wellfields will be temporarily increased (after a special request is submitted and approved by the South Florida Water Management District) to make up the difference in the water supply demand as the issue is addressed.

3. The threat of saltwater intrusion and sea level rise to the County's water supply, particularly for the wellfields located in the eastern portions of the county, such as the Alexander Orr complex, requires the flexibility to increase the groundwater withdrawal rate in any of the wellfields in the event of a partial or complete shutdown. Saltwater intrusion within a wellfield protection area will result in a permanent shutdown of affected production wells. As a consequence, the deficit in the drinking water supply would require an increase in the current groundwater withdrawal of one or more of the other County's wellfields.

Therefore, the WPAs are defined based on the installed capacity of the existing infrastructure to ensure the current and future drinking water demands of Miami-Dade County's residents are met.

Unanimous Recommendation: The TWG recommends that the simulations for the development of well-field protection areas should use installed capacity of the production wells and infrastructure, as is used in the USGS model.

Comment 5: The report was not subjected to the necessary and appropriate levels of review. The USGS report is an open-file report, indicating that it did not go through the highest level of review associated with USGS reports. The County should use reports subject to the highest level of review in making significant decisions related to the region's water supply.

Response: The TWG concludes that the USGS report was subjected to the necessary and appropriate levels of review. USGS Open File reports receive the same level of technical review as any other USGS interpretive product, for example Scientific Investigation reports, Professional Papers, or Scientific Investigation Maps, and complies with all USGS Fundamental Science Practices (https://www2.usgs.gov/fsp/). These include at least two technical peer reviews (the USGS report under consideration herein had three technical peer reviews), as well as several levels of supervisory and technical expert reviews and approvals, and ultimate Bureau Approval by the Bureau Approving Official. USGS Specific Review processes are described and available for review at: https://www2.usgs.gov/usgs-manual/500/502-4.html.

The primary difference between an Open File report and any other USGS interpretive reports is the editorial standards. To publish a report as an Open File Report instead of a Scientific Investigation Report requires one of several specific justifications. In the case of the 2013 USGS report under consideration, the report was released as an Open File report to avoid delays based on report layout and map and illustration formatting.

Unanimous Recommendation: The TWG concludes that the report and model has been appropriately peer reviewed. The TWG recommends that any additional modeling efforts be subject to an appropriate level of peer review.

Comment 6: The MODFLOW model does not indicate the ultimate source of the water coming into the west wellfield. Because it creates an artificial western boundary in its model, the USGS model does not answer questions about the water that will be pulled into the wellfields, nor about the potential impacts to Everglades National Park.

Response: The MODFLOW model has a 2-D representation (one layer vertically) and it was not intended to determine potential underflow in the western boundary canals, and was not designed to distinguish canal-underflow seepage between the wellfields and Everglades National Park (ENP). ENP and the contributing water conservation areas to the west of the wellfields already have a high level of protection.

This modeling is one part of a wellfield protection program that is focused on protecting the public water supply from sources of contamination. The modeling component is intended to identify those properties that have the potential to contribute groundwater to the public water supply so that appropriate restrictions can be placed on the use and storage of hazardous chemicals at those properties. Given that Everglades National Park is upstream from the West Wellfield, it is likely that water from the Park eventually is captured by the wellfield. However, ENP is managed as a natural area with no development and no use or storage of materials that could cause contamination to the aquifer. Therefore, ENP is not a concern in regards to drinking water quality and wellfield protection.

In regards to water use, the impact of the wellfield to Everglades National Park has been a concern since planning for the wellfield began in the 1980s. The planning culminated in an agreement between relevant state agencies including Miami Dade WASD, FDEP, and SFWMD, and the National Park Service known as the "Four Party Agreement". This is a 50-year agreement that expires in 2044 and limits the pumping rate to no more than 40 MGD at the West Wellfield. MDWASD has funded a monitoring program, operated by the USGS, in accordance with the Four Party Agreement since the 1992 that includes flow monitoring on the L31N canal as well as water level monitoring in and around the wellfield. The West Wellfield has an installed capacity of 25 MGD and has been operational since 1997. To date, adverse impacts have not been measured in Everglades National Park. If adverse impacts are measured in the L31N or ENP, the Four Party Agreement includes a process to address the issue.

Unanimous Recommendation: The TWG recognizes that ENP is a potential source of water, but not a potential source of contamination for public water supply in the West Wellfield. Impacts to the ENP are beyond the scope of the wellfield protection program, however, there is a separate process identified in the Four Party Agreement, as described above, which addresses water quantity issues related to the ENP. The TWG believes the boundaries are appropriately represented and accounted for in the USGS model.

Comment 7: MODFLOW is too simplified to assess flows in this area. Renken et al. (2008) states that given the complexity of water flow through karstic aquifers, water resources management "cannot be undertaken using simplified conceptual models of groundwater flow regimes based on estimates of bulk hydraulic properties.

Response: The TWG acknowledges that the aquifer hydrogeology is unique and complex, and MODFLOW has been questioned as to the adequacy of simulating groundwater flows using the modeling principles in MODFLOW. However, the MODFLOW is suitable for the analysis, and has been used successfully in South Florida for decades by all federal, state and local agencies, as well as stakeholders, and it is an accepted tool for planning purposes. MODFLOW is a state-of-the-art model, which is well-founded on sound governing equations and widely accepted by the scientific and regulatory communities, as long as it is used within its limitations (as is the case with any other model). Other operational tools which are uniquely different from MODFLOW are not available for this region.

Unanimous Recommendation: MODFLOW is suitable for the groundwater flow analysis for this wellfield protection effort.

Comment 8: Reductions in protections are tied to current pumping levels, without adequate safeguards being in place to assure that pumping from the West Wellfield does not increase.

Response: For the West Wellfield, delineation for wellfield protection is based on installed capacity of 25 mgd. Water use is regulated through the South Florida Water Management District (SFWMD) Water Use Permit (WUP) 13-00017-W, not through the WPA ordinance. Any future increases to WWF pumpage would need to be permitted through the SFWMD. As a part of any such request for increase, Miami-Dade Water and Sewer Department (WASD) would be required to demonstrate no impacts per the SFWMD Applicants Handbook for Water Use Permit Applications Section 3.3. In addition, the County would also be required to obtain agreement in accordance with the Memorandum of Understanding dated October 26, 1994, (Attachment C) between the U.S. Department of Interior, the Governor of the State of Florida, the SFWMD, and Metropolitan Dade County (now Miami-Dade County).

Unanimous Recommendation: The TWG concludes that this comment is appropriately addressed in the modeling effort. In the event more pumpage is permitted at the WWF above 25 MGD, the WPA would need to be reviewed and updated if necessary at that point. Please also see the response to Comment 4.

Comment 9: The County has insufficiently analyzed the ways in which climate change may affect wellfield use throughout the County.

Response: This is outside the scope of work of this Technical Working Group, however, Miami-Dade Water and Sewer Department's (WASD) prepares a 20-Year Water Supply Facilities Work Plan as required by Section 163.3177(6)(c)3 of the Florida Statutes. Under the statute, local governments are required to update their Water Supply Facilities Work Plan (Work Plan) through an amendment to their Comprehensive Development Master Plan (CDMP) at a minimum of every five (5) years, and within 18 months of the South Florida Water Management District (SFWMD) Governing Board's adoption of the applicable Regional Water Supply Plan. The Work Plan identifies alternative water supply projects, traditional water supply projects and conservation and reuse measures necessary to meet projected water demand. WASD completed the 20-Year Water Supply Facilities Work Plan (2014 –2033) in November 2014, and the Work Plan was adopted by the Miami-Dade County Board of County Commissioners on February 4, 2015. Through the CDMP process, the County's Planning Section submitted the Work Plan to the Florida Department of Economic Opportunity (DEO). Link to the complete plan is: Water Supply Facilities Work Plan - Miami-Dade County http://www.miamidade.gov/water/water-supply-facilities-work-plan.asp.

WASD's evaluation and planning for sea level rise and climate change is detailed over the planning horizon in the Work Plan Section 6 (Attachment D). The primary concern to WASD water supply is salt water intrusion into the freshwater Biscayne aquifer, the primary source of drinking water in Miami-Dade County. Results of evaluation and data analysis completed to date indicate that within the next thirty years, WASD will be able to operate its wellfields and water treatment facilities as designed, as groundwater modeling indicates even with a high level of projected sea level rise, the wellfields will not be impacted by salt water intrusion. Further modeling is currently underway to extend the planning scenarios to Year 2075, and will include climate change such as increases and decreases in annual precipitation, and extreme weather events.

Unanimous Recommendation: This is outside the scope of work of this Technical Working Group, however, the TWG concludes that the County is currently analyzing impacts to water resources as a result of climate change and sea level rise adequately. Please see response to Comment 4 also.

Comment 10: *Travel times should be used to calculate distance between potential sources of pollution and any potable water supply – 100 feet is not sufficiently protective of water supply.*

Response: This is outside the scope of work of this Technical Working Group.

Staff Response: The minimum separation provided in Section 24-43(4)(a) is specific to the minimum distance between an on-site sewage treatment and disposal system and a private (non-utility) source of potable water (e.g. a private well) and is consistent with and a bit more conservative than the minimum separation provided for in 62-532 Florida Administrative Code (FAC) and 64E-6 FAC which requires a 75 foot separation. Miami-Dade County's policy is that requiring a private entity (in the case of a WPA the most common situation would be a private residence) to perform modeling to determine travel time for locations served by an onsite potable water source and on on-site sewerage treatment would represent on unreasonable burden.

Section 24-43(5)(a) is an additional condition to Section 24-43(5)(b) through 24-43(5)(f) and merely adds another level of protection for already allowable land uses. The introduction of *"and not less than 10 days travel time"* language as suggested by the stakeholder would be inconsistent and confusing at a minimum.

Comment 11: ***Hazardous materials should be more limited in wellfield protection zones, and enforcement should be prioritized.***

Response: This is outside the scope of work of this Technical Working Group.

Staff Response:

The hazardous material prohibitions and the land use provisions in the Wellfield Protection Section of the Code are designed to progressively limit the use, storage , generation and handling of hazardous material so that the restrictions are more stringent at shorter travel time distances from the production wells. As such, with very specific exceptions (e.g. de minimis quantities of hazardous material, personal care products, etc.) hazardous material is prohibited with the 210 day travel time distance from the production wells. For the Miami-Dade County Wellfields this provides a distance of over 500 feet in the case of the smaller wellfield protection areas in the southern reaches of Miami-Dade County to over 6,000 feet for the Northwest Wellfield.

Compliance with the land use restriction and hazardous waste prohibitions is accomplished via county permits and regular permit inspections.

The proposed modification of the wellfield protection ordinance which would relax the restrictions against small quantity generators of hazardous waste outside the basic wellfield protection area of the West Wellfield WPA (for areas within the UDB) recognizes that the eastern portion of the West Wellfield (the area outside the basic) is urbanized; therefore, allowing small quantity generators of hazardous waste in these areas provides consistency with the other urban wellfields. Additionally, consistent with the land use restrictions in the un-urbanized Northwest Wellfield, hazardous waste would continue to be prohibited in the areas of the West Wellfield areas outside the UDB.

Comment 12: ***Proposed land uses designated "compatible" with wellfield protection should be reconsidered***

Response: This is outside the scope of work of this Technical Working Group.

Staff Response: Notwithstanding the land use categories provided in Section 24-43(10) the Director's approval is required for any land use within the Northwest Wellfield or West Wellfield. Therefore, if the assumption of no hazardous material use, generation, handling, etc., is not valid in an individual situation the Director has the authority to prohibit the land use under the other sections of the Code.

Comment 13: ***The potential consequences from predictable land use changes in or near the West Wellfield must be considered.***

Response: The USGS used a 1999 aerial photograph to determine the outlines of the lakes during the timeframe of the transient model, as lake images were collected near the middle of the 1996 – 2004 simulation period. The steady-state scenario utilized a newer shapefile developed from 2004 aerial photography. The USGS also ran a scenario utilizing the proposed lake expansion as outlined in the Lake Belt Phase II Plan.

Unanimous Recommendation: The TWG concludes that the modeling based on the above is appropriate and should utilize the proposed lake expansion as outlined in the Lake Belt Phase II Plan in future modeling efforts.

Comment 14a: ***USGS delineation of travel-time contours in NWWF and WWF***

Response

The previously provided responses specifically, Responses 2, 3, 4 and 7, partially addresses this comment. In addition, the use of the 0.25-foot drawdown, in the case of the Northwest Wellfield, and the 0.1-foot drawdown in the case of the West Wellfield for wellfield protection area delineation is consistent with and recognized as appropriate threshold values to establish drawdowns pursuant to the EPA 1987 “Guidelines for Delineating a Wellfield Protection Area”

Comment 14b: ***USGS Model use of “average” effective porosity***

Response: Please refer to Comments 1 and 2. In addition the following was provided by the USGS in response to the stakeholder’s comment.

Limited observations of total porosity (tp) in the Biscayne aquifer indicate a wide range of values and significant spatial variability. Effective porosity (ep) is the fraction of tp through which most water and transported constituents flow through the aquifer; ep is thus smaller than tp. As a result of the lack of detailed data, there is considerable uncertainty in values and spatial distribution of ep at the field scale. In such situations, it is standard practice to use an average value for the parameter. This is consistent with the principle of parsimony (simplest approach) which requires the model to use the approach that introduces the least uncertainty into the model necessary while maintaining the modeling objectives.

References

Harvey, R.W., Metge, D.W., Shapiro, A.M., Renken, R.A., Osborn, C.L., Ryan, J.N., Cunningham, K.J., and Landkamer, L.L., 2008, Pathogen and chemical transport in the karst limestone of the Biscayne aquifer: 3. Use of microspheres to estimate the transport potential of Cryptosporidium parvum oocysts: Water Resources Research, v. 44, W08431, doi:10.1029/2007WR006060.;

Renken, R.A., Cunningham, K.J., Shapiro, A.M., Harvey, R.W., Zygnerski, M.R., Metge, D.W., and Wacker, M.A., 2008, Pathogen and chemical transport in the karst limestone of the Biscayne aquifer: 1. Revised conceptualization of groundwater flow: Water Resources Research, v. 44, W08429, doi: 10.1029/2007WR006058;

Renken, R.A., Shapiro, A.M., Cunningham, K.J., Harvey, R.W., Metge, D.W., Zygnerski, M.R., Osborn, C.L., Wacker, M.A., and Ryan, J.N., 2005, Assessing the vulnerability of a municipal well field to contamination in a karst aquifer: Environmental and Engineering Geoscience, v. 11, no. 4, p. 319-331.;

Shapiro, A.M., Renken, R.A., Harvey, R.W., Zygnerski, M.R., and Metge, D.W., 2008, Pathogen and chemical transport in thekarst limestone of the Biscayne aquifer: 2. Chemical retention from diffusion and slow advection: Water Resources Research, v. 44, W08430, doi:10.1029/2007WR006059.) ,

Shapiro, A.M., Renken, R.A., Osborn, C.L., Ryan, J.N., Cunningham, K.J., and Landkamer, L.L., 2008, Pathogen and chemical transport in the karst limestone of the Biscayne aquifer:

ATTACHMENT A

Public Comments

Clean Water Action • Everglades Law Center
Florida Wildlife Federation • National Parks Conservation Association
Sierra Club Miami Group • Tropical Audubon Society

June 30, 2014

Lee Hefty
Miami-Dade County Division of Environmental Resources Management
Sent via email: HeftyL@miamidade.gov

Dear Mr. Hefty,

We write on behalf of the undersigned organizations to address the county's proposed Wellfield Protection Amendment Ordinance. We support the proposed ordinance's new language to address hazardous materials in the wellfield protection area and in increasing some of the travel times for areas in the Northwest Wellfield. However, we also have serious concerns with the proposed ordinance amending sections 24-5 and 24-43 of the Miami-Dade County Code, in particular plans to reduce the area protected for the County's West Wellfield. The proposed changes to the West Wellfield protection rules would strip away significant protections for critical water supply for all County residents, exposing the public to increased risk of health threats and additional future remediation costs.

Three significant issues undermine the proposal to reduce the scope of wellfield protections:

- While we appreciate the work done to begin to incorporate our understanding about travel times in the aquifer in this region, the model still makes assumptions that likely understate travel times. In particular, in the West Wellfield, where no tracer studies have been conducted, tracer tests should be conducted before any protections are reduced. Using models to predict travel times is complicated in karst aquifers and depends on accurate data and model calibration.
- Reductions in protections are mainly tied to current pumping levels, without adequate safeguards being in place to assure that pumping from the West Wellfield does not increase.
- There is insufficient analysis of the ways in which climate change may affect wellfield use throughout the County.

In addition to concerns about shrinking the protection zones, we also have concerns about proposed changes (hazardous materials limitations and appropriate land uses) to specific protections that apply within the wellfield protection zones.

Once wellfield protections are removed, land uses will likely change, precluding any changes back if the models and the projections they produce are incorrect. The current

CDMP highlights the importance of our wellfields, and the need for land uses to be compatible with their protection:

"Land uses and activities near and upgradient from wellfields directly impact the quality of water ultimately withdrawn from the wells….[T]he County restricts land use within portions of cones of influence of all public water supply wellfields to minimize the threat of water pollution. Moreover, newly constructed and future regional wellfields warrant greater and more extensive protection for two reasons. First, the opportunity still exists to maintain pristine water quality around the new and future wellfields because the land within the full extent of their cones of influence is largely undeveloped. Secondly, if these become contaminated there are no alternative sites for the construction of comparable high-capacity wellfields."[1]

Furthermore, the CDMP finds,

"It is reasonably safe to assume…that the areas least suitable for urban development today will remain least suitable in the future. These areas include the remaining high-quality coastal and Everglades wetland areas in the County, the coastal high hazard areas, and the Northwest Wellfield protection area."[2]

If the county wants to ensure that it is not precluding future protections for the wellfields, additional studies are needed before these changes are finalized.

The study still makes assumptions that likely understate travel times. In particular, in the West Wellfield, where no tracer studies have been conducted, tracer tests should be conducted before any protections are reduced. Using models to predict travel times is complicated in karst aquifers and depends on accurate data and model calibration.

Actual travel time data exists in the vicinity of the Northwest Wellfield from tracer tests conducted by the USGS in 1998, 1999, and 2003.[3] Those studies showed that water and contaminants can travel much more quickly than scientists and managers predict based on models. Red dye was injected into a test well in 2003 that was expected to trickle into the county's production wells over two or three days. Instead, it made it into the wells in 6 hours, turning tap water pink and red.[4] At the time, the USGS recognized the import of that study: "The highly porous nature of the Biscayne aquifer presents significant water-management implications, especially as it relates to the inadvertent release of

[1] Miami-Dade County Comprehensive Development Master Plan at I-77.
[2] *Id.* at I-79.
[3] SS Papadopulos, "Evaluation of Tracer Tests Conducted at the Northwest Wellfield, Miami-Dade County, Florida, February 5, 2004, attached as Exhibit 1.
[4] See Miami Herald, Curtis Morgan, "Studies: Mining expansion poses water big risk," August 31, 2008, attached as Exhibit 2, and Miami New Times, Steven Dudley, "Beneath the Pink Underwear" June 5, 2003, attached as Exhibit 3.

contaminants within or immediately outside the well field protection area."[5]

A scientist with decades of experience assessing aquifer transport properties, Dr. Stavros Papadopulos, used the results of those tests to revisit the Northwest Wellfield protection area and concluded that travel time protections should be significantly larger than either the current or the proposed zones.[6] Dr. Papadopulos concluded that if travel-time based setbacks were going to be used to protect public water supplies in this area (with documented well connected, karstic flow zones), then additional tests should be conducted in the area to assess the transport properties of the aquifer. In the absence of such tests, wellfield setbacks should be based on the tests and data collected to-date – the extensive protection zones he set out in his report.[7]

Since the main objective of the model was to determine travel times, the model should have been calibrated based on travel times determined through tracer studies rather than observed groundwater levels. The USGS MODFLOW model utilized by the County incorporated the 2003 tracer tests of the Northwest Wellfield into the effective porosity parameter; however, with this method of calibration, potential errors in water levels would lead to greater errors in travel times. Moreover the inherent heterogeneity and anisotropy of the aquifer is not taken into account. No tracer studies have been conducted for the West Wellfield and should be obtained in order to make informed decisions of travel time in that area

In addition:

- **The report was not subjected to the necessary and appropriate levels of review.** The USGS report is an open-file report, indicating that it did not go through the highest level of review associated with USGS reports. The County should use reports subject to the highest level of review in making significant decisions related to the region's water supply.
- **The MODFOW model does not indicate the ultimate source of the water coming into the West Wellfield.** Because it creates an artificial western boundary in its model, the USGS model does not answer questions about the water that will be pulled into the wellfields, nor about the potential impacts to Everglades National Park.[8]
- **MODFLOW is too simplified to assess flows in this area.** Renken et al. (2008) states that given the complexity of water flow through karstic aquifers, water resources management "cannot be undertaken using simplified conceptual models of groundwater flow regimes based on estimates of bulk hydraulic properties."[9]

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[5] USGS, USDOI News Release, "Water Supply at Greater Risk than Expected", August 27, 2008, attached as Exhibit 4.
[6] Exhibit 1: Figs. 3a, 3b, 4a, 4b.
[7] *Id.*
[8] To better understand the flows from the western side of the West Wellfield protection area, we recommend the County use a tracer study. By conducting a tracer test near the L-31 N canal, similar to the Northwest Wellfield red dye study from 2003, the County could accurately track what water will travel to the wellfield, and how quickly it will get there.
[9] Renken, R. A., Cunningham, K. J., Shapiro, A. M., Harvey, R. W., Zygnerski, M. R., Metge, D. W., & Wacker, M. A. (2008). Pathogen and chemical transport in the karst limestone of the Biscayne

If Miami-Dade County seeks to use travel time zones to protect its public water supply, it must base those zones on real data, not modeling assumptions that oversimplify the available data. The USGS report does not appropriately use the data it has, does not reflect efforts to obtain additional needed data, and should not be the basis of wellfield protection zone revisions that increase risks (both health risks and the risks of increased remediation costs) to the public.

Reductions in protections are tied to current pumping levels, without adequate safeguards being in place to assure that pumping from the West Wellfield does not increase.

Although the County contends that a reduction in the protection zone is appropriate based on how much pumping is expected out of the West Wellfield – which it puts at 15MGD – there is little support that pumping will, in fact, remain limited. Permits can change when modified or renewed, and current rules that purport to "cap" water use at existing levels allow for exceptions, including where a user proposes "offsets" to ensure sufficient Everglades protection. To similar effect, an intergovernmental agreement designed to protect Everglades National can be modified if the parties agree.[10] None of these rules or agreements provides long-term assurance that additional pumping – up to the wellfield's true capacity of 140MGD – will not occur in accordance with existing permits and regulations.

To claim that reduced protections are appropriate based on the amount of pumping possible at the West Wellfield, the County must provide additional assurances that pumping will continue to be limited as a matter of law, not simply because of an agency's discretionary choices. The County is proposing to eliminate a significant amount of protected area east of the L-31N of the West Wellfield protection area. Once the protections are eliminated, land uses are likely to change in ways that are incompatible with water supply protection and increase the risk of future conflicts over how to provide and protect the public's water supply.

The County has insufficiently analyzed the ways in which climate change may affect wellfield use throughout the County.

Climate change may affect Miami-Dade County's water supply in direct and indirect ways; the decision to reduce the West Wellfield protection was done without real attention to these overarching threats to water supply.

Eastern wellfields in the County may become less available as a result of salt water intrusion due to climate change. Miami-Dade County's Water and Sewer Department

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aquifer: 1. Revised conceptualization of groundwater flow. *Water Resources Research, 44*(8). doi:10.1029/2007WR006058. Attached as Exhibit 5.

[10] *Id.* at p. 9.

(WASD) has only modeled the impacts of salt water intrusion through the current permit timeframe of 2040, and yet county departments have generally recognized that two feet of sea level rise is likely to occur in Miami-Dade County by 2060,[11] and WASD is urging further study on the degree of salt water intrusion corresponding to 1 foot of sea level rise.[12] Additional salt water intrusion could complicate plans for meeting Miami-Dade County's water supply demands, and reduction in wellfield protection zones should only be made with additional information about those impacts.

To similar effect, the high-energy demands (and greenhouse gas emissions) of reverse osmosis – a technology the County considers an option in the event of increased salt water intrusion – may raise red flags as Miami-Dade County attempts to grapple with the effects of climate change. Growing consensus about the need to reduce greenhouse gas emissions may mean the environmental costs associated with increased use of an energy-intensive water treatment option like reverse osmosis makes it more costly and difficult to permit.

Given the likely permanent effects of reduced wellfield protections (additional, deep rock mining pits), decisions about whether and how to reduce protections around the West Wellfield to reflect current use levels should reflect a long-term understanding of water supply needs and available resources, and the way in which needs and resources may change in light of climate change.

Travel times should be used to calculate distance between potential sources of pollution and any potable water supply – 100 feet is not sufficiently protective of water supply.

In two places in the proposed ordinance the language sets a minimum distance of 100 feet between potential sources of contamination, septic tanks and septic drain fields and potable water supply wells.[13] This measurement is grossly inadequate to protect potable water supply wells in Miami-Dade County. Miami-Dade County's Department of Environment and Resource Management staff indicated that this measurement was based on Palm Beach County regulations. Palm Beach County, however, is not dependent on the Biscayne Aquifer and the geology and hydraulic conductivity in that area is distinct from that of Miami-Dade County. Therefore, the application of the 100 foot rule from Palm Beach County is not appropriate for Miami-Dade County. This 100 foot rule would replace a requirement that septic tanks and septic drain fields be at least 10 days travel time from any potable supply well. This proposed change is significantly less protective of nonutility supply wells. The 100 foot rule as it applies to utility and nonutility potable supply wells does not effectively protect the water supply from contamination.

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[11] The Miami-Dade County Sea Level Rise Task Force held significant discussion on predicted level of rise throughout a series of meetings including representatives from county departments.
[12] Discussion item for Sea Level Rise Task Force from Virginia Walsh, P.G., Ph.D., May 9, 2014, attached as Exhibit 6.
[13] See proposed ordinance lines 242 – 249 and lines 656 to 665.

In fact, hydraulic conductivity in the uppermost formation in western Miami-Dade County averages 40,000 feet per day,[14] with values not uncommonly orders of magnitude greater. With the upper formation of the Biscayne aquifer in western Miami-Dade County being such a transmissive aquifer, there might be areas where travel time over 100 feet would take less than 10 days, perhaps even hours. It therefore does not protect the water supply to set requirements based on feet between the potential source of contamination and a potable supply well. Even if a distance were used as opposed to a travel time, 100 feet is an inadequate distance to require between any potential source of contamination and a potable water supply in the Biscayne Aquifer.

We suggest that section 24-43(4) change the 100 feet requirement to 10 days travel time, so that it reads:

> The Director or the Director's designee shall issue written approval only if the Director or the Director's designee finds that all onsite sewage treatment and disposal systems, storm water disposal methods and liquid waste storage, disposal or treatment methods will be installed upon the property as far away as is reasonably possible, but not less than >>10 days travel time<< from all potable supply wells, and: ...
>
> Section 24-43(4), lines 242-249.

Section 24-43(5)(a) should be changed to read:

> (a) All potential sources of pollution will be installed upon the property as far away as is reasonably possible >>and not less than 10 days travel time<< from all potable water supply wells;

Hazardous materials should be more limited in wellfield protection zones, and enforcement should be prioritized.

The regulations of hazardous materials of section (5) include many measures that are appropriate to safely regulate activities within wellfield protection areas. However, we would like additional information regarding how this will be enforced. Enforcement provisions should be added to this section, and enforcement should be given priority within wellfield protection areas.

The proposed ordinance would allow "small quantity generators of hazardous waste… within that portion of the West Wellfield protection area which is outside the basic wellfield protection area but within the Urban Development Boundary…"[15] Why is this special exception being made for the West Wellfield? Generation of hazardous waste within a wellfield protection area, even in small quantities, poses a threat to the water supply. We recommend removing this exception.

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[14] See http://sofia.usgs.gov/publications/wri/90-4108/wdade.html

[15] Draft ordinance, lines 710-729.

The water pollution prevention and abatement measures required for rock mining should be adjusted.[16] Although any entity storing hazardous materials that is not a rock mining operation can only store an aggregate of 55 gallons of hazardous materials,[17] hazardous materials related to rock mining could be stored in infinite amounts, as long as secondary containment is used.[18] This should be changed to provide that no more than an aggregate of 55 gallons of hazardous materials are allowed to be stored within a wellfield protection area and that any and all hazardous materials must be stored in secondary containment.

Section (5)(b) provides for circumstances when hazardous materials may be allowed within a building.[19] Building should be defined for this section so that protective containment of such materials is assured.

Proposed land uses designated "compatible" with wellfield protection should be reconsidered.

The proposed ordinance includes several categories of land use that the Director or Director's designee shall consider as compatible with wellfield protection, including agricultural use, dry manufacturing and garment manufacturing (no dyes). We are concerned that these uses may result in contamination of the wellfield.

Dry manufacturing may involve the use of materials that if spilled onto the ground could be transported by rainwater and contaminate the wellfield. To that extent we question whether it is appropriate to allow any type of manufacturing within the wellfield protection area. To the extent dry manufacturing is allowed, it should be limited to manufacturing activities that do not involve the use of potential wellfield contaminants or hazardous materials.

Garment manufacturing that does not include the use of dyes may nonetheless include the use of potential wellfield contaminants or hazardous materials, in which case garment manufacturing should be omitted.

Agricultural use includes application of pesticides, which could contaminate wellfield sites. Florida Statute section 163.3162(3)(e) provides that counties may regulate farming activity within a wellfield area to the extent the "implemented best management practice, regulation, or interim measure does not specifically address wellfield protection."[20] Other counties in Florida like Alachua County require best management practices in their wellfield protection ordinance.[21]

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16 *Id.* at lines 753-775
17 *Id.* at lines 663-676.
18 *Id.* at lines 760-761.
19 *Id.* at lines 689-708
20 Fl. Stat. 163.3162(3)(e)
21 http://www.alachuacounty.us/Depts/EPD/WaterResources/CodesAndCompliance/Documents/Murphree%20Code.pdf

We recommend that the ordinance add language requiring that agricultural uses within the wellfield protection area follow best management practices as defined by the latest version of the Florida Department of Agriculture and Consumer Services and Florida Department of Environmental Protection Best Management Practices. To the extent that such Best Management Practices do not specifically address wellfield protection, Miami-Dade County should regulate farming activity to the extent necessary for the protection of the potable water supply.

The potential consequences from predictable land use changes in or near the West Wellfield must be considered.

It is widely acknowledged that if the West Wellfield Protection Area decreases, additional land uses, including rock mining and even a wastewater treatment plant, among other uses, may likely occur. These land uses pose significant contamination risks that are highly problematic in such close proximity to our wellfields.

This is one of the water supply for Miami-Dade county residents. The consequences of getting this outcome wrong are enormous. Yet, the current reassessment of the wellfield protection areas fails to consider these additional contamination risks posed by new land uses**.** For example, the USGS MODFLOW model shows that with expansion of mining, the wellfields preferentially pull water from mining pits, from which the USGS report contends "it is possible that contamination could reach the well fields quickly, within 10 days in some cases." Renken et al. (2005) conclude from the 2003 tracer tests that "demonstrated potential contamination risks in the Northwest well field that are far greater than previously considered, indicating the need for reassessment of existing rock-mine setback distances"[22]. The protection areas should take into account the implications of additional rock mining, and other land uses that pose contamination risks, which poses potential high risk to human health and safety.

Thank you for the opportunity to provide these comments, and your consideration.

Sincerely,

Kathy Aterno
Florida Director
Clean Water Action / Clean Water Fund
katerno@cleanwater.org

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[22] Renken, R. A., K. J. Cunningham, M. R. Zygnerski, M. A. Wacker, A. M. Shapiro, R. W. Harvey, D. W. Metge, C. L. Osborn, and J. N. Ryan (2005), Assessing the Vulnerability of a Municipal Well Field to Contamination in a Karst Aquifer, Environ. Eng. Geosci., 11(4), 319–331, doi:10.2113/11.4.319. See Exhibit 4.

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Evaluation of Tracer Tests Conducted at the Northwest Wellfield Miami-Dade County, Florida

S.S. PAPADOPULOS & ASSOCIATES, INC.
Bethesda, Maryland

February 5, 2004

7944 Wisconsin Avenue, Bethesda, Maryland 20814-3620 • (301) 718-8900

Executive Summary

The Northwest Wellfield in Miami-Dade County, Florida consists of 15 wells supplying the current demand of 150 million gallons per day and permitted to pump up to 225 millions gallons per day, from the Biscayne Aquifer. The wellfield is located in an area where rock-mining operations result in lakes that may be source of pathogens or of other contaminants transported by surface water. To protect the wellfield from the potential migration of these pathogens and/or contaminants, mining regulations based on travel-time distances to the wellfield have been established. Mining is prohibited within a 30-day travel-time distance and is subject to a depth restriction of 40 feet between the 30-day and 210-day travel-time distance; this depth restriction is waived and mining below a depth of 40 feet is allowed if mining occurs beyond the 60-day travel-time distance.

To provide better estimates of the rate at which pathogens and contaminants may migrate in the aquifer several tracer tests were conducted near the wellfield in 1998, 1999, and 2003. The 2003 test, conducted by the U. S. Geological Survey in cooperation with the Miami-Dade Department of Environmental Resources Management and other local agencies, reflected a very short travel-time in comparison to several of the earlier tests.

The Natural Resources Defense Council and the Sierra Club requested S. S. Papadopulos & Associates, Inc. to evaluate the results of these tracer tests and assess their implication on rock-mining setbacks. For a wellfield pumping at a given rate from an aquifer of a given transmissivity and regional gradient, a critical parameter in determining the rate of migration of a tracer, or contaminant, towards the wellfield is the product of the effective porosity and thickness of the aquifer. The evaluation was, therefore, aimed at determining the value of this product reflected by each of the tracer tests conducted near the wellfield.

The results of the evaluation indicate that the values of the porosity-thickness product reflected by the tests ranges from 1.33 feet for the 2003 test to 10.3 feet for the 1999 test. (A low value of this product implies a rapid rate of migration, and vice versa.) Of the two 1998 tests that were also evaluated, the first had a low value of 1.37 feet, similar to that for the 2003 test, and the second one a value of 7.32 feet. The results indicate that the porosity-thickness product for the aquifer may be different at different locations and over different travel distances.

The porosity-thickness products determined from the evaluations were used to calculate the maximum and minimum travel-time distances corresponding to current pumping rates and to the full pumping capacity of the wellfield. At full capacity, the 30-day travel-time distance, within which rock mining should be prohibited under the current regulations, ranges from 0.8 mile for the high porosity-thickness product determined from the 1999 test to about 3.5 miles for the low porosity-thickness product determined from the 2003 test; the corresponding range of the 60-day travel-time distance, beyond which there are no restrictions to the mining depth, is 1.4 to more than 5 miles. The setback requirement for rock-mining permits issued in 2002 is approximately 0.5 mile, less than even the 0.8 mile distance to the 30-day travel-time boundary and significantly less than the 1.4 mile distance to the 60-day travel time boundary calculated using the highest porosity-thickness product determined from the evaluation of the tracer tests.

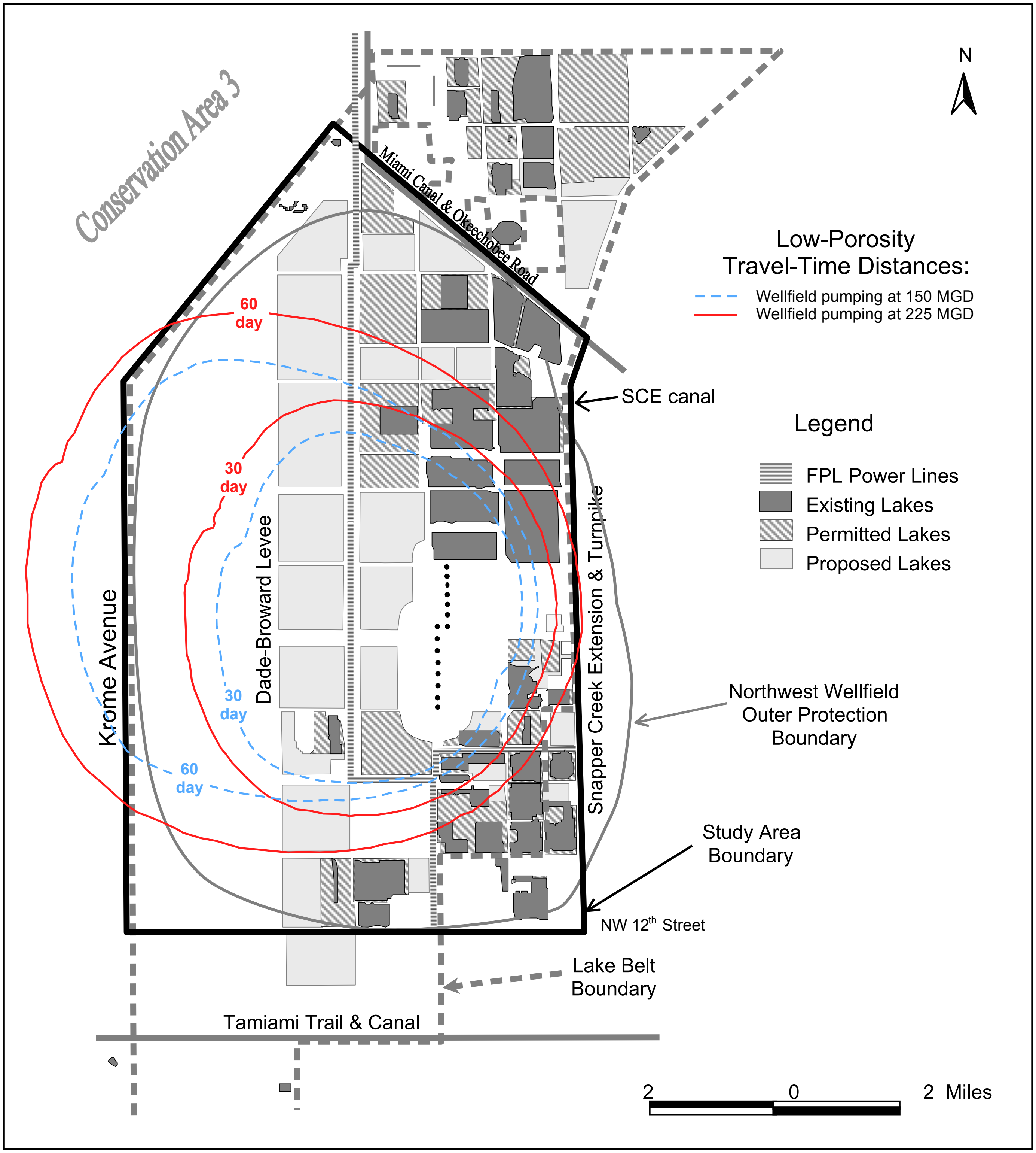
The similar porosity thickness products reflected by the 2003 and the first 1998 test are indicative of a good hydraulic connection through karstic flow zones in the area between production wells PW-8 and PW-9; studies by the U.S. Geological Survey indicate that these karstic zones extend at least one mile west of the wellfield. Thus, the results of the 2003 and the first 1998 tests may be representative of conditions in areas west of the wellfield. If that is the case, then some of the permitted and most of the proposed rock-mining areas are within distances with less than 30-day and 60-day travel times to the wellfield (see Figure ES-1)* even under the current pumping rates; mining operations in these areas should be prohibited or restricted under the terms of the current regulations.

The tests conducted to date were located either east (downgradient) of the wellfield or within the wellfield. The critical areas for mining operations are the areas to the west, north, and south of the wellfield. If travel-time based mining setbacks are to be applied to these areas, then data on the transport properties of the aquifer should be collected from tests conducted in these areas. In absence of such tests, regulation of mining operations in the vicinity of the wellfield should be based on the results of tests conducted to date, and mining should be prohibited or restricted in areas where these results indicate potential travel times of less than 30 or 60 days to the wellfield.

* The permitted and proposed lakes (rock-mining areas) shown in this figure represent conditions in 2000; certain lakes designated as proposed have been permitted since 2000 (personal communication, staff of NRDC).

Figure ES-1

Comparison of Travel-Time Distances to Rock-Mining Areas



Note: Base Adapted from Miami-Dade DERM (2000b), Figure 2.

Evaluation of Tracer Tests Conducted at the Northwest Wellfield Miami-Dade County, Florida

Prepared For:

Natural Resources Defense Council and Sierra Club

Prepared By:

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Table of Contents

List of Figures

List of Tables

List of Appendices

REPORT

Section 1
Introduction

The Northwest Wellfield (NWWF) in Miami-Dade County, Florida consists of 15 high-capacity wells (see Figure 1) completed within the Biscayne Aquifer, a karstic limestone, which is the major source of water supply in southeast Florida. The wellfield supplies the current demand of 150 million gallons per day (MGD) [Miami-Dade County Department of Environmental Resources Management (Miami-Dade DERM), 2000b], and is permitted to produce at its design capacity of 225 MGD, or 15 MGD per well.

The Biscayne aquifer is also a source of limestone and the NWWF is within an area of open-pit rock mining activities. After the mining of the limestone, the open pits fill with water forming lakes that are hydraulically connected to the Biscayne Aquifer. Several such lakes exist to the north and south of the NWWF. To protect the wellfield from potential contamination associated with mining activities, setback regulations based on the travel time of groundwater to the wellfield have been established. These regulations prohibit mining within the area of the 30-day travel-time boundary (see Figure 1); within the area that lies between the 30-day and the 210-day travel-time boundaries, mining is restricted to a depth of 40 feet. This depth restriction is waived if mining occurs outside an area corresponding to a 60-day travel time, however, the 60-day travel-time boundary has not been delineated by the regulatory agencies. Approximately 5,000 acres of proposed and permitted mining operations lie in the area east of the Dade-Broward Levee (see Figure 1) and beyond the 60-day travel-time boundary for the wellfield as extrapolated by mining company consultants.

In recent years, the Miami-Dade DERM and other local, state, and federal agencies have been concerned that the lakes that form as a result of mining activities could become a source of pathogens, particularly Cryptosporidium and Giardia, and of other contaminants that may enter the lakes from fowl and wildlife wastes, or by surface water transport, and then migrate from the lakes to the wellfield. A series of dye tracer tests were conducted in 1998, 1999, and 2003 to determine the transport properties of the aquifer in the vicinity of the NWWF. Additional tests, using polystyrene microspheres of a diameter comparable to that of Cryptosporidium oocysts, are planned to assess colloidal transport of pathogens.

During the 1998 and 1999 dye tracer tests, the travel times between the dye injection wells and the nearest production or monitoring wells (see Figure 2), at distances of 450 to about 900 feet, ranged from a few days to more than hundred days. The 2003 test was conducted by the U. S. Geological Survey (USGS) in cooperation with Miami-Dade DERM and other local agencies and partially funded by the American Water Works Association Research Foundation (AwwaRF). The dye tracer was injected in a well 100 meters (330 feet) from production well PW-9; the dye arrived to the production well within a few hours after the injection.

The Natural Resources Defense Council (NRDC) and the Sierra Club engaged the services of S. S. Papadopulos & Associates, Inc. (SSP&A) to review and evaluate the results of the tracer tests conducted near the NWWF, and assess the implications of these results on existing rock-mining regulations. The results of the evaluations conducted by SSP&A are presented in this report. Section 2 of the report presents some theoretical concepts that need to be considered in evaluating tracer test data; the section is aimed to the non-hydrologist who may not be familiar with these concepts. Section 3 provides a brief description of the 1998, 1999, and 2003 tracer tests based on the information made available to SSP&A by NDRC and the Sierra Club. The results of the evaluation of the tests and the calculation of travel-time distances based on these results are presented in Section 4; a discussion of the results is also presented in this section. Section 5 discusses the implications of the tests results on rock-mining setbacks and recommends additional testing for delineating these setbacks in the areas currently permitted or proposed for mining operations. References cited in the report are listed in Section 6.

The evaluations presented in this report were conducted by, or under the direct supervision of, Stavros S. Papadopulos, Founder & Senior Principal of SSP&A. Dr. Papadopulos' resume is presented in Appendix A. Information on the tracer tests conducted at the NWWF was included in electronic files and documents on four compact disks (CDs) and other documents provided to SSP&A by NRDC and the Sierra Club. The contents of these four CDs are listed in Appendix B. Also included in this appendix is a list of additional documents provided to SSP&A in e-mails and/or by fax.

Section 2
Theoretical Considerations

The hydraulic head h (water level) at a point (x, y) in the vicinity of a wellfield located in an aquifer with uniform regional flow can be expressed with the following equation (see Tonkin and Larson, 2002):

$$h = A + I_x x + I_y y - (1/4\pi T) \sum_{j=1}^{N_w} Q_j \{B - \ln[(x - x_j)^2 + (y - y_j)^2]\} \quad (1)$$

where A and B are constants, I_x and I_y are the components of the regional hydraulic gradient that would prevail in the area of the wellfield under non-pumping conditions, T is the transmissivity of the aquifer, N_w is the number of wells in the wellfield , Q_j is the pumping rate of the j'th well, and x_j and y_j are the location coordinates of the j'th well.

The first three terms of the equation represent the hydraulic head that would have prevailed in the area of the wellfield under non-pumping conditions. The fourth term (the summation term) represents the drawdown[1] induced by the pumping from the wellfield, based on the Thiem (1906) equation or on the Cooper-Jacob (1946) approximation to the Theis (1935) equation.

The velocity, **v,** of groundwater in the vicinity of the wellfield is:

$$\mathbf{v} = \{ v_x^2 + v_y^2 \}^{1/2} \quad (2)$$

where v_x and v_y are the components of the velocity in the x and y direction. Based on Darcy's Law, these velocity components are given by:

$$v_x = - (K/n) (\partial h/\partial x) \quad (3)$$

$$v_y = - (K/n) (\partial h/\partial y) \quad (4)$$

where K and n are the hydraulic conductivity and porosity of the aquifer, respectively. Tests conducted to determine the hydraulic properties of aquifers usually yield the value of transmissivity, which is the product of hydraulic conductivity and aquifer thickness, b. The velocity components, therefore, can be also expressed as:

$$v_x = - (T/nb) (\partial h/\partial x) \quad (5)$$

$$v_y = - (T/nb) (\partial h/\partial y). \quad (6)$$

[1] Drawdown is the difference between the water level that would have prevailed under non-pumping conditions and that which prevails under pumping conditions.

The partial derivatives $\partial h/\partial x$ and $\partial h/\partial y$ represent the hydraulic gradient components under pumping conditions and can be obtained from equation 1. The resulting equations for the velocity components are:

$$v_x = - [(TI_x/nb) + (1/2\pi nb) \sum_{j=1}^{N_w} Q_j \{ (x - x_j)/[(x - x_j)^2 + (y - y_j)^2]\}] \qquad (7)$$

$$v_y = - [(TI_y/nb) + (1/2\pi nb) \sum_{j=1}^{N_w} Q_j \{ (y - y_j)/[(x - x_j)^2 + (y - y_j)^2]\}] \qquad (8)$$

The first term in these equations represents the increment of the velocity component due to the regional groundwater flow; the second term represents the increment of the velocity component induced by pumping from the wellfield. The tracer-test evaluations presented in this report were based on these equations.

Several points pertinent to the evaluation of tracer tests can be made from these equations. To simplify the discussion of these points, consider an aquifer with uniform flow in the x-direction, that is $I_y = 0$, and a wellfield with a single well pumping at a rate Q and located at x = 0 and y = 0. Under these conditions equations 7 and 8 take this form:

$$v_x = - \{(TI_x/nb) + (Q/2\pi nb) [x/ (x^2 + y^2)]\} \qquad (9)$$

$$v_y = - (Q/2\pi nb) [y/(x^2 + y^2)] \qquad (10)$$

For regional flow in the x-direction, I_x is negative and thus the regional velocity increment in equation 9 is positive; it will be denoted as v_{reg}. Also the term $(x^2 + y^2)$ is the square of the radial distance r from the well to any point (x, y). Making these substitutions the velocity equations become:

$$v_x = v_{reg} - (Q/2\pi nb) (x/ r^2) \qquad (11)$$

$$v_y = - (Q/2\pi nb) (y/r^2). \qquad (12)$$

The velocity increments induced by pumping represent a radial velocity increment that can be expressed as:

$$\mathbf{v_r} = \{[- (Q/2\pi nb) (x/ r^2)]^2 + [- (Q/2\pi nb) (y/r^2)]^2\}^{1/2} = (Q/2\pi nb) (1/r) \qquad (13)$$

First, note that the only aquifer property that controls this radial velocity increment is the porosity-thickness product "nb." Note also that the radial velocity increment is directly proportional to the pumping rate, and inversely proportional to the porosity-thickness product "nb" and to the radial distance from the wellfield; therefore, the magnitude of this increment increases with the pumping rate but decreases with "nb" and the radial distance from the well.

Second, note that the sign of the velocity increment induced by pumping in equations 11 and 12 changes depending on whether x or y are larger or smaller that x_j or y_j, respectively. This is expected since this increment is radial, towards the well which is pumping at x= 0 and y= 0. Thus, upgradient from the well (negative x) this increment is added to the regional velocity increment v_{reg} and the total velocity towards the well is higher than the total velocity downgradient from the well (positive x) where this increment is subtracted from v_{reg}. Therefore, a tracer injected into the aquifer a given distance upgradient from the pumped well would reach the well faster than a tracer injected at the same distance downgradient from the well.

Finally, note that downgradient from the well there is a point where the pumping-induced velocity increment is equal to but opposite to the regional velocity increment; the velocity at this point is, therefore, zero. This point lies at a distance:

$$x = Q/2\pi nbv_{reg} = -Q/2\pi TI_x \qquad (14)$$

and is called the "stagnation point." The stagnation point forms the apex of a parabola that limits the area within which all groundwater is flowing towards and is captured by the well[2]; outside this "capture zone" limit, groundwater by-passes the well and continues to flow in the general direction of the regional gradient. The velocities within the capture zone but near the stagnation point are very small, and a tracer injected near the stagnation point would take a long time to reach the well. Of course, tracers injected outside the capture zone, or contaminants from sources outside the capture zone, would move in the general direction of regional flow and will not reach the well.

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[2] If the aquifer receives recharge within the capture zone of the well, either from infiltration or from leakage, then the limits of the capture zone upgradient from the well begin approaching each other until they intersect and form a closed capture zone encompassing an area whose product with the recharge rate equals the pumping rate of the well.

Section 3
Description of the NWWF Tracer Tests

Brief descriptions of the tracer tests conducted at the NWWF in 1998, 1999, and 2003 are presented below.

Four tracer tests (or trials) were conducted in 1998 (Miami-Dade DERM, 1999). During the first test, 186 grams of red dye (Rhodamine WT) was introduced into the aquifer on January 28, 1998, through a shallow well located 450 feet to the east of PW-8 and about 950 feet to the west of PW9 (see Figure 2). The dye was first detected in well PW-8 after 1.3 days and reached peak concentration after 1.9 days[3]. During the second test, conducted simultaneously with the first test (January 28, 1998), and the third test (July 13, 1998), yellow dye (sodium-fluoroscein), 302 and 1260 grams, respectively, was injected through well NWTR-7C (see Figure 2) 1800 feet to the east of PW-9. The second test was abandoned after 78 days of sampling with no detection of dye in well PW-9; the third test was also abandoned due to non-detection, but its duration prior to abandonment is not reported in the Miami-Dade DERM (1999) report. During the fourth 1998 test, 1635 grams[3] of Rhodamine WT red dye was injected on December 17, 1998 through well NWTR-1 870 feet to the east-southeast of PW-9 (see Figure 2). The dye was first detected in PW-9 after 5.3 days, and the concentration peaked 9.5 days[3] after the injection.

The 1999 test (Miami-Dade DERM, 2000) consisted of injecting dyes through the well pair NWTR-2A/2B, located 3040 feet to the east of PW-9 (see Figure 2). Fluorescein dye (30 pounds) was injected through well NWTR-2A, screened between a depth of 60 to 80 feet; Rhodamine WT dye (10 pounds) was injected through well NWTR-2B, screened between a depth of 40 to 50 feet. The dyes were injected on September 10, 1999. Dye concentrations were monitored in well pairs NWTR-3A/3B, NWTR-4A/4B, and NWTR-7C/7D, and in production well PW-9. The distance between the injection wells and monitoring well pairs NWTR-3A/3B, NWTR-4A/4B, and NWTR-7C/7D is about 530, 710, and 1230 feet, respectively. The travel time to these monitoring wells was more than hundred days and the dyes were not detected in the production well PW-9. The time from injection to the first detection and to the occurrence of the peak concentration in each monitoring well, as interpolated from breakthrough curves presented in Guha, Kottke and Harrison (2003) are summarized in the following table.

[3] These numbers are based on those listed on Table 1 of the Miami-Dade DERM 1999 report. Different numbers are reported in the description of the tests presented in later sections of the Miami-Dade DERM report. The peak arrival times listed on Table 1 of the report, rather than those reported in the description of the tests, were used by Miami-Dade DERM in the analysis of Tests 1 and 4 by the QTRACER model. The Table 1 peak arrival times are, therefore, also used in the evaluations presented in this report.

Monitoring Well	Time, in days			
	Fluorescein		Rhodamine WT	
	First Detection	Peak	First Detection	Peak
NWTR-3A	120	170	120	180
NWTR-3B	115	170	115	145
NWTR-4A	108	125	108	130
NWTR-4B	108	125	108	125
NWTR-7C	130	160	130	170
NWTR-7D	130	170	130	170

The 2003 test was conducted as part of the studies undertaken by the USGS, Miami-Dade DERM, and other agencies to evaluate pathogen transport in karstic flow zones of the Biscayne Aquifer. The test was conducted by injecting Rhodamine WT red dye and Deuterated Water through well G-3773, located 100 meters (330 feet) to the west of PW-9 (see Figure 2). Based on preliminary assessments of dilution effects and of travel times, the amount of dye injected in the well was 50 kilograms. The dye and the deuterated water were injected on April 22, 2003. Within 4 hours both the dye and the deuterated water were detected in well PW-9 and reached peak concentrations at 6.5 hours. This unexpected rapid movement of the dye into the production well caused the water pumped by the well to turn red, and resulted in the shutdown of the well after about 13 hours since the beginning of the test; pumping resumed about 26 hours later.

Section 4
Evaluation of the Tracer Test Results

The evaluations presented in this report are based on the assumption that the dominant transport mechanism during the tests was advection, that is, that the tracers were transported at about the same rate as the moving groundwater. Given the karstic character of the Biscayne Aquifer, and the conservative nature of the dye tracers, this assumption is reasonable. Earlier evaluations of the 1998 and 1999 tests, by methods that considered dispersion and other transport mechanisms (Miami-Dade DERM, 1999; 2000; Guha, Kottke and Harrison, 2003), also support this assumption. Furthermore, the primary purpose of the evaluations presented in this report was to provide a common basis of comparison for the tests conducted at the NWWF. The evaluations did take into account, however, the effects of regional gradients, and of the distribution of pumpage among the wells of the wellfield.

The evaluations were aimed at determining the effective porosity-thickness product, nb, reflected by each test, and calculating the travel-time distances corresponding to the maximum and minimum value of the porosity-thickness product determined from the tests.

4.1 Determination of the Porosity-Thickness Product

A particle tracking routine based on equations 7 and 8 was used to determine the porosity-thickness product reflected by each test. The transmissivity of the aquifer and the regional hydraulic gradient were assumed to be uniform and the same for all tests. For each test, the process of determining "nb" involved the following steps:

1) An initial value for "nb" was assumed;
2) A particle was introduced at the injection well location;
3) The velocity components for that location were calculated based on equations 7 and 8;
4) Using these velocity components and a small time interval, the particle was moved to a new location;
5) The velocity components were calculated again for the new location, and the process was repeated until the particle reached the receptor well for each test;
6) The calculated travel time was compared to the actual travel time and the value of "nb" was increased or reduced to reduce or increase the calculated travel time; and
7) Steps 3 through 6 were repeated until the calculated travel time matched the actual travel time.

Tests 1 and 4 of 1998, and the 1999 and 2003 tests were evaluated using this approach. For tests that involved more than one tracer, the evaluation was limited to the results corresponding to the breakthrough of Rhodamine WT. The 1999 test was conducted over a period of about six months and was subject to seasonal variations in pumping rates and climatic conditions, including heavy precipitation from Hurricane Irene in October 14-16, 1999. To average the effects of these seasonal variations in pumping rates and climatic conditions, the evaluation of this test was based only on data from well pair NWTR-7C/7D, the well pair most distant from the injection well. The "actual" travel time for the evaluation of each test was taken as the elapsed time between the injection of the dye and the occurrence of the peak concentration at the receptor well.

Based on the results of the analysis of drawdown data from well G-3773 (Renken, 2003), the injection well for the 2003 test, a transmissivity of 3,500,000 feet squared per day was used in the evaluations. Maps of the water table for the Biscayne Aquifer prior to the installation of the NWWF (Miller, 1989; Fish and Stewart, 1991) indicate the regional gradient at the area of the wellfield to be to the east-southeast with a magnitude of about 0.5 foot per mile. A gradient of about 0.0001, in a direction of about 20 degrees south of east was used.

For the 1999 test, the files provided to SSP&A included monthly pumping rate data for each of the 15 wells of the wellfield for a period of one year, from September 1999 to August 2000. To evaluate this test, during which the peak concentration in the well pair NWTR-7C/7D occurred after 170 days, the average pumping rate for the six-month period September 1999 to March 2000 was used. For the 1998 test, except for general statements indicating that the total pumpage from the wellfield was about 90 MGD, the documents provided to SSP&A did not include pumping data for individual wells. Since the 1998 tests were conducted in January and December of that year, it was assumed that the pumping rates of individual wells could be the same as during the corresponding months in 1999 or 2000; the January 2000 rates were used in evaluating the first 1998 test and the December 1999 rates for the fourth 1998 test[4]. For the 2003 test, the files provided to SSP&A included daily pumping rates between February 1, 2003 and April 30, 2003. The pumping rates for April 22, 2003 were used for evaluating this test.

The pumping rates used in the evaluation of each test, and their distribution among the production wells of the NWWF are summarized in Table 1. The travel distances associated with each test and the porosity-thickness products determined from the evaluation of the tests are presented below:

Tracer Test	**Travel Distance, in feet**	**Porosity-Thickness Product, in feet**
1998 - Test 1	450	1.37
1998 - Test 4	870	7.32
1999	1230	10.3
2003	330	1.33

[4] If the actual pumping rates during these tests were higher, than the porosity-thickness products determined from these tests are underestimated; conversely, if the actual pumping rates were lower, the porosity-thickness products determined from these tests are underestimated.

These results indicate that the porosity-thickness product for the Biscayne Aquifer in the vicinity of the NWWF varies with location. The first test of 1998 and the 2003 test, both conducted in the middle of the wellfield in the area between production wells PW-8 and PW-9, reflect a low porosity-thickness product. The fourth 1998 test and the 1999 test, both conducted downgradient from the wellfield, reflect porosity-thickness products that are about 5 to 8 times higher. The results also suggest that the porosity-thickness product may be a function of the distance between the injection and the receptor well; the 2003 test that had the smallest travel distance between the injection well and the receptor well yielded the lowest porosity-thickness product, and the 1999 test that had the largest travel distance yielded the highest value of this product. This may be partly due to the greater likelihood of the presence of continuous preferential pathways over short distances than their presence over large distances.

To put the values of the porosity-thickness product obtained from the evaluation of the tests into perspective, note that if the porosity thickness product at the location of the 2003 test was the same as that determined from the 1999 test, then the time to the arrival of the peak concentration to well PW-9 would have been 50 hours instead of 6.5 hours; conversely, if the porosity thickness product at the location of the 1999 test was the same as that determined from the 2003 test, then the time to the arrival of the peak concentration in the well pair NWTR-7C/7D would have been 22 days instead of 170 days. Although the travel times would have still been significantly different (50 hours versus 170 days, or 6.5 hours versus 22 days), both tests would have yielded the same porosity-thickness product. The difference in travel-time would have been solely due to the much steeper gradients near the wellfield than those farther away and downgradient from the wellfield.

4.2 Calculation of Travel-Time Distances

Travel-time based distance boundaries for the NWWF were calculated for the highest and smallest values of the porosity-thickness product determined from the evaluation of the tracer tests: (1) the value of 10.3 feet determined from the 1999 Test, and (2) the value of 1.33 feet determined from the 2003 Test. Travel-time distances corresponding to each of these two porosity-thickness products were calculated for two pumping rates and distributions: (1) a pumping rate of 150 MGD corresponding to the current demand and distributed equally among the 15 production wells (10 MGD per well), and (2) a pumping rate of 225 MGD corresponding to the wellfield capacity, with each well pumping at 15 MGD. The distances corresponding to different travel times were calculated by reverse particle-tracking from each production well by using equations 7 and 8.

The results of the calculations corresponding to the current demand of 150 MGD are shown in Figures 3a and 3b; those corresponding to the wellfield capacity of 225 MGD are shown in Figures 4a and 4b. Also shown in these figures are the capture zones of the wellfield at each of these two pumping rates. The travel-time distances east of the wellfield are restricted by the downgradient extent of the capture zone of the wellfield; the capture zone is independent of the porosity-thickness product and remains the same for a given pumping rate (and a given transmissivity and regional hydraulic gradient).

West of the wellfield, travel-time distances are larger than those in the existing rock-mining setback regulations (Figure 1), even for the highest porosity-thickness product determined from the tests and at the current pumping rates (Figure 3a). For the low porosity-thickness product, corresponding to the results of the 2003 Test (Figures 3b and 4b), the 30-day travel-time boundaries are farther from the wellfield than the 210-day boundary under the existing setback regulations (Figure 1); the 100-day and 210-day travel-time boundaries were not calculated for this case as the western extent of the 60-day boundary is already beyond the western limit of the area covered by the figure, and beyond the drawdown-based[5] Outer Protection Boundary (see Figure 1) for the wellfield.

4.3 Discussion of the Evaluation Results

The determinations of the porosity-thickness products from the tracer tests conducted at the NWWF and the calculations of travel-time distances presented above were based on several assumptions. The effects of these assumptions on the values of the porosity-thickness products determined from the tests, and hence on the travel-time distances, are briefly discussed below.

The evaluations assumed that the transmissivity of the aquifer and the regional hydraulic gradient were uniform and the same at all test locations, and representative of average conditions in the vicinity of the NWWF. The transmissivity used in the evaluations was that determined at the location of the 2003 test, and the regional hydraulic gradient was estimated from maps depicting the configuration of the water table in the aquifer prior to the installation of the NWWF (Miller, 1989; Fish and Stewart, 1991). Both the transmissivity and the hydraulic gradient affect only the regional increment of the velocity (see equations 7 and 8). A higher transmissivity and/or hydraulic gradient imply a higher rate of regional groundwater flow, and vice versa.

The 2003 test was an upgradient test, that is, during the test the tracers moved in the same direction as the regional groundwater flow. If the regional hydraulic gradient is higher than assumed, then the porosity-thickness product determined from the tests is underestimated; conversely, if the regional hydraulic gradient is lower than assumed, then the porosity-thickness product determined from the tests is overestimated. (A gradient of 0.0002, double that assumed, would have resulted in a porosity-thickness product of about 1.7; a gradient of 0.00005, half of that assumed, would have resulted in a porosity-thickness product of about 1.1.)

The other three evaluated tests were downgradient tests, that is, during these tests the tracers moved in a direction opposite to that of regional flow. If the transmissivity at these test locations and/or the regional hydraulic gradient during the tests was higher than assumed, then the porosity-thickness products determined from the tests are overestimated; conversely, if the transmissivity at these test locations and/or the regional hydraulic gradient during the tests was lower than assumed, then the porosity-thickness products determined from the tests are underestimated.

[5] There is no technical basis for imposing a drawdown-based protection boundary for a wellfield.

The transmissivity and the regional hydraulic gradient also affect the capture zone of the wellfield. For a higher transmissivity and/or hydraulic gradient, that is, for a higher rate of regional groundwater flow, the capture zones of the wellfield at each of the two pumping rates that were considered, would have been narrower and their downgradient limit (and stagnation point) would have been closer to the wellfield. Conversely, for a lower transmissivity and/or hydraulic gradient, the capture zones would have been wider and their downgradient limit would have been farther from the wellfield.

The effects of a higher or lower transmissivity and/or hydraulic gradient (higher or lower rate of regional groundwater flow) on the extent of the capture zones, on the porosity-thickness products determined from the 1999 and 2003 tests, and on the calculated travel-time distances shown in Figures 3 and 4 are summarized in the following table:

Regional Rate of Groundwater Flow	**Extent of Capture Zone**	**Porosity-Thickness Product**		**Downgradient Travel-Time Distances**	**Upgradient Travel-Time Distances**
		1999 Test	**2003 Test**		
Higher than assumed in the evaluations	Narrower than shown in Figures 3&4; downgradient limit closer to wellfield	Lower than determined	Higher than determined	Closer to the wellfield than Figures 3&4; restricted by the limit of the capture zone	Farther from the wellfield than Figures 3&4
Lower than assumed in the evaluations	Wider than shown in Figures 3&4; downgradient limit farther from wellfield	Higher than determined	Lower than determined	Farther from the wellfield than Figures 3&4; restricted by the limit of the capture zone	Closer to the wellfield than in Figures 3&4

The evaluations also assumed that the primary transport mechanism for the tracers was advection; the effects of other transport mechanisms such as dispersion or sorption were not considered. Analyses of the 1998 and 1999 tests that considered dispersion (Miami-Dade DERM, 1999; 2000a; Guha, Kottke and Harrison, 2003) indicate that the dispersivity reflected by the tests is small; therefore, dispersion had a small effect on the transport of the tracers. The tracers used in the tests are conservative and are not subject to significant sorption by the karstic limestone aquifer. Neglecting these transport mechanisms does not, therefore, have a significant effect on the results of the evaluations.

Finally, the calculations of travel-time distances assumed that the porosity-thickness product and the transmissivity of the aquifer are uniform. The results of the tracer tests indicate that the porosity thickness product varies with location and that may also be a function of the travel distance. In a karstic aquifer, such as the Biscayne Aquifer, transmissivity is also expected to be spatially variable. Regardless of whether or not available data are adequate for defining spatial variations for these aquifer properties, consideration of spatial variations would have required the development of a numerical groundwater flow model that can incorporate these variations. Development of such a numerical model was well beyond the scope of this study.

Section 5
Implications on Rock-Mining Setbacks

The current rock-mining regulations prohibit mining within the area of the 30-day travel-time boundary for the NWWF, and place a depth restriction of 40 feet within the area that lies between the 30-day and the 210-day travel-time boundaries; this depth restriction is waived if mining occurs outside an area corresponding to a 60-day travel time. As indicated in Figures 3 and 4, the distances to travel-time boundaries vary with the pumping rate and with the effective porosity-thickness product of the aquifer. Assuming that the intent of the regulations is to protect the NWWF at all potential pumping rates, the wellfield capacity of 225 MGD is the appropriate pumping rate for determining mining setback boundaries. At this pumping rate and over the range of the porosity-thickness products determined from the tracer tests, the distance to the 30-day travel-time boundary, within which mining should be prohibited according to the regulations, ranges from about 0.8 mile (Figure 4a) to about 3.5 miles (Figure 4b) west of the wellfield. The distance to the 60-day travel-time boundary, outside of which mining depth restrictions do not apply, ranges from about 1.4 mile (Figure 4a) to beyond the western boundary of the figure (Figure 4b) which lies about 5 miles from the wellfield.

The U. S. Army Corps of Engineers (USACE) issued several permits in 2002 allowing rock mining to occur outside of an approximately ½ mile setback from the NWWF for at least 3 years pending the completion wellfield protection studies in addition to those conducted in 1998 and 1999 (personal communication, staff of NRDC). Note that the setback distance of ½ mile stipulated in these permits is less than even the 0.8 mile distance to the 30-day travel-time boundary and significantly less than the 1.4-mile distance to the 60-day travel-time boundary calculated using the highest porosity-thickness product determined from the evaluations of the tracer tests (see Figure 4a).

The 2003 test was conducted as part of the studies undertaken by the USGS, Miami-Dade DERM, and other agencies to evaluate pathogen transport in karstic flow zones of the Biscayne Aquifer. The dye and deuterium tracer test is presented as the first step in a series of field and laboratory studies planned for the evaluation of pathogen transport. Regardless of conclusions that may be drawn from the results of other planned tests using the same field arrangement, the small travel time, and hence the high velocity, observed during the tracer test is indicative of a good hydraulic connection through a karstic flow zone between the injection well and production well PW-9. In fact, the logs of the injection well (G-3773) and of monitoring well G-3772, installed between the injection well and PW-9, show several karstic flow zones in this area. Note that the first 1998 test also reflected a porosity-thickness product essentially identical to that from the 2003 test. Thus, the karstic flow zones may be extending across the entire area between production wells PW-8 and PW-9. Studies by the USGS have also identified these karstic zones in two wells about one mile west of the NWWF, and about 1.5 miles apart along a north-south alignment (Baker, 2003). Thus, the results of the first 1998 and the 2003 tests may be representative of conditions west of the wellfield. If that is the case, then some of the permitted and most of the proposed rock-mining areas are within distances with less than 30-day and 60-day travel times to the wellfield (see Figure 5)[6] even under the current pumping rates; mining operations in these areas should be prohibited or restricted under the terms of the current regulations.

The tests conducted to date were located either east (downgradient) of the NWWF or within the wellfield. The critical areas for mining operations are the areas to the west, north, and south of the wellfield; first, because east of the wellfield the limit of the capture zone is probably a better criterion for limiting or prohibiting mining than travel-time based distances, and second, because most of the currently permitted or proposed mining areas are to the west, north and south of the wellfield. If travel-time based mining setbacks are to be applied to these areas, then data on the transport properties of the aquifer should be collected from tests conducted in these areas. In absence of such tests, regulation of mining operations in the vicinity of the NWWF should be based on the results of tests conducted to date, and mining should be prohibited or restricted in areas where these results indicate potential travel times of less than 30 or 60 days to the wellfield.

Tests conducted in areas of proposed mining operations should include multiple monitoring and injection wells, and be designed to evaluate the transport properties of the aquifer over different travel distances so that the results can be used to assess whether or not a correlation exists between these properties and the travel distance. Any model, or models, used to design these tests, interpret the test results, and delineate rock-mining setback distances protective of the NWWF should consider the effects of both the regional groundwater flow and of the pumping from the wellfield.

[6] The permitted and proposed lakes (rock-mining areas) shown in this figure represent conditions in 2000; certain lakes designated as proposed have been permitted since 2000 (personal communication, staff of NRDC).

Section 6
References

Baker, Julie, 2002, Memorandum from Julie Baker, Special Project Administrator 1, to John W. Renfrow, P.E., Director Environmental Resources Management, on the subject "**Summary of April 2003 NWWF Tracer Test and the "Red Dye Incident" at the Preston WTP**": July 25.

Cooper Jr., H. H., and C. E. Jacob, 1946, **A Generalized Graphical Method for Evaluating Formation Constants and Summarizing Well-Field History**: *Transactions, American Geophysical Union,* v. 27, p. 526-534.

Fish, J. E., and Mark. Stewart, 1991, **Hydrogeology of the Surficial Aquifer System, Dade County, Florida**: *U.S. Geological Survey Water-Resources Investigations,* WRI 90-4108, 50 p.

Guha, Hillol, Harvey Kottke, and Theodore Harrison, 2003, **Dye Tracer Study near a High Capacity Public Water Supply System, Miami-Dade County, Florida, U.S.A**: *American Water Resources Association 2003 International Congress,* New York, NY, June 29-July 2.

Miami-Dade County Department of Environmental Resources Management, Water Supply Section, 1999, **Description and Analysis of Preliminary Tracer Trials Conducted at the Northwest Wellfield, Miami-Dade County, Florida**: 16 p., May.

Miami-Dade County Department of Environmental Resources Management, Water Supply Section, 2000a, **Description and Analysis of Full-Scale Tracer Trials Conducted at the Northwest Wellfield, Miami-Dade County, Florida**: 20 p., July.

Miami-Dade County Department of Environmental Resources Management, Office of the Director, 2000b, **Northwest Wellfield Watershed Protection Plan, Miami-Dade County, Florida**: Technical Report prepared for South Florida Water Management District, C-8797, 59 p., August 16.

Miller, James A., 1989, **Ground Water Atlas of the United States; Segment 6, Alabama, Florida, Georgia, and South Carolina:** *U.S. Geological Survey Hydrologic Investigations Atlas*, HA-0730-G, 28 sh.

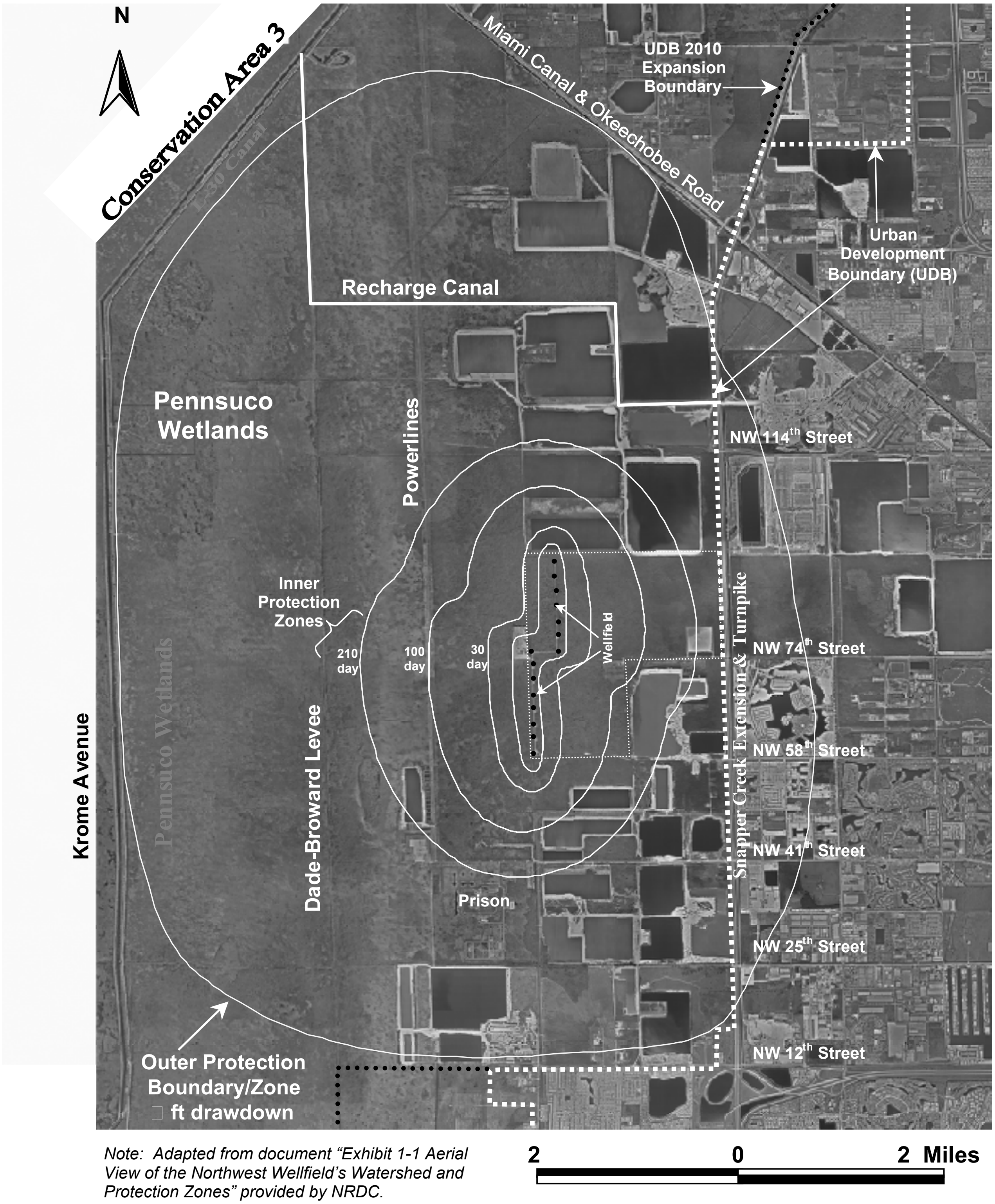
Renken, Robert A, 2003, **Evaluation of Pathogen Transport in Karst Flow Zones of the Biscayne Aquifer near the Northwest Well Field, Miami-Dade County, Florida**: PowerPoint presentation consisting of 31 slides, April 23.

Theis, C.V., 1935, **The Relation between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Groundwater Storage**: *Transactions, American Geophysical Union,* v. 16, p. 519-524.

Thiem, Gunther, 1906, **Hydrologische Methoden (Hydrologic Methods):** J. M. Gebhardt, Leipzig, 56 p.

Tonkin, M. J., and S. P. Larson, 2002, **Kriging Water Levels with a Regional-Linear and Point-Logarithmic Drift**: *Ground Water,* v. 40, no. 2, p. 185-193.

FIGURES



Note: Adapted from document "Exhibit 1-1 Aerial View of the Northwest Wellfield's Watershed and Protection Zones" provided by NRDC.

Figure 1 The Northwest Wellfield and Existing Travel-Time and Drawdown Based Protection Zones

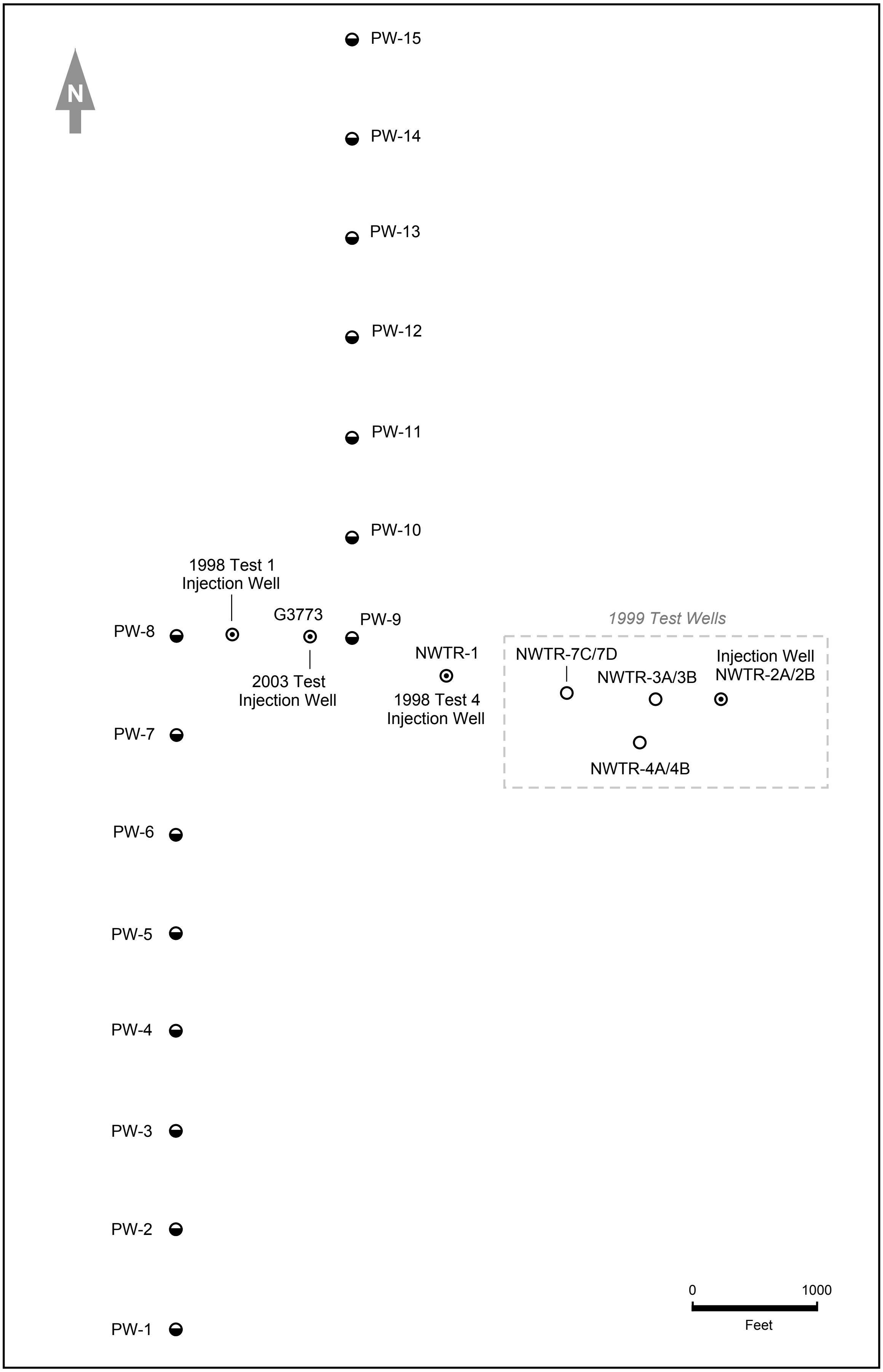
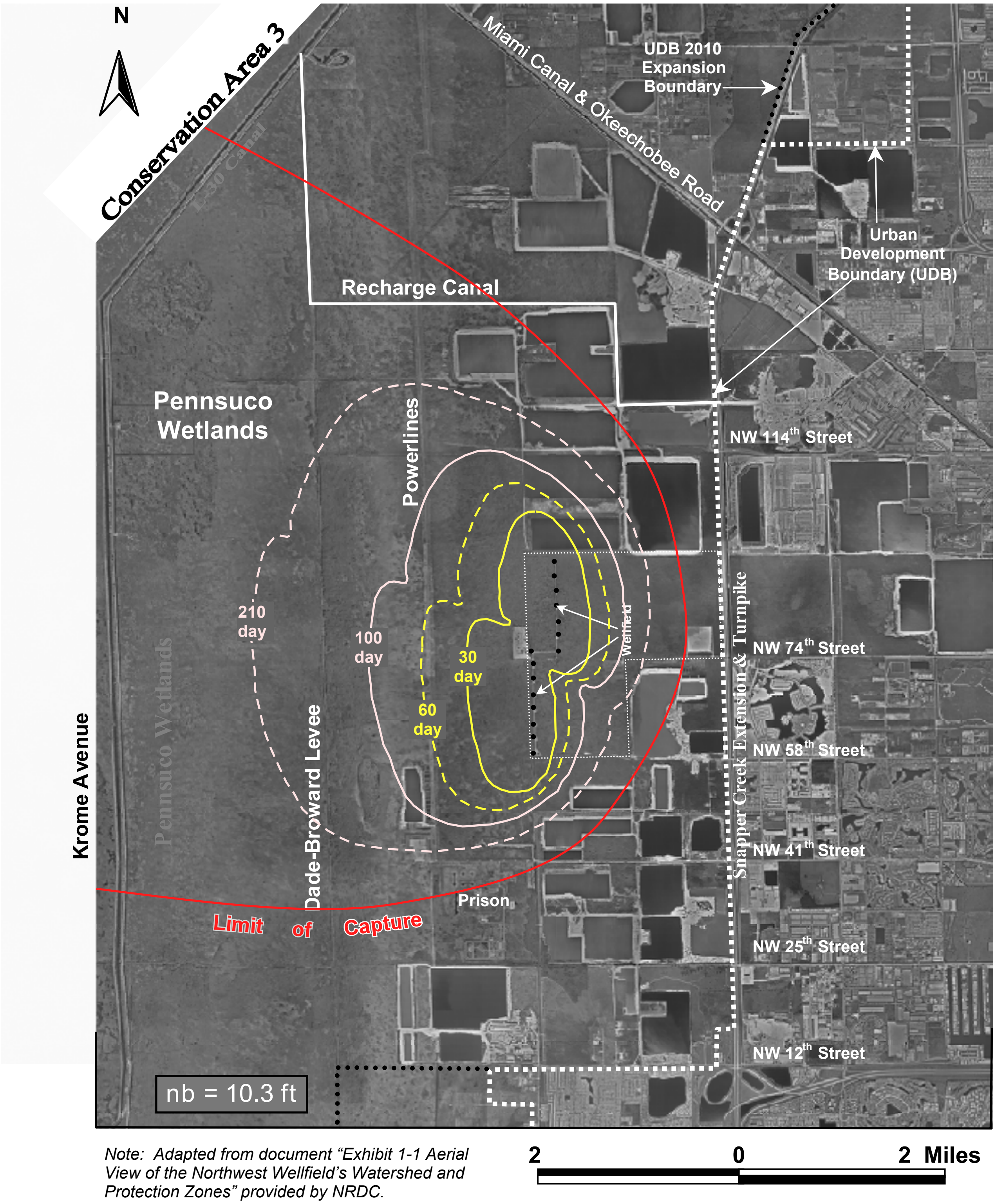
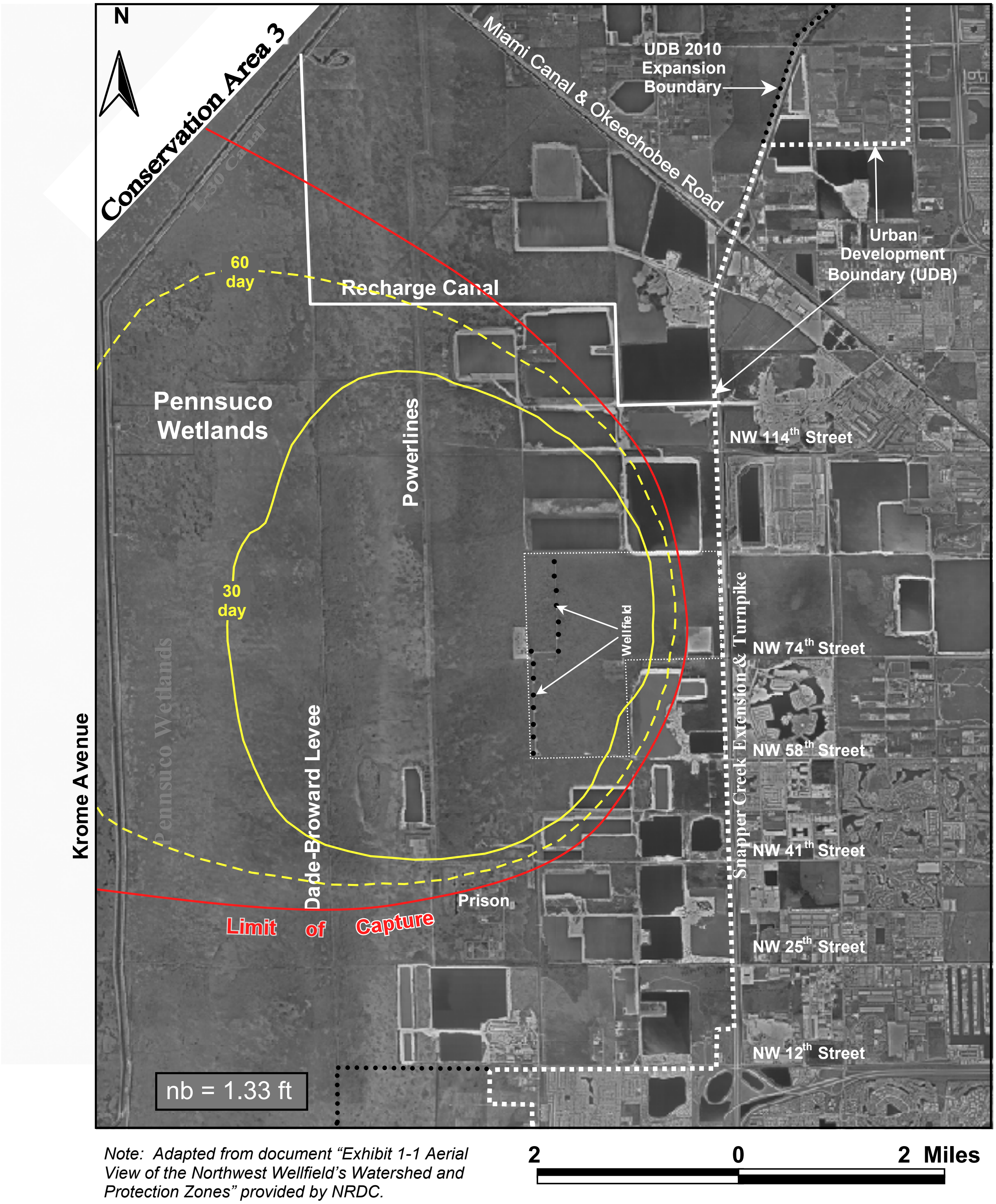


Figure 2 Relative Location of the Nothwest Wellfield and of Tracer Test Wells



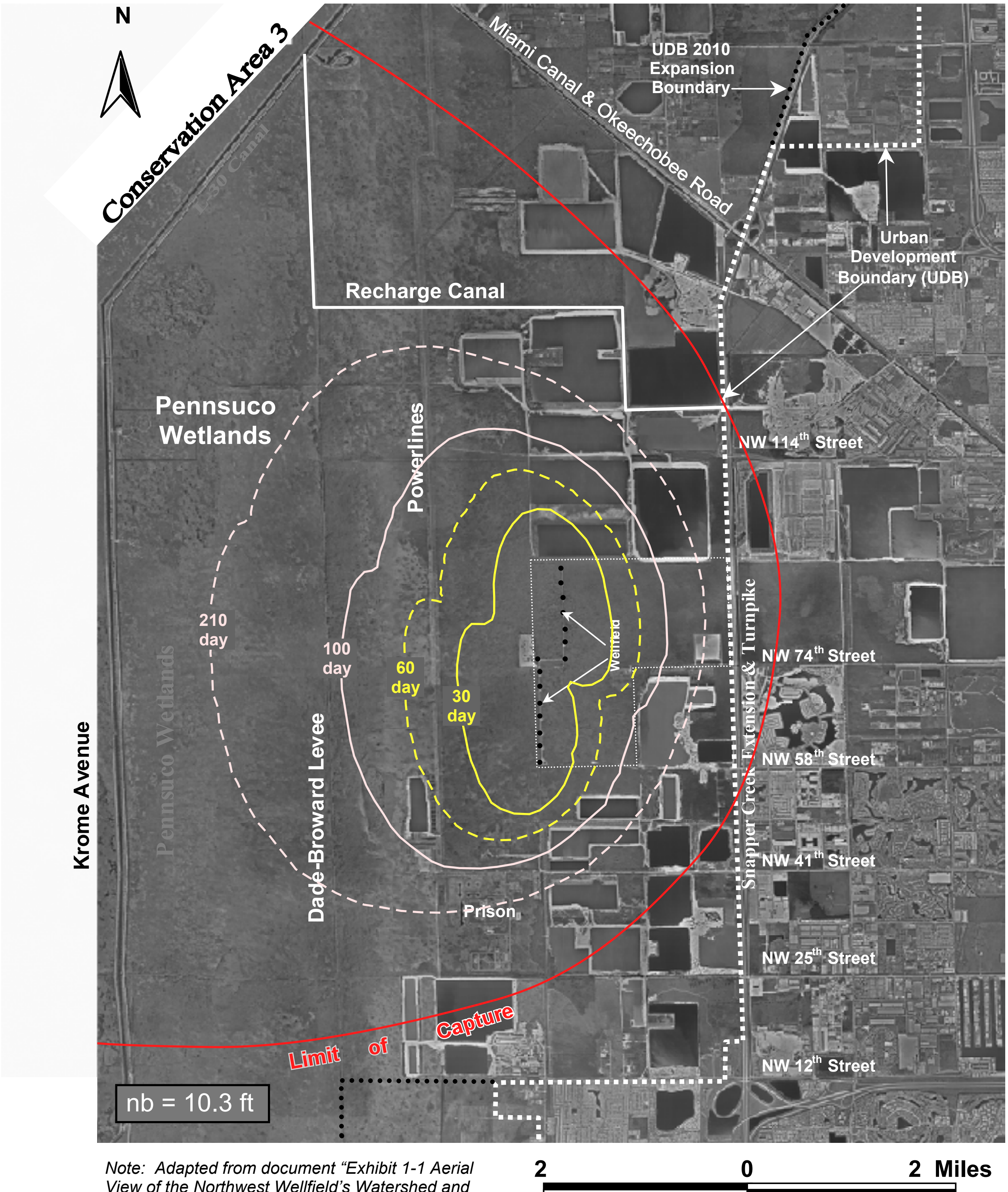
Note: Adapted from document "Exhibit 1-1 Aerial View of the Northwest Wellfield's Watershed and Protection Zones" provided by NRDC.

Figure 3a Travel-Time Distances Corresponding to the Current Demand of 150 MGD High Porosity-Thickness Case



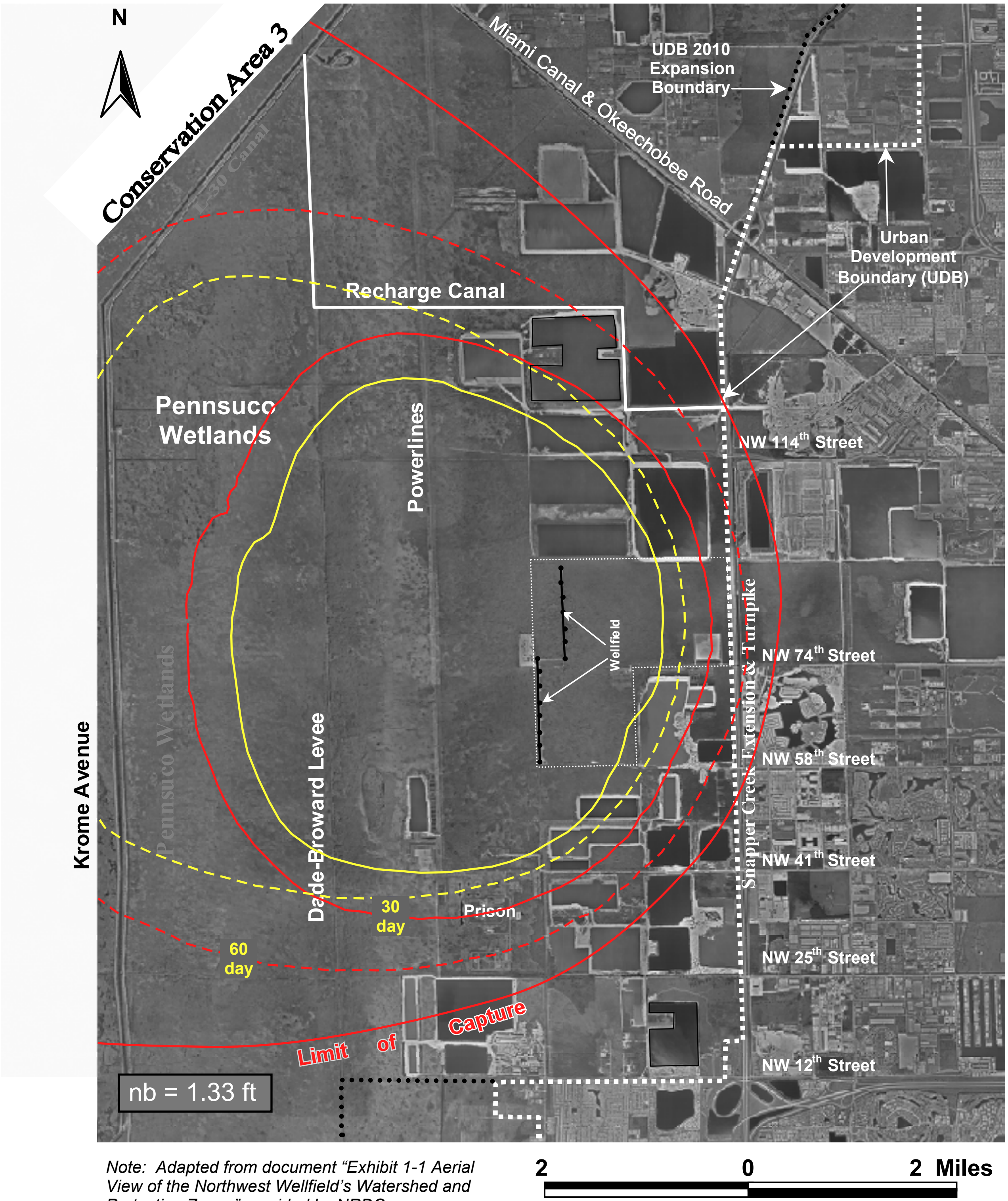
Note: Adapted from document "Exhibit 1-1 Aerial View of the Northwest Wellfield's Watershed and Protection Zones" provided by NRDC.

Figure 3b Travel-Time Distances Corresponding to the Current Demand of 150 MGD
Low Porosity-Thickness Case



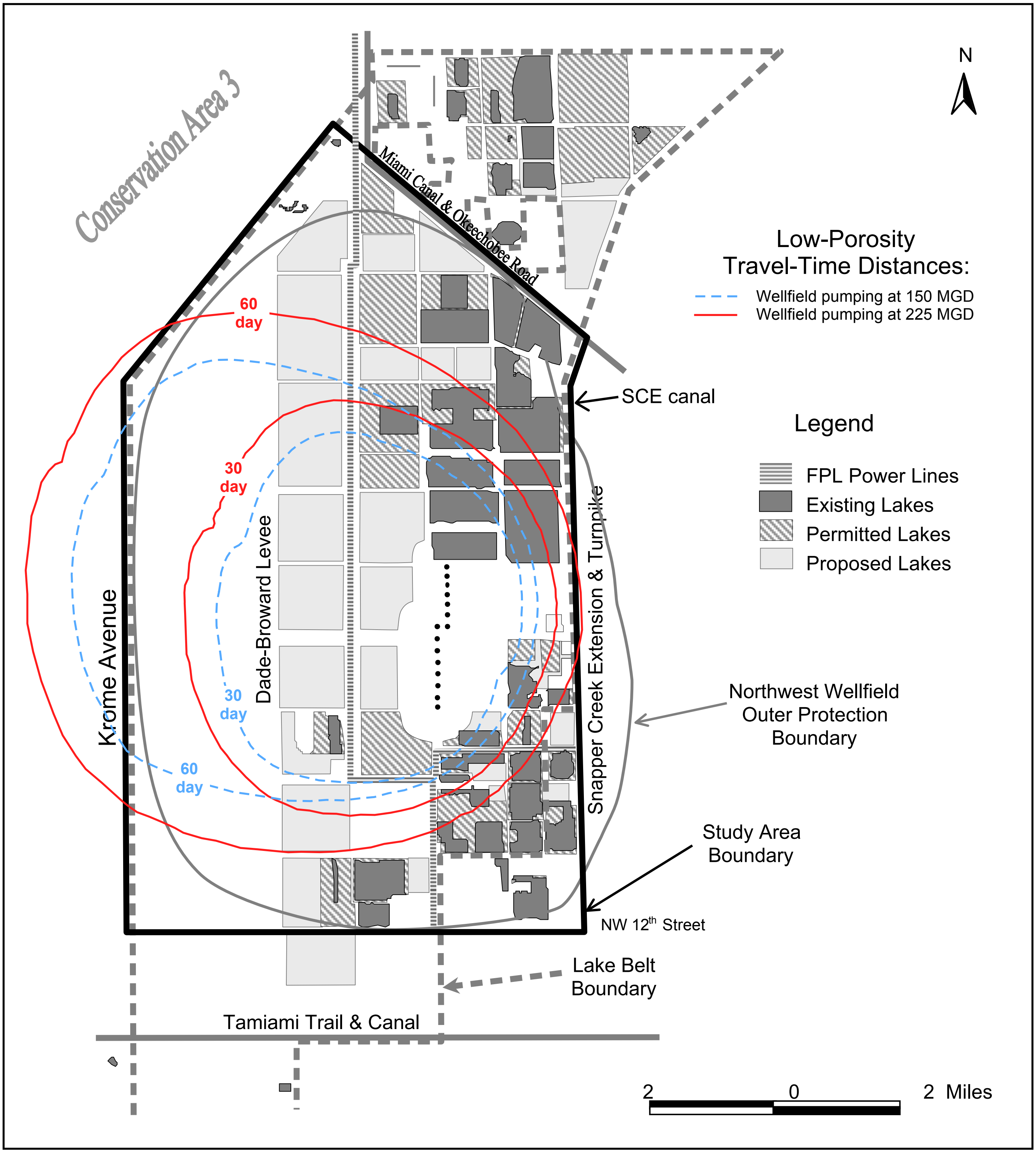
Note: Adapted from document "Exhibit 1-1 Aerial View of the Northwest Wellfield's Watershed and Protection Zones" provided by NRDC.

Figure 4a Travel-Time Distances Corresponding to the Wellfield Capacity of 225 MGD
High Porosity-Thickness Case



Note: Adapted from document "Exhibit 1-1 Aerial View of the Northwest Wellfield's Watershed and Protection Zones" provided by NRDC.

Figure 4b Travel-Time Distances Corresponding to the Wellfield Capacity of 225 MGD
Low Porosity-Thickness Case



Note: Base Adapted from Miami-Dade DERM (2000b), Figure 2.

Figure 5 Comparison of Travel-Time Distances to Rock-Mining Areas

TABLES

Table 1

Pumping Rates Used in the Evaluation of the NWWF Tracer Tests, and their Distribution among Production Wells, in MGD

Production Well No.	1998 Test 1	1998 Test 4	1999 Test	2003 Test
1	10.000	10.000	10.000	10.362
2	0.000	3.333	1.875	10.362
3	0.000	0.000	0.000	10.362
4	0.000	0.000	0.000	10.362
5	0.000	0.000	0.000	0.441
6	0.000	10.000	1.667	0.000
7	15.000	12.083	14.514	0.000
8	15.000	7.500	13.750	0.000
9	15.000	12.083	13.854	9.921
10	10.000	8.750	9.792	0.000
11	0.000	0.000	0.000	0.000
12	0.000	4.583	2.083	0.000
13	10.000	10.000	8.681	0.000
14	0.000	10.000	7.986	10.362
15	0.000	10.000	8.333	10.583
Total	**75.000**	**98.332**	**92.535**	**72.756**

APPENDIX A

Appendix A

Resume of
Stavros S. Papadopulos, PhD

STAVROS S. PAPADOPULOS

Groundwater Hydrologist

Education

PhD in Civil Engineering, 1964. Princeton University, Princeton, New Jersey
MA in Civil Engineering. 1963. Princeton University, Princeton, New Jersey
MS in Ground-Water Hydrology, 1962, New Mexico Institute of Mining and Technology, Socorro. New Mexico
BS in Civil Engineering, 1959, Robert College, Istanbul, Turkey

Registrations

Professional Engineer, District of Columbia, No. 7754

Languages

English, French, Greek, Turkish, knowledge of Spanish

Professional History

S.S. Papadopulos & Associates, Inc., Bethesda, Maryland: President, 1979-1993; Chairman, Board of Directors, 1993 to 2001; Founder & Senior Principal, 2001-present.
U.S. Geological Survey, Reston, Virginia: Research Hydrologist, 1970-1974; Hydrologist, 1974-1979.
University of Illinois at Chicago Circle, Chicago, Illinois: Associate Professor, and Harza Engineering Company, Chicago, Illinois: Chief Groundwater Consultant (part-time), 1969-1970.
Harza Engineering Company, Chicago, Illinois: Groundwater Specialist, 1967; Head of Hydrology Department, 1967-1969; and University of Illinois at Chicago Circle, Chicago, Illinois: Visiting Associate Professor (part-time), Spring Quarter 1968.
University of Minnesota, Minneapolis, Minnesota: Associate Professor, 1966-1967.
U.S. Geological Survey, Arlington, Virginia: Hydraulic Engineer, 1963-1964; Research Engineer, 1964-1965; Research Hydrologist, 1965-1966; and George Washington University, Washington, D.C.: Part-time Associate Professional Lecturer, 1965-1966.
New Mexico Institute of Mining and Technology, Socorro, New Mexico: Research Assistant, Summer 1963.
Princeton University, Princeton, New Jersey: Graduate Assistant, 1961-1963.
U.S. Geological Survey, Trenton, New Jersey: Hydraulic Engineer (part-time), 1963.
U.S. Geological Survey, Denver, Colorado: Hydraulic Engineer, Summer 1962.
New Mexico Institute of Mining and Technology, Socorro, New Mexico: Graduate Research Assistant, 1959-1961.
The U.S. Army Corps of Engineers, Trabzon and Sinop, Turkey: Assistant Engineer, Summers 1958 and 1959.

Summary of Qualifications

Dr. Papadopulos is an internationally recognized expert on the analysis of groundwater systems. His areas of expertise include • the evaluation of aquifer test data, • the use of analytical and numerical models for interpreting groundwater flow and contamination problems and for resolving groundwater supply issues, • assessment of groundwater flow and quality conditions at hazardous waste sites and identification of potential receptors, and • the design of monitoring networks and of extraction well systems for groundwater remediation. He has served on advisory panels offering technical opinion on complex groundwater issues and has provided expert testimony in court proceedings and/or administrative hearings. He has planned and directed research on groundwater systems and on the development of new methods for analyzing aquifer tests. He is the author and co-author of publications on well hydraulics, aquifer test methodology, groundwater resource evaluations, and subsurface waste disposal.

STAVROS S. PAPADOPULOS
Groundwater Hydrologist

RESUME -- Page 2

Appointments

Member of the Groundwater Protection Strategy Work Group, Montgomery County, Maryland, April–November 2001.
Member of Committee for the O. E. Meinzer Award, Geological Society of America, Hydrogeology Division, 1993-1995.
Member of Water Science & Technology Board, National Research Council, 1991-1994.
Member of Advisory Council to School of Engineering and Applied Science, Princeton University, 1988-1992.
Chairman of Advisory Council to Department of Civil Engineering and Operations Research, Princeton University, 1984-1992.
Member of Commission on Engineering and Technical Systems, Geotechnical Board, National Research Council, 1988-1989.
Member of U.S. National Committee, International Association of Hydrogeologists, 1981-1984.
Member of Committee on Ground-Water Hydrology, Hydraulic Division, American Society of Civil Engineers, 1975-1981.

Awards & Honors

New Mexico Institute of Mining and Technology Alumni Association's *Distinguished Achievement Award*, in recognition of outstanding achievement, leadership, and creative contribution in occupation and profession, May 9, 1998.
Actuary Archon of the Ecumenical Patriarchate; honorary title conferred by Bartholomew I, Ecumenical Patriarch of the Orthodox Church, Istanbul, Turkey, October 15, 1995.
Medal of the City of Montpellier, awarded at the International Symposium on the Implications of Hydrogeology on Earth Sciences, Montpellier, France, September 11-16, 1978.
U.S. Geological Survey *Special Achievement Award*, September 1977.
U.S. Department of Interior *Meritorious Service Award*, May 1977.

Representative Project Experience

S.S. Papadopulos & Associates, Inc., Bethesda, Maryland.

Dr. Papadopulos has directed and/or conducted quantitative groundwater studies at numerous project sites throughout the United States and overseas. His project experience includes the evaluation of hydrogeologic conditions and/or the design of remedial measures at Superfund sites and at commercial facilities. For several of these projects, he has provided litigation support and/or expert testimony on issues related to groundwater contamination. A few examples of his project experience are presented below:

- **Coors Road Project, Sparton Technology, Inc., New Mexico —** Provided technical assistance in developing off-site and source containment systems for a contaminant plume associated with this facility. Participated in settlement negotiations with regulatory agencies to develop work plans for the installation and testing of these containment systems and for the evaluation of aquifer restoration. Testified in court proceedings associated with the installation of the off-site containment system. Analyzed aquifer-test and water-level data to determine the operating pumping rate for the off-site containment well and its capture zone. Since the implementation of the off-site containment system, continues to provide technical advice on issues related to site data collection and interpretation. Has primary responsibility for developing a groundwater flow-and-transport model for the site and for preparing annual reports on the status of the remedial operations and progress in aquifer restoration.

STAVROS S. PAPADOPULOS
Groundwater Hydrologist

RESUME — Page 3

Representative Project Experience
— continued

S.S. Papadopulos & Associates, Inc. – *continued*

- **Chem-Dyne Superfund Site, Hamilton, Ohio** — Dr. Papadopulos has been involved in investigations and studies associated with this site for over 20 years. His involvement with the site began in 1982 when, on behalf of a number of potentially responsible parties (PRPs), he provided oversight of remedial investigations that were being conducted by regulatory agency contractors. This led to his directing additional investigations on behalf of the PRPs, and to his participation in the design of remedial actions for the site. Dr. Papadopulos also participated in negotiations with the regulatory agencies that led to a Consent Decree entered in October 1985. After the signing of the Consent Decree, he directed the installation of the groundwater extraction system (25 extraction wells), the testing and evaluation of these wells, and the determination of their pumping rates. Since the beginning of remedial operations in 1987, Dr. Papadopulos has been responsible for the preparation of the Annual Reports for the site, for the conduct of special investigations (including the development of a groundwater flow model), and for regulatory agency interactions that became necessary during the last 15 years of remedial system operations. Currently, he is directing the development of a fate-and-transport model for the site to evaluate alternate or additional actions that may accelerate meeting the termination criteria for the remedial system.
- **Puente Valley Project - TRW Inc., California —** Provided technical assistance to TRW in developing a position paper on the allocation of remedial costs among potentially responsible parties (PRPs) in the Puente Valley Operable Unit of the San Gabriel Valley Superfund Site. Directed an extensive review of available reports and data to evaluate hydrogeologic conditions at more than 50 PRP sites within Puente Valley, and to develop groundwater flow-and-transport and optimization models for determining the relative contribution of each site to groundwater contamination.
- **Tyson Superfund Site, Ciba-Geigy Corporation, Pennsylvania —** Provided technical assistance in remedial investigations and in the design of remedial measures at this site where wide-spread migration of DNAPLs occurred in fractured bedrock. Designed an extraction system to intercept contaminated groundwater discharging from shallow bedrock into the adjacent river. Directed the development of several groundwater flow models of the site to design the extraction system, assess its performance over time, and evaluate flow conditions in deeper bedrock. Formulated additional field investigations to assess the deep bedrock, evaluated data, and designed a groundwater extraction system for the deep bedrock. After installation of the deep bedrock system, directed periodic evaluations of system performance.
- **Kodak Park Projects, Eastman Kodak Company, New York —** Participated in a Groundwater Advisory Panel (GAP) providing technical advice to Kodak on issues related to groundwater contamination and remediation at its Rochester facilities. Directed projects involving the development of regional and local groundwater flow-and-transport models of the hydrogeologic system underlying Kodak Park, the design of interim remedial measures at several Kodak Park sections, and the conduct of Corrective Measure Studies for Kodak Park West and for the northeastern area of Kodak Park East.

STAVROS S. PAPADOPULOS
Groundwater Hydrologist

RESUME — Page 4

Representative Project Experience — *continued*

S.S. Papadopulos & Associates, Inc. – *continued*

- **Cyril Project – Union Texas Petroleum Energy Corporation: —** Served as Technical Representative of Union Texas on the Cyril Technical Committee of the Oklahoma Corporation Commission (OCC). The Committee conducted investigations to determine the extent and the feasibility of remediating a chloride plume caused by past oil production operations. Assisted the Committee in the selection of a consultant for field investigations, and prepared the sampling and testing protocols to be used by the consultant. Evaluated aquifer-test, streamflow, and water-quality data, and developed numerical groundwater flow and transport models for the site to assess the fate-and-transport of the chloride plume and to evaluate remedial alternatives. Served on the subcommittee preparing the Final Report and had primary responsibility for the modeling and several other appendices to the report.
- **Glendale Mediation Project, Intra-Glendale Operable Unit, California —** Served as Technical Advisor to the Mediator/Arbitrator for cost allocation among PRPs at the Glendale Operable Unit of the San Fernando Valley Superfund Site. Evaluated several allocation schemes developed by PRP consultants, and advised the Mediator/Arbitrator on their technical merit. Discussed with PRP consultants the results of their investigations at their client's facility and the potential relative contribution of the facility to groundwater contamination. Based on these evaluations and discussions, provided guidelines to the Mediator/Arbitrator for his mediation, and planned the technical approach to be used during the arbitration phase.

U.S. Geological Survey, Water Resources Division, Reston, Virginia.

- Conducted research in the analysis of groundwater systems and development of methods for analysis of aquifer test and groundwater resources.
- Served as Research Advisor to the Assistant Division Chief for Research and Technical Coordination and to his Deputy for Research.
- Investigated the energy potential of the Gulf Coast geopressured zones, water-supply potential of the Coastal Plain aquifers near Washington, DC, feasibility of aquifer thermal energy storage, and potential shallow burial sites for low-level radioactive wastes.
- Evaluated sources of additional water supply for Riyadh, Saudi Arabia, and the groundwater resources of the Setubal peninsula in Portugal.

University of Illinois at Chicago Circle, **Department of Geological Sciences,** Chicago, Illinois.

Taught courses in groundwater hydrology, engineering and structural geology. Conducted research on the application of digital computer techniques to well hydraulics and aquifer evaluation studies.

Harza Engineering Company, Chicago, Illinois.

Directed all aspects of planning involving groundwater resources, including preliminary and detailed exploration programs, pumping tests, resource evaluation, and aquifer protection studies. Major assignments included:

- Groundwater studies for the Chicago Deep Tunnel Project.
- Reconnaissance studies to determine the groundwater development potential of the Ullum Valley in Argentina and of limestone aquifers in Northern Guatemala.

STAVROS S. PAPADOPULOS
Groundwater Hydrologist

Representative Project Experience *— continued*

Harza Engineering Company, Chicago, Illinois — *continued*

- Formulation of groundwater exploration programs for several areas in Java and Sumatra to assess the technical feasibility of developing groundwater for irrigation and to identify pilot studies that would demonstrate the conjunctive use of surface and groundwater supplies for large-scale irrigation projects.

University of Minnesota, Department of Geology and Geophysics, Minneapolis.

Taught undergraduate and graduate courses in groundwater hydrology. Conducted research in well hydraulics and aquifer evaluation methods.

U.S. Geological Survey, Water Resources Division, Arlington, Virginia.

Conducted research of the mechanics of groundwater flow. Served as consultant to other USGS offices on special problems such as developing seepage estimates for Cedar Lake in Washington; analyzing limited data from pumping tests in Puerto Rico, Virgin Islands, North Carolina and Florida; and evaluating tracer test data in Colorado

Professional Societies

American Society of Civil Engineers (Life Member since January 2001)
American Geophysical Union
Association of Ground Water Scientists and Engineers
International Association of Hydrogeologists
Geological Society of America (Fellow since May 1993)
Sigma Xi

STAVROS S. PAPADOPULOS
Groundwater Hydrologist

PUBLICATIONS

Papadopulos, S.S, J.W. Houlihan, GD. Bennett, and G.V.Costanzo, 1997, **Evaluation of Hydrogeologic Conditions and of Remedial Alternatives at Kodak Park, Rochester, New York**. ASCE, Aesthetics in the Constructed Environment, Proceedings of the 24th Annual Water Resources Planning and Management Conference, Houston, Texas, April 6-9, 1997, pp. 370-375.

Papadopulos, S.S., 1992, **Performance of a Plume Removal System in a Sand and Gravel Aquifer** (abstract). Program, Aquifer Restoration: Pump -and-Treat and the Alternatives, National Ground Water Association, 44th Annual Convention and Exposition, Las Vegas, Nevada, September 30 - October 2, 1992.

Papadopulos, S.S. and L.A. Wood, 1991, **Progress in Remediating a Sand and Gravel Aquifer** (abstract). *Abstracts with Programs,* 1991 Geological Society of America Annual Meeting, San Diego, California, p. A187.

Andrews, C.B., D.L. Hathaway, and S.S. Papadopulos, 1990**, Modeling the Migration and Fate of Polychlorinated Biphenyls in the Subsurface.** PCB Forum, 2nd International Conference for the Remediation of PCB Contamination, Houston, Texas, April 2-3.

Konikow, L.F., and S.S. Papadopulos, 1988, **Scientific Problems**. in *The Geology of North America*, Geological Society of America, v. O-2, Chap. 49, pp. 503-508.

Harris, R.H., J.V. Rodricks, C.S. Clark, and S.S. Papadopulos, 1987, **Adverse Health Effects at a Tennessee Hazardous Waste Disposal Site.** in *Health Effects from Hazardous Waste Sites*, by J.B. Andelman and D.W. Underhill, Lewis Publishers, pp. 221-240. (Paper presented at Fourth Annual Symposium on Environmental Epidemiology, University of Pittsburgh Graduate School of Public Health, Pittsburgh, Pennsylvania, May 1983).

Bredehoeft, J.D., S.S. Papadopulos, and H.H. Cooper, Jr., 1982, **Groundwater: The Water-Budget Myth**. in *Scientific Basis of Water-Resource Management, Studies in Geophysics*, National Research Council, Geophysics Study Committee, National Academy Press, Washington, DC, p. 51.

Larson, S.P., S.S. Papadopulos, and J.E. Kelly, 1981, **Simulation Analysis of a Double-Transmissivity Concept for the Madison Aquifer System** (abstract). Proceedings, 10th Annual Rocky Mountain Ground-Water Conference, April 30 - May 2, Laramie, Wyoming, p. 76.

Kelly, J.E., S.S. Papadopulos, W.L. Burnham, and K.E. Anderson, 1981, **The Evolution of a Double-Transmissivity Concept for the Madison Aquifer System** (abstract). Proceedings, 10th Annual Rocky Mountain Ground-Water Conference, april 30 - May 2, Laramie, Wyoming, pp. 74-75.

Bredehoeft, J.D. and S.S. Papadopulos, 1980, **A Method for Determining the Hydraulic Properties of Tight Formations**. *Water Resources Research*, v. 16, no. 1, pp. 233-238.

Papadopulos, S.S. and S.P. Larson, 1978, **Aquifer Storage of Heated Water: Part II -Numerical Simulation of Field Results**. *Ground Water*, v. 16, no. 4, pp. 242-248.

Papadopulos, S.S., 1977, **Predictive Modeling in Hydrogeology--A Brief Review** (abstract). *Abstracts with Programs, 1977* Geological Society of America Annual Meeting, Seattle, Washington, v. 9, no. 7, p. 1124.

Larson, S.P., S.S. Papadopulos, H.H. Cooper, Jr. and W.L. Burnham, 1977, **Simulation of Wastewater Injection into a Coastal Aquifer System near Kahului, Maui, Hawaii.** Proceedings, ASCE 25th Annual Hydraulic Division Specialty Conference on the "Hydraulics in the Coastal Zone", Texas A&M University, College Station, Texas, August 10-12, pp. 107-116.

STAVROS PAPADOPULOS

Groundwater Hydrologist

Larson, S.P., T. Maddock III, and S.S. Papadopulos, 1977, **Optimization Techniques Applied to Ground-water Development.** Memoires XXIII. Congress of the International Association of Hydrogeologists, Birmingham, England, July 24-30, v. XIII, Part I, pp. E57-E66.

Papadopulos, S.S., 1976, **Flow to Water-Table Wells Deriving their Discharge from Capture** (abstract). in *Advances in Ground-water Hydrology*, edited Z. A. Saleem, American Water Resources Association, Minneapolis, Minnesota, p. 329.

Papadopulos, S.S., 1975, **The Energy Potential of Geopressured Reservoirs: Hydrogeologic Factors**. Proceedings of the 1st Geopressured Geothermal Energy Conference, University of Texas, Austin, Texas, June 2 4, pp. 173-192.

Papadopulos, S.S., R.H.Wallace, Jr., J.B. Wesselman, and R.E.Taylor, 1975, **Assessment of Onshore Geopressured-Geothermal Resources in the Northern Gulf of Mexico Basin.** in *Assessment of Geothermal Resources of the United States - 1975*, U.S. Geological Survey Circular 726, pp. 125-146.

Papadopulos, S.S. and I.J.Winograd, 1974, **Storage of Low-level Radioactive Wastes in the Ground: Hydrogeologic and Hydrochemical Factors**, with an appendix on **The Maxey Flats, Kentucky, Radioactive Waste Storage Site: Current Knowledge and Data Needs for a Quantitative Hydrogeologic Evaluation.** U.S. Environmental Protection Agency report 520/3-74-009, 49 p.

Papadopulos, S.S., R.R. Bennett, F.K. Mack, and P.C. Trescott, 1974**, Water from the Coastal Plain Aquifers in the Washington, D.C., Metropolitan Area**. U.S Geological Survey Circular 697, 11 p.

Wolff, R.G. and S.S. Papadopulos, 1973, **Reply to T.L. Holzer's Comments on 'Determination of the Hydraulic Diffusivity of a Heterogeneous Confining Bed' by R.G. Wolff and S.S. Papadopulos**. *Water Resources Research*, v. 9, no. 4, p. 1106.

Papadopulos, S.S., J.D. Bredehoeft, and H.H. Cooper, Jr., 1973, **On the Analysis of 'Slug Test' Data**. *Water Resources Research*, v. 9, no. 4, pp. 1087-1089.

Pinder, G.F., E.O. Frind, and S.S. Papadopulos, 1973**, Functional Coefficients in the Analysis of Ground-water Flow**. *Water Resources Research*, v. 9, no. 1, pp. 222-226.

Wolff, R.G. and S.S. Papadopulos, 1972**, Determination of the Hydraulic Diffusivity of a Heterogeneous Confining Bed**. *Water Resources Research*, v. 8, no. 4, pp. 1051-1058.

Papadopulos, I.S., W.R. Larsen, and F.C. Neil, 1969**, Ground-water Studies - Chicagoland Deep Tunnel System**. *Ground Water*, v. 7, no. 5, pp. 2-15.

Papadopulos, IS. and R.E. Aten, 1968**, Investigation Program for Aquifer Protection Requirements, Chicagoland Deep Tunnel Plan**. *Ground Water*, v. 6, no. 3, pp. 4-9.

Papadopulos, I.S. and H.H. Cooper, Jr., 1968, **Reply to T.N. Narasimhan's Discussion of Paper Entitled "Drawdown in a Well of Large Diameter by I.S. Papadopulos and H.H. Cooper, Jr."** *Water Resources Research*, v. 4, no. 2, p. 461.

Papadopulos, I.S., 1967, **Drawdown Distribution Around a Large-Diameter Well**. Proceedings, National Symposium on Ground-Water Hydrology, San Francisco, California, November 6-8, pp. 157-168.

Cooper, H.H. Jr., J.D. Bredehoeft, and I.S. Papadopulos, 1967**, Response of a Finite-Diameter Well to an Instantaneous Charge of Water**. *Water Resources Research*, v. 3, no. 1, pp. 263-269.

Papadopulos, I.S. and H. H. Cooper, Jr., 1967**, Drawdown in a Well of Large Diameter**. *Water Resources Research,* v. 3, no. 1, pp. 241-244.

Bredehoeft, J.D., H.H. Cooper, Jr., and I.S. Papadopulos, 1966, **Inertial and Storage Effects in Well-Aquifer Systems: An analog Investigation**. *Water Resources Research*, v. 2, no.4, pp. 697-707.

STAVROS PAPADOPULOS
Groundwater Hydrologist

PUBLICATIONS -- Page 3

Papadopulos, I.S., 1966, **Nonsteady Flow to Multiaquifer Wells**. *Journal of Geophysical Research*, v. 71, no. 20, pp. 4791-4797.

Stallman, R.W. and I.S. Papadopulos, 1966**, Measurement of Hydraulic Diffusivity of Wedge-Shaped Aquifers Drained by Streams**. U.S. Geological Survey Professional Paper 514, 50 p.

Bredehoeft, J.D., H.H. Cooper, Jr. and I.S. Papadopulos, 1965, **Inertial Effects in Well-Aquifer Systems: An Analog Study** (abstract). *Abstracts with Programs 1965*, Geological Society of America Annual Meeting, November 4-6, Kansas City, Missouri, pp. 16-17.

Papadopulos, I.S., 1965**, Nonsteady Flow to a Well in an Infinite Anisotropic Aquifer.** Proceedings, International Symposium on Hydrology of Fractured Rocks, Dubrovnik, Yugoslavia, International Association of Scientific Hydrology, v. 1, pp. 21-31.

Bredehoeft, J.D., I.S. Papadopulos, and J.W. Stewart, 1965, **Hydrologic Effects of Ground-Water Pumping in Northwest Hillsborough County, Florida.** U.S. Geological Survey Open-File Report, 23 p.

Cooper, HH., Jr., J.D. Bredehoeft, I.S. Papadopulos, and R.R. Bennett, 1965**, The Response of Well-Aquifer Systems to Seismic Waves**. *Journal of Geophysics*, v. 70, no. 16, pp. 3915-3926. Also reprinted in *The Great Alaska Earthquake of 1964*, Part A, Publication 1603, National Academy of Sciences, 1968, pp. 122-132.

Bredehoeft, J.D., H.H. Cooper, Jr., I.S. Papadopulos, and R.R. Bennett, 1965**, Seismic Fluctuations in an Open Artesian Water Well**. U.S. Geological Survey Professional Paper 525-C, pp. C51-C57.

Bredehoeft, J.D. and I.S. Papadopulos, 1965**, Rates of Vertical Groundwater Movement Estimated from the Earth's Thermal Profile**. *Water Resources Research*, v. 1, no. 2, pp. 325-328.

Papadopulos, I.S., 1963**, Preparation of Type Curves for Calculating T/S of a Wedge-Shaped Aquifer.** U.S. Geological Survey Professional Paper 475-B, Article 54, pp. B196-B198.

Hantush, M.S. and I.S. Papadopulos, 1963, **Flow of Ground Water to Collector Wells (Closure)**. Proceedings, American Society of Civil Engineers, *Journal of the Hydraulics Division*, HY4, p. 225-227.

Hantush, M.S. and I.S. Papadopulos, 1962, **Flow of Ground Water to Collector Wells**. Proceedings, American Society of Civil Engineers, *Journal of the Hydraulics Division*, HY5, pp. 221-224.

APPENDIX B

Appendix B

Electronic Files and Other Documents Provided by Natural Resources Defense Council and Sierra Club

Appendix B
Electronic Files and Other Documents
Provided by the
Natural Resources Defense Council and the Sierra Club

❑	Folder Name
▪	File Name
- or [ ]	Notes

Compact Disk 1 – 20031009162431

Tracer dye study data + information from Natural Resources Defense Council

- ❑ Data and calculations 2003
  - ❑ Fitted_Data
  - ❑ General wells and rainfall
  - ❑ Inventory [TROLL BIN FILE INVENTORY]
  - ❑ QTRACER2
    - ❑ Tracer
      - ❑ firstday
  - ❑ Rainfall_April_2003
  - ❑ SCADA [Pumping data, Pump 1 – 15]
  - ❑ Troll_Data
    - ❑ Troll Bin Files
    - ▪ RE Completed Inventory list of files.msg
    - ▪ Troll_Files.zip
  - ❑ Well1
    - ❑ work
    - ▪ SCENARIO 1.doc
    - ▪ site1.zip
    - ▪ well1.gwv
  - ❑ well2
    - ❑ work
    - ❑ work3mgd
    - ▪ SCENARIO 2.doc
    - ▪ well2.gwv
  - ❑ well3
    - ❑ work
    - ❑ work3mgd
    - ▪ SCENARIO 3.doc
    - ▪ Well3.gwv
  - ❑ well4
    - ❑ work
    - ❑ work3mgd
    - ▪ SCENARIO 4.doc
    - ▪ Well4.gwv
  - ❑ work60
  - ▪ cooper-jacob guesstimate.msg
  - ▪ Fitted_Data.JNB
  - ▪ Fitted_Data_ALL.JNB
  - ▪ pdf of electromagnetic flowmeter.msg
  - ▪ pump60.gwv

- ❑ Dye Tracer 1999
  - AWRA_2003.pdf
  - Dye_rpt_hk0816r.doc
  - DyeTracer.xls
  - Summary of Dye Tracer 1999.rtf
- ❑ Dye tracer 2003
  - ❑ AWWARF Proposal
    - ❑ Edwards Aquifer
    - ❑ Resumes
    - ❑ Support Letters
    - *Many other files*
  - ❑ Dye tracer 2003 Analysis
    - ❑ Conclusions re travel time
    - ❑ Excel spreadsheets summarizing results
      - Dye_Conc2.xls [Data and Charts: NWWF Well #9, samples before & after shutoff]
      - Dye_Conc3.xls [Data and Charts: NWWF Well #9, samples before & after shutoff]
      - Dye_Conc4.xls [Data and Charts: NWWF Well #9, samples before & after shutoff]
      - Dye_Conc.xls [Data and Charts: NWWF Well #9, samples before & after shutoff]
      - Dye_Conc_Fredrick.xls [Data and Charts]
      - Inventory.xls
      - Prelim WTP data.xls [Data and Charts]
      - well_on_and_off_data.xls [Pumps 1-15]
    - ❑ Mass calculation
      - mass calculation you were looking for.msg
      - mass_calculation.xls
      - mass_calculations.doc
    - ❑ Models
      - Fracture Flow Models.doc
      - Modeling.Karst.Aquifers_burns.zip (ppt)
      - Risk Assessment for the NWWF area-hillol.doc
    - ❑ Next steps
      - Status of Aquifer Straining Study.doc
  - ❑ Interim Reports
    - AWWARF_progress_report_Metge_05092003.doc [REPORT: Evaluation of Pathogen Transport in Karst Flow Zones of the Biscayne Aquifer Near the Northwest Well Field, Miami-Dade County, Florida, PROJECT 2920, Second INTERIM REPORT, May 2003, U.S. Geological Survey
    - AwwaRF-interim-101502.doc [REPORT:… FIRST INTERIM REPORT, October 2002]
    - CWRS_2080SI900_May.doc [REPORT: PROJECT PROGRESS, (Dec-May.), Updated 5/12/03]
    - Harvey-2003-05-10- Progress Rpt to DERM.doc
    - NWWF1_COMBO.pdf
    - Periodic-nwwf012703.doc [REPORT: FIRST PERIODIC REPORT, JANUARY 2003]
  - ❑ Project Tracking
    - ❑ Equipment
  - ❑ Report_April
    - AWWARF_April.doc [REPORT: Second INTERIM REPORT, May 2003]
    - Figure 1.doc [Figure 1: Location of Wells Where Pressure Transducers Were Installed.]
    - G-3772_COMBO.pdf
    - G-3773_COMBO.pdf
  - ❑ USGS Proposal
    - 2002-0310 - mass_calculations (H Guha).doc
    - USGS Final Proposal BCCversion-061202.doc
    - USGS MOA Memo-Draft1.doc
  - ❑ WASD Cost Sharing
  - Corrected version1 of CH2 report.doc

  - detailed work schedule (tentative) for tracer test ---.msg
  - Draft Technical Memo for proposed upcoming North West Well .msg
  - draft_techmemo_healthdept.doc
  - Dye 2003 location sketch.doc
  - Final test schedule -- April 10th to May 1st .msg
  - NWWFMicro051502.doc
  - Review of Amount of Dye Tracer Used.doc
  - techmemo_healthdept.doc
  - tracer 2003 location sketch 11X17 land.doc
  - tracer_test_design.pdf
  - Tracers Injection at Northwest Wellfield.msg
  - Tracers Test x-section.doc
- Presentations
  - Agenda.doc
  - AwwaRF_meeting notes101702.doc
  - DERM.ppt
  - draft.pps
  - zoom.wmf

Compact Disk 2 - NWWF 1

- AwwaRF
  - list_of_reviewersl.pdf
- Conservative_Test
  - Instrumentation
  - Sampling
  - Test data **[2003 data]**
    - apr 2003 pumpage.pdf [NW1 to NW15]
    - Conc_Calc.pdf
    - DERM.pdf
    - Dilutions.opx
    - Distances.pdf [Distances to Production Well #9]
    - Drawdowns2_Calcs.pdf
    - Drawdowns2_Data.pdf
    - Drawdowns_data2.pdf [Medley Wellfield MDWSA, Wells near #8]
    - Drawdowns_data.pdf [Medley Wellfield MDWSA, Well 1000ft E of #8]
    - Dye_Conc.pdf [well #9 and other samples from NWWF]
    - Dye_Conc_analysis.pdf [sample # 1 – 52]
    - Dye_Conc_Fredrick_MOdata.pdf
    - Dye_Conc_MO.pdf [sample # 1 – 52]
    - Dye_Conc_Shidmadzu_data.pdf
    - Dye_Conc_shimadzu_results.pdf [sample # 1 – 52]
    - Dye_Conc_USGS.pdf [Samples from NWWF Production Well #9, before and after shutoff]
    - Results_031003.pdf
    - Supplies_ColePalmer.pdf
    - Supplies_Fisher.pdf
    - Tape_downs.pdf
    - TrollCalibration.pdf
    - Well_Characteristics.pdf [depth, casing, diameter of wells]
  - Test_planning
- Cores
  - coregroup1-10 [unable to open files (.cpt)]
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  - PW12

- Core in Box [photos of cores]
- Slabbed Core [photos of cores]
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#2 Oct. 1, 2003 SFWMD Presentation, AQUIFER STRAING STUDY, Barbara Lang

- SFWMD.PPT
  [PowerPoint Presentation, *Miami-Dade County, April 23, 2003, Northwest Well Field—Lake Belt area*]

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    - Porosity-40%
    - Input Variables.doc
    - Time Schedule.xls
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      - Flowrate Summary.xls
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    - Peclet No. = 20
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    - Moench_Radial.exe
- Maps
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  - NWWF_Map1.jpg [map of well locations]
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- proposal
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- Qtracer
  - Dye_Conc.pdf [sample # 1 – 52]
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- Description and Analysis of Preliminary Tracer Trials Conducted at the Northwest Wellfield Miami-Dade County Florida, Miami-Dade County Department of Environmental Resources Management, Water Supply Section, May 1999, 16 p.

- Description and Analysis of Full-Scale Tracer Trials Conducted at the Northwest Wellfield Miami-Dade County Florida, Miami-Dade County Department of Environmental Resources Management, Water Supply Section, August 2000, 20 p.

- Injection Wells1.pdf [Logs of wells G3773 and G3772]
- Memo – Summary of April 2003 NWWF Tracer Test1.pdf [Summary of the April 2003 NWWF Tracer Test and the "Red Dye Incident" at the Preston WTP, Memo from Julie Baker, Special project Administrator 1 to John W. Renfrow, P.E., Director Environmental Management, July 25, 2002]
- Well map comparison1.pdf [Well Hydrographs 4/1/03 - 5/15/03]
- Pages 106-107 of the Water Facilities Master Plan by CH2MHill [CH2Mhill, 2003, Water Facilities Master Plan, Volume 1 – Report, prepared for Miami Dade Water and Sewer Department, September]

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WATER SUPPLY

Studies: Mining expansion poses water bug risk

New studies suggest that expanded mining will heighten contamination risks for the public water supply, but industry leaders and county and federal regulators are downplaying the threat.

Posted on Sun, Aug. 31, 2008

By CURTIS MORGAN

cmorgan@MiamiHerald.com

Blasting 80-foot holes near a water supply for a million people likely raises contamination risks that the county's no-mining buffer zone is too small to prevent, federal scientists concluded in newly published research on rock mining in Northwest Miami-Dade.

A trio of studies by the U.S. Geological Survey echo some of the key findings of Senior U.S. District Judge William Hoeveler, whose order last year to halt mining in hundreds of acres surrounding the county's largest well field was overturned in May by an appeals court.

Environmentalists seized on the research as fresh ammunition in a long-running legal battle over industry plans to excavate 20,000-plus acres of quarries adjacent to the Everglades and the Northwest well field. Mining companies dismissed the studies as old news, overblown and flawed.

Miami-Dade's water department and the U.S. Army Corps of Engineers, which regulates the industry, insisted that the research offered no compelling new evidence that rock pits expose the public water supply to any imminent health risk.

The prime focus of the studies -- a nasty, tough-to-kill parasite called *cryptosporidium* that has sickened people drinking from some tainted municipal water systems -- has never been detected in 14 years of testing, said John Renfrow, director of Miami-Dade's Water and Sewer Department. ''The water is perfectly safe to drink,'' he said.

But attorney Paul Schwiep said the studies validate the ''grave concerns'' raised by a Miami federal judge when he imposed an expanding no-mining zone around the wells in July 2007.

''This is unassailable confirmation from an independent government agency that Judge Hoeveler was right,'' said Schwiep, a Miami attorney who represents the Sierra Club, Natural Resources Defense Council and the National Parks Conservation Association, which sued the Corps in 2002 over the mining approvals.

Schwiep said he intends to ask the Corps to enforce the judge's boundaries -- at least until Hoeveler completes a new review of the case requested by the 11th Circuit Court of Appeals in Atlanta. It seems unlikely the Corps will grant the request.

Last year, the agency issued the draft of a new court-ordered review that concluded the industry's plans to excavate a chain of massive quarries bordering the well field would pose no significant environmental or health risks. The Corps is considering plans that could quadruple the 5,700 acres of rock pits the agency has already permitted.

Leah Oberlin, a Corps' project manager for an area miners dubbed ''the Lake Belt,'' said federal regulators would incorporate the USGS studies into the final review, expected to be completed in November or December.

But, she said, ``There is no surprise in these studies. They basically reinforce concerns we were already aware of.''

The basic results of the studies, commissioned by Miami-Dade County and conducted in 2003 and 2004, have been known publicly since 2006, but the USGS's formal findings weren't published until this month in the journal Water Resources Research.

DYE EXPERIMENT

The most eye-opening test occurred in April 2003, when a harmless red dye was injected into a test well. It was expected to trickle underground to the county's string of production wells over two, perhaps three days. Instead, a strong concentration shot there in four to six hours, stunning scientists and residents alike by tinting canals and tap water shades of red and pink.

''We realized that things travel a lot faster than was originally thought,'' said Allen Shapiro, a USGS research hydrologist based in Virginia who coauthored the studies. Not unlike a sponge, the limestone that makes up the vast Biscayne Aquifer is pocked with holes, cracks and voids he likened to ``superhighways where you have a lot of traffic moving quickly''

While the dye test made the nightly news and headlines, a more sophisticated follow-up the next year showed that tiny plastic ''microspheres'' modeled to mimic *cryptosporidium*, which has been linked nationwide to outbreaks of illness marked by severe diarrhea, also moved quickly underground and that the limestone did a marginal job of filtering it out.

That is a potential problem because the hardy organism can survive for months in water, cause infections in very small concentrations and is resistant to chlorine that Miami-Dade and most municipal systems commonly use to treat underground water supplies.

The tests, the USGS team concluded, showed the 2,500-foot mining setback zone the county established in 1980 -- before the parasite became a public health concern -- were based on ''oversimplified'' models and ''not sufficient'' to safeguard the wells from contamination.

The studies do not attempt to calculate how much the rock pits raise contamination risk or specifically how large the protective zone should be. But one draft of one county modeling study in 2006 suggested the zone might be several miles too small.

The Miami-Dade Limestone Products Association, a coalition of companies that have excavated the area for decades, issued a release calling the USGS studies riddled with errors and the results `irresponsibly exaggerated.''

Among a litany of complaints, miners contend federal scientists pumped 100 times too much dye underground than needed for testing and 400 million times too many microspheres -- all injected too close to an operating well.

The county's well field zones block most obvious sources of parasites, such as sewage plants and cattle pastures.

But the expanding network of massive rock pits could be vulnerable to exposure from wild animals, trespassers or even hurricane flood waters and Renfrow acknowledged they were drawn up decades ago with industrial pollution, not pathogens such as *cryptosporidium* in mind.

''This is a different ballgame,'' he said. `This is not chemical, this is bugs. You can approach it in different ways.''

Instead of bigger buffer zones, which would require buying a lot of expensive land from mining companies, the county's plan is to upgrade its water treatment plants -- an expected $125 million-plus tab mining companies are in line to pick up. Though the industry maintains that its quarries pose no threat to drinking water, its lobbyists helped push a bill through the Legislature in 2006 that will pay for the upgrades through increased state fees on mined rock.

`PROACTIVE'

''Right now, we've contracted with a consulting engineering firm to start the design of these treatment systems for these bugs, even though we haven't detected them,'' said Renfrow. `We're being proactive.''

Under federal law, municipal drinking water systems that draw from lakes and rivers are required to install more sophisticated treatment systems to control *cryptosporidium*, *giardia* and other such pathogens that frequently spread through animal or human waste.

It's not mandatory for underground supplies, which are considered less vulnerable to sewage or waste spills. But the county acknowledges that at full ''mine-out,'' decades from now, the vast open waters and aquifer would be so directly connected that mandatory treatment for the parasite would be likely.

The county does not yet have an estimate for when upgrades would come on line but construction is expected to take several years.

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Beneath the Pink Underwear

Water pollution is more serious than the WASD plan would have you believe

By Steven Dudley *Thursday, Jun 5 2003*

If you didn't know better, you'd have thought the news had it covered. It was April 23, and red dye was streaming through faucets and showerheads in northern Miami-Dade. Some underwear turned pink in the washing machines. On TV, there were live pictures of red water along the edges of the Miami River and in the Northwest Wellfield. The county reacted quickly and calmed the storm. The dye was harmless, the Water and Sewer Department (WASD) said. "Residents need not boil their water," NBC 6 told viewers.

But beneath the pink underwear lay another story, which though less sexy, is much more important. It involves a complicated test by WASD, the Department of Environmental Resources Management (DERM), and the United States Geological Survey (USGS) to find out how quickly water moves through limestone near the Northwest Wellfield. The preliminary results of this test provoked nothing less than shock in the scientists who performed it. Their reactions had more to do with drinking water, taxes, and the multimillion-dollar limestone mining industry than with the color of folks' unmentionables.

For years, state and county officials as well as environmental agencies have expressed concern over the Northwest Wellfield. It is located in an area that services just over a million residents in North Dade, and is surrounded by rock quarries. Nearly half the state's limestone comes from these mines; the stone is used for road construction and concrete. But the mines are also a danger to the water supply. "Quarry lakes have the potential to contain substantially more disease-causing organisms than groundwater," former County Manager Merrett Stierheim wrote in July 2000 to the Army Corps of

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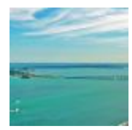
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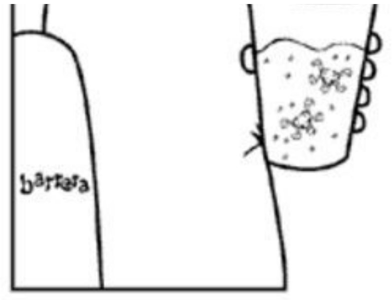
Engineers, which issues permits for the mining area. "One such organism, *cryptosporidium*, may survive up to one year in the surface water and had been detected in canals in Miami-Dade County."

Cryptosporidium is a single-celled parasite. Once infected, humans and animals carry it in their intestines. It's passed through contact with infected feces. While it causes watery diarrhea and drowsiness in most, it can also kill. In 1993 several people died from a massive infection in Milwaukee. Another 400,000 people were infected. In 1987 13,000 people caught it in a small town in Georgia.

Stierheim's concerns about protozoa were echoed by the Florida Department of Health and the Environmental Protection Agency. So worried were Stierheim and the EPA that they recommended denying miners work permits to expand until more studies were done. The Army Corps of Engineers issued some of the permits anyway in 2002. At the heart of the issue is whether these protozoa can survive long trips from the mines through the limestone to our drinking water. Initial results of the red dye test seemed to indicate they can.

On the morning of April 22, one day before people noticed their underwear was stained, USGS scientists drilled a test well about 100 meters from the Northwest Wellfield and injected what is indeed a harmless dye known as rhodamine into the limestone. Based on previous DERM water models for North Miami-Dade, they expected the dye would take two to three days to appear. The first traces showed up in about four hours.

Understandably, DERM and WASD don't want to talk much about the test. After all, these are preliminary results. Several more will follow, as well as lab analyses. In all, the study, which is being conducted by USGS, will take until 2005 to complete. Then the county can issue its three-year review on the rock-mining permits. In the meantime, DERM and WASD continue to rigorously test the wellfields for protozoa. "This is not a two-dimensional issue," says Jim Ferro, special projects administrator for DERM. "This could be multidimensional."



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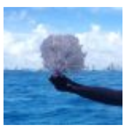

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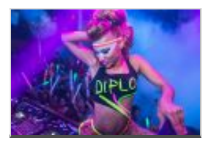

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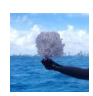

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Which means the issue is complicated, but beneath the jargon are a myriad of straightforward issues the county may be loath to face. The most troublesome are the models DERM has been using to protect drinking water for over one million residents in North Miami-Dade; they're not simply wrong, they're way wrong. The county has what are called "cones of influence" around the wellfields; these boundaries are determined by how quickly water can reach the well, calculated in days. County ordinance requires that there be a minimum 30-day travel time between the mines and the Northwest Wellfield. Such a long time would theoretically kill off protozoa like *cryptosporidium* that might enter the wells. But these travel times are based on old models. If two days' travel time now means four hours, where does that leave us?

"Miami-Dade County seems to be at best sticking its head in the sand," says Brad Sewell of the Natural Resources Defense Council, based in New York City, "at worst, handing over the safety of the water supply to the mining industry."

Sewell's council and two other environmental groups filed suit against the Fish and Wildlife Service and the Army Corps of Engineers last year for issuing rock-mining permits near federally protected wetlands in the Everglades. He insists the initial results of the red dye test illustrate a serious point: "Regardless of this particular test, it's absolutely clear to everyone involved that allowing [a large] amount of mining is not compatible with protecting the wellfield."

Ironically Stierheim could see this coming years ago. He also saw the possible repercussions. In his 2000 letter to the Army Corps of Engineers, the then-county manager noted that granting licenses to the mining companies "has the potential to increase the risk of water quality contamination at the wellheads and result in the necessity for upgrading the water treatment plants to treat for disease."

The unexpected results of the red dye test could not have come at a worse time for the county. It's still struggling with its most basic problem: water supply. On June 10 WASD will present its master plan to the county commission's operations and environmental committee, and in July, WASD will show the plan to the commission. Its 250-plus pages are designed to reassure the commission that the water supply is in good shape until 2020. But among environmentalists, there are already rumblings that the plan is littered with half-truths and suspicious calculations. Its most noticeable weakness is that it relies on unproven technology like the aquifer storage and recovery (ASR) system, designed to capture water in the wet season, inject it into the ground, then recover it for use during the dry season. ASR may seem like a Spielberg film, but it's how the county hopes to make up for an expected water shortfall in the coming years. What's more, as in the case of red dye, environmentalists are feeling left out of the process. "Short of litigation," says Alan Farago of the Sierra Club Florida Chapter, "I don't see how we can get any input on this."

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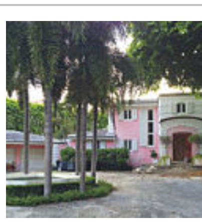

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Assessing the Vulnerability of a Municipal Well Field to Contamination in a Karst Aquifer

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Key Terms: ***Karst Aquifers, Ground-Water Tracers, Pathogens, Well Field Protection***

ABSTRACT

Proposed expansion of extractive lime-rock mines near the Miami–Dade County Northwest well field and Everglades wetland areas has garnered intense scrutiny by government, public, environmental stakeholders, and the media because of concern that mining will increase the risk of pathogen contamination. Rock mines are excavated to the same depth as the well field's primary producing zone. The underlying karst Biscayne aquifer is a triple-porosity system characterized by (1) a matrix of interparticle porosity and separate vug porosity; (2) touching-vug porosity that forms preferred, stratiform passageways; and, less commonly, (3) conduit porosity formed by thin solution pipes, bedding-plane vugs, and cavernous vugs. Existing ground-water flow and particle tracking models do not provide adequate information regarding the ability of the aquifer to limit the advective movement of pathogens and other contaminants. Chemical transport and colloidal mobility properties have been delineated using conservative and microsphere-surrogate tracers for *Cryptosporidium parvum*. Forced-gradient tests were executed by introducing conservative tracers into injection wells located 100 m (328 ft) from a municipal-supply well. Apparent mean advective velocity between the wells is one to two orders of magnitude greater than previously measured. Touching-vug, stratiform flow zones are efficient pathways for tracer movement at the well field. The effective porosity for a continuum model between the point of injection and tracer recovery ranges from 2 to 4 percent and is an order of magnitude smaller than previously assumed. Existing well-field protection zones were established using porosity estimates based on specific yield. The effective, or kinematic, porosity of a Biscayne aquifer continuum model is lower than the total porosity, because high velocities occur along preferential flow paths that result in faster times of travel than

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can be represented with the ground-water flow equation. Tracer tests indicate that the relative ease of contaminant movement to municipal supply wells is much greater than previously considered.

1. INTRODUCTION

Florida's largest municipal well field, the Northwest well field in north-central Miami–Dade County, is contained within a marginal wetland area (Figure 1). The well field is located on the eastern edge of a 231-km^2 (89-mi^2) Lake Belt "mining district" area that buffers intensively developed urban areas from critical ecosystems and wetland areas of the Florida Everglades to the west. The highly transmissive Biscayne aquifer underlies the well field and has been designated a sole source of potable water by the U.S. Environmental Protection Agency (U.S. EPA) (Federal Register Notice, 1979).

South Florida's extractive limestone mine industry is permitted, by regulatory authority of the U.S. Army Corps of Engineers, to remove limestone rock on adjacent, private land. Extraction activities are creating borrow-pit "lakes" that are up to 12–18 m (40–60 ft) deep, some of which will be in close proximity to the 60-day well-field production zone. There is concern that municipal supply wells will be directly influenced by the quality of surface water contained within these mines if excavation near the Northwest well field continues as planned. Some existing borrow-pit lakes are within 247 m (810 ft) of production wells (Figure 2).

The U.S. EPA requires use of enhanced disinfection and filtration treatment processes to remove pathogenic organisms if ground-water withdrawals from municipal well fields are determined to be under the direct influence of surface water (Federal Register Notice, 2000). Microbial contamination of ground water is a serious public health concern and the cause for more than half of the Nation's waterborne disease outbreaks (Macler and Merkle, 2002).

The U.S. Geological Survey, in cooperation with the Miami–Dade Department of Environmental Resources Management, Miami–Dade Water and Sewer Department, and the American Water Works Research Foundation, have engaged in an integrated study to (1) assess transport of solute contaminants and pathogenic protozoa within a highly permeable, karstic limestone aquifer and (2) examine the importance of straining or other filtration mechanisms that may or may not impede microbial advective movement. This article outlines project objectives, discusses the status of laboratory and field activities, and examines well-field vulnerability-assessment issues that pertain to the Biscayne aquifer in north-central Miami–Dade County, Florida.

Fifteen municipal water-supply wells compose the Northwest well field, with an approximate combined permitted capacity of 587,740 m^3/day (155 Mgal/day) and a planned capacity of 851,700 m^3/day (225 Mgal/day). In 2003, daily withdrawals averaged about 242,300 m^3/day (64 Mgal/day). Regional ground-water movement is eastward from the Everglades and Pennsuco wetland areas (Figure 1). Conveyance canals that border the well field in all directions help to recharge it. The eastern canal is designed to maintain stage levels that limit eastward expansion of the cone of depression during the dry season. Cone enlargement into urban areas could increase the risk of well-field contamination (Walters, 1987).

2. VULNERABILITY-ASSESSMENT UNCERTAINTIES IN THE NORTHWEST WELL FIELD

Process-based vulnerability assessments generally contain two principal sources of uncertainty (National Research Council, 1993). One source of uncertainty is associated with application of numerical or analytical models that are not well suited to address physical system complexities. Miami–Dade County has used ground-water flow and particle-tracking models to identify flow path lines and to define time-of-travel protection zones (Camp, Dresser, and McKee, Inc., 1982, 1985; CH2M HILL, 2001). However, there is an important limitation in an equivalent continuum model when it is applied to triple-porosity aquifers (principally matrix and touching-vug porosity with rare conduit porosity visible in the Northwest well field based on digital borehole images). For example, an inherent assumption with a finite-difference ground-water flow model is that the aquifer can be treated as an equivalent porous medium; namely, the aquifer is formed of porous material, in which void space is uniformly distributed. Additionally, the equation assumes laminar flow, which may not be the case in conduits that may behave as pipes or open channels. Therefore, the conventional ground-water flow equation may not be valid for the Biscayne aquifer's entire flow domain.

Equivalent continuum, single-porosity models do provide reasonable volume-averaged approximations of large-scale ground-water flow (National Research Council, 1996). Under the continuum approach, however, the heterogeneity of a generalized karst-aquifer conceptual model is highly simplified, even though it may be characterized by high-velocity, turbulent ground-water flow within solution-enhanced fractures, conduits, or stratiform passageways. Near- and very near-field conditions may be poorly represented in the continuum approach (Cacas et al., 1990a, 1990b; Bear, 1993), and patterns of simulated flow and particle movement are marked by latent uncertainty (Anderson and Woessner, 1992).

The second source of uncertainty is associated with the quality and spatio-temporal relevance of data that are available to quantify vulnerability. Preexisting field data may not necessarily provide the physical parameters best

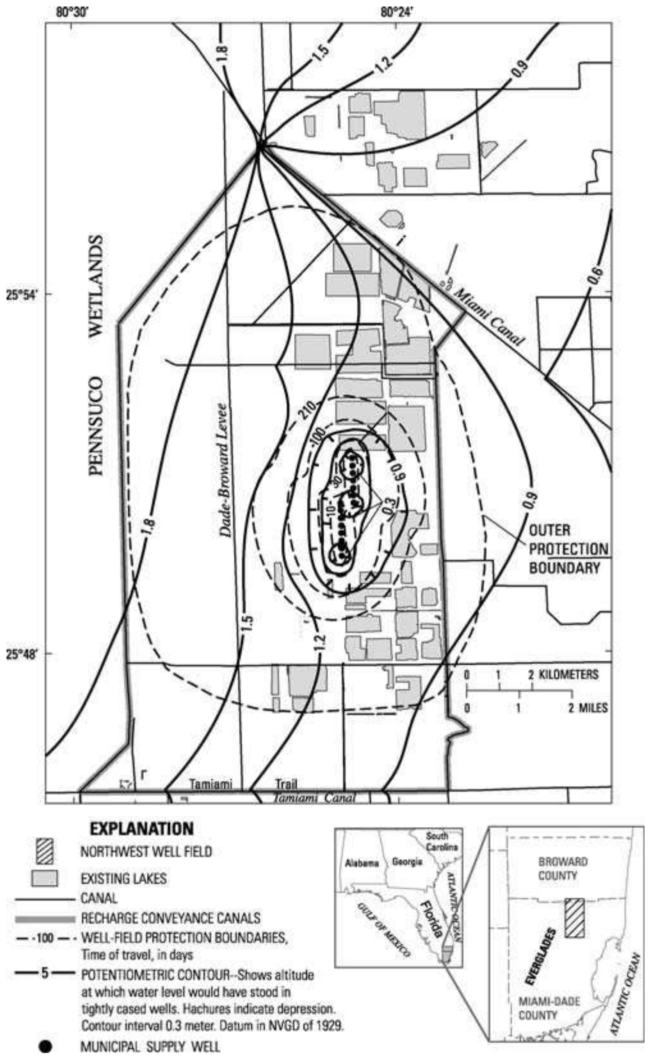

Figure 1. Location of the Northwest well field, the potentiometric surface on April 22, 2003, and existing well-field protection boundaries in north-central Miami–Dade County.

suited to assess the risk of contamination. Critical data gaps may exist that cannot be resolved except through labor-intensive data acquisition. Hydraulic parameters may have been obtained as part of a separate, unrelated investigation with different objectives or needs; for example, cyclic water-table fluctuations near tidal canals have been used to determine Biscayne aquifer hydraulic properties, but represent conditions only within the uppermost part of the aquifer penetrated by the depth of the canal (Fish and Stewart, 1991). Hydraulic parameters may have been determined through other indirect methods, including model calibration and verification. Similarly, estimates of aquifer porosity may be determined by visual examination, laboratory measurements of core samples, or indirectly use of borehole geophysical tools; however, those estimates can differ considerably from the effective porosity used in continuum models.

Even the judicious application of process-based methods to assess movement and fate of contaminants may not necessarily offer a reliable denouement (National Research Council, 1993, p. 6). Therefore, the recognition of inherent model- and data-related uncertainties becomes a critical element in any municipal well-field vulnerability assessment. Incorporation of such irresolution becomes a necessary factor for consideration in preparation of a coordinated water-resource and land-use policy.

The Northwest well-field protection zone was established in 1981 and was based, in part, on an existing (1970's) understanding of bacterial transport rates and rates of viral die-off in soils and ground water (Metropolitan Dade County, 1980, 1981). A numerical ground-water flow model was used to simulate flow under existing permitted withdrawal rates (568,700 ft^3/day or 150 Mgal/day) and to define time-of-travel protection zones (Prickett and Lonnquist, 1971; Camp, Dresser, and McKee, Inc., 1982, 1985). Time-of-travel well-field protection zones have been used to regulate land use and to limit activities that could adversely affect the ambient quality of ground water near the Northwest well field. Although limestone extraction activities are permitted within the protection zone, Miami–Dade County established regulatory ''setback distances,'' thus limiting the depth of mines within 30- and 60-day time-of-travel zone areas (Metropolitan Dade County, 1983, 1985a, 1985b). A rock-mine setback distance refers to the minimum horizontal distance allowed between an extractive mine and a municipal production well. This requirement was established as the result of the realization that lime-rock mines excavated to the same depth as the major production zone increased contamination risks.

In 1996, Krupa and others (2001) performed horizontal flow-meter tests within the Northwest well-field protection area in selected observation wells that were 518–853 m (1,700–2,800 ft) from active production wells (Table 1). These tests were conducted to verify the simulated advective movement of ground water. Under well-field operational conditions on April 8–9, 1996, the velocity of ground water within the protection area is reported to have ranged between 0.52 and 4.8 m/day (1.7 and 16 ft/day, respectively) (Krupa et al., 2001). These velocity measurements, however, likely represent a low baseline estimate, largely owing to uncertainties associated with the observation well construction and screen interval placement (Krupa, 2005). These deficiencies also should be considered in the general context of horizontal flow-meter measurement uncertainties, even under more ''ideal'' circumstances (Wilson et al., 2001).

The Miami–Dade County Department of Environmental Resources Management (1999, 2000a) has conducted a series of traces, injecting fluorescent dye in selected wells at various distances from pumping supply wells (Table 1). In 1998, fluorescent dye was injected into wells

Figure 2. North-facing oblique aerial photo showing a partial view of well field and active rock-mine lakes north of production well 15. Production well 9 pump house (S-3164) is visible near the lower right corner (photo taken by Shane Ploos, U.S. Geological Survey, April 2004).

located 257 m (845 ft) east of production well S-3163, 272 m (894 ft) east of production well S-3164, and 558 m (1,830 ft) east of production well S-3164 (Miami–Dade Department of Environmental Resources Management, 1999). Mean velocity of the tracer pulse is reported to have ranged from 21.5 to 27.6 m/day (70.5–90.6 ft/day) in short-distance traces, but dye was not detected at production well S-3164 in traces conducted over distances that exceeded 272 m (894 ft). In 1999, fluorescein and rhodamine WT dye were introduced into injection wells located 926 m (3,040 ft) east of the S-3164 production well (Guha et al., 2003). Dye was recovered in observation wells located 552–768 m (1,810–2,520 ft) east of well S-3164, but could not be detected in this production well (Kottke and Harrison, 2005). The mean advective velocity was reported to range from about 1.04 to 2.9 m/day, or 3.4 to 9.4 ft/day (Guha et al., 2003). The 1999 tracer experiments were considered inconclusive because of poor mass recovery, variable wet- and dry-season climatic conditions that affected the hydraulic gradient, tracer dilution within the aquifer caused by downward seepage of surface water, and a poor understanding of continuity of ground-water flow zones (Guha et al., 2003). Well design and construction uncertainties (as previously outlined) also applied to the outcomes of the 1998 and the 1999 tracer tests.

To minimize public exposure under future withdrawal rates and land-use scenarios, Miami–Dade County is reviewing rock-mine setback distances that achieve a 3.5- to 4.5-log (logarithmic) reduction in concentration of the pathogen *Cryptosporidium parvum*. An approach is being considered that evaluates pathogen removal by filtration, rate of pathogen die-off (Walker and Steninger, 1999), simulated ground-water flow patterns, and time-of-travel estimates (CH2M-HILL, 2001; Miami–Dade Department of Environmental Resources Management, 2000b). Log reduction is the terminology used to describe a reduction in the abundance of pathogens by sorptive filtration, straining, die-off, and inactivation. This reduction refers to the factors of 10 by which the number of viable pathogens are reduced. For example, a 4-log reduction of *Cryptosporidium parvum* corresponds to a 99.99 percent reduction in the viable numbers or inactivation and (or) removal of all but 10 of 100,000 viable öocysts. At present, this new method conservatively assumes little or no mechanical or absorptive filtration of *Cryptosporidium*

Table 1. *Estimated mean tracer velocity and horizontal flow-meter velocity under pumping well field operational conditions.*

Test	Release Date	Distance to Production Well	Mean Velocity	Citation
Horizontal flow meter	4/8/96–4/9/96[1]	518–853 m (1,700–2,800 ft)	0.52–4.76 m/day (1.70–15.62 ft/day)	Krupa et al., 2001
Conservative tracers rhodamine WT and fluorescein (three traces)	1/28/98–12/17/98	257–849 m (845–1,830 ft)[2]	21.5–27.6 m/day (70.5–90.6 ft/day)	Miami–Dade Department of Environmental Resources Management, 1999
Conservative tracers rhodamine WT and fluorescein	9/10/99	926 m (3,040 ft)[3]	1.04–2.86 m/day (3.4–9.4 ft/day)	Guha et al., 2003
Conservative tracer rhodamine WT and deuterium	4/22/03	100 m (328 m)	386 m/day (1,266 ft/day)	This report

[1]Twenty-three velocity measurements were obtained using a horizontal flow meter in eight observation wells.
[2]Not detected in wells located more than 272 m (894 ft) from the point of injection.
[3]Detected only in observation wells, not in the S-3164 supply well.

parvum, because it is not known if mechanical filtration (settling and attachment) can attenuate microbial transport in the Biscayne aquifer. Unlike granular media, in which processes of colloidal filtration have been documented and analytically formulated (Harvey and Garabedian, 1991), the efficacy of solution-enhanced limestone to impede subsurface movement of protozoa has not been previously determined (Osborn et al., 2004).

3. ASSESSING POTENTIAL FOR GROUND-WATER PATHOGEN TRANSPORT

Pathogens cannot be introduced into a ground-water system to assess their potential for transport; instead, alternative investigations and proxies for ground-water pathogens must be used. In this study, a coupled laboratory and field investigative strategy was employed to assess Biscayne aquifer pathogen transport potential. Laboratory static- and flow-through column tests were performed to determine if equivalently sized colloidal particles (carboxylated polystyrene microspheres) function as a viable surrogate for the *Cryptosporidium parvum* pathogen. A geologic site investigation was conducted in conjunction with hydraulic tests to characterize preferential pathways for ground-water flow. Three field tracer tests were performed between April 2003 and March 2004 using a suite of conservative tracers—fluorescent dye, bromide, deuterium (^2H), dissolved gas including halon 1211 ($CBrClF_2$) and sulfur hexafluoride (SF_6), and the microspheres.

3.1. Laboratory Column Studies

Column study experiments using *Cryptosporidium parvum* (Sterling Parasitology Laboratory, University of Arizona, Tucson, AZ) and carboxylated polystyrene microspheres (Polysciences, Inc., Warrington, PA) were designed to assess physicochemical properties, attachment behavior, and transport within the Biscayne aquifer under controlled laboratory conditions. Experiments using partially crushed limestone rock within a saturated column of static artificial ground water comparable to ambient well-field conditions were used to assess the effect of calcium-bicarbonate water, dissolved organic carbon, pH, and ionic strength. These vertical saturated column property tests indicate that physicochemical properties of ~2-, ~3-, and ~5-μm size microspheres compare favorably with *Cryptosporidium parvum* and, therefore, could be used as an applicable proxy (Osborn et al., 2004). Analysis of flow-through column experiments using intact whole-core samples of representative lithofacies that compose the aquifer is underway. This evaluation is expected to provide additional insight regarding vertical and horizontal pathogen movement within the internal rock fabric of the aquifer.

3.2. Hydrogeologic Characterization

Karst aquifers are traditionally characterized by interparticle matrix porosity, fracture porosity, and large cavernous porosity (Martin and Screaton, 2001). This has led many to view karst aquifers as two-component systems, in which much of the ground-water storage occurs in the matrix porosity or fractures or both and in which transport of ground water takes place in the large dissolution conduits (cf. Martin and Screaton, 2001). In the young eogenetic karst that defines the Pleistocene limestone of the Biscayne aquifer, however, touching-vug porosity is especially important in terms of conveyance of ground water (Vacher and Mylroie, 2002; Cunningham et al., 2006). The karstic Biscayne aquifer is a triple-porosity system that is mostly characterized by (1) a matrix of interparticle porosity and separate vugs, (2) stratiform preferred ground-water passageways formed by touching vugs (Lucia, 1995, p. 1260, 1999), and (3) less common conduit porosity composed mainly of bedding-plane vugs, thin solution pipes, and cavernous vugs. Touching-vug pore space is pore space formed by vugs that coalesce as an interconnected pore system of significant extent. Stratiform refers to the three-dimensional aspects of the porosity; that is, it is constrained to a layer, bed, or stratum with lateral continuity (Jackson, 1997). Cunningham and others (2004b, 2004c, 2006) have developed a conceptual model of the hydrogeology of the Biscayne aquifer in the Lake Belt area in which they have delineated, classified, and mapped the aquifer's internal pore system.

A high-resolution hydrogeologic framework was mapped within the Northwest well field, demonstrating the utility of carbonate cyclostratigraphic concepts for predicting the spatial distribution of preferred ground-water flow zones within the eogenetic karst Biscayne aquifer (Cunningham et al., 2006). The cyclostratigraphy presented herein divides fundamental depositional cycles (high-frequency cycles) into units defined by distinct vertical lithofacies successions bounded by surfaces across, in which there is evidence for a relative increase in ancient sea level (cf. Kerans and Tinker, 1997). The vertical and lateral distribution of mapped high-frequency cycles (HFCs) in the Northwest well field is shown in Figure 3.

Movement of ground water within water-bearing strata of the Biscayne aquifer occurs within pore classes I, II, and III (Table 2 and Figure 3). Each pore class comprises a unique category of lithofacies and pore systems (Cunningham et al., 2006). Carbonate-rock lithofacies and pore systems can be arranged within the context of high-frequency carbonate cyclostratigraphy. The porosity of pore class I typically is characterized by touching-vug and conduit porosity. Pore class II is distinguished by matrix porosity. The porosity of pore class III typically is separate vugs within a very low-permeability micrite (mud-sized limestone) matrix that may be perforated by small semivertical solution pipes of limited vertical extent or may have associated bedding plane vugs. The overall permeability of pore class III is commonly low, but leaky. The distribution of these three pore classes occurs within vertical and horizontal spatial patterns because their manifestation is directly related to the vertical assemblage of lithofacies within high-frequency cycles (Cunningham et al., 2006). Whole-core and digital borehole-image log data have been used to quantify Biscayne aquifer porosity within the well field using the methods described in Cunningham and others (2004a). Interval vuggy porosity values for slabbed whole-core samples from high-frequency limestone cycles in the Lake Belt area can range from less than 1 to 41.4 percent (Cunningham et al., 2004a), but characterization of porosity specific to different facies or pore-system flow class was not conducted.

Three injection wells (G-3773, G-3816, and G-3817) and one observation well (G-3772) were drilled as part of the field investigation (Figure 3) and showed correlative geologic and hydrogeologic relations within the well field. On the basis of descriptive core analyses, borehole data (geophysical, optical image, and flow-meter profiles), and aquifer performance tests, touching-vug zones dominate the lower part of the Biscayne aquifer from an altitude of –8.5 to –20.5 m (–28 to –67 ft) (Figure 3).

Borehole flow profiles of tracer injection wells using a Century Geophysics™ electromagnetic flow meter (Tulsa, OK) were performed to identify prospective high-permeability flow zones and to qualitatively assess borehole formation properties. Single-well and cross-borehole flow-meter tests were conducted to assess the continuity and interconnection of flow zones between the injection wells G-3773, G-3816, and G-3817 and the S-3164 production well during ambient and short-term stress conditions. Profiles indicated that substantial loss of vertical bore flow occurred within all three flow zones; therefore, they were considered to be important high-permeability ground-water flow pathways. Ground-water flow zones identified within high-frequency cycles HFC 2a, HFC 2b, and HFC 2e2 were selected for further field analysis (Figure 3).

3.3. Hydraulic Test Activities

Aquifer performance tests were conducted at production well S-3164 in the center of the Northwest well field and were performed in conjunction with controlled, forced-gradient tracer tests during April 2003 and February and March 2004. Withdrawals within the entire well field were highly regulated during test activities, and drawdown measurements were collected at observation wells located 10–2,590 m (33–8,500 ft) from the production well. The Biscayne aquifer is highly transmissive, with values reportedly ranging from 102,230 to 269,410 m^2/day (1,100,000–2,900,000 ft^2/day) near the Northwest well field (Fish and Stewart, 1991).

Traditionally, the Biscayne has been described as an unconfined aquifer (Parker et al., 1955; Fish and Stewart, 1991). Permeable ground-water flow zones within the Biscayne aquifer, however, appear to be semiconfined in an area southwest of the Northwest well field (Cunningham et al., 2004c). In north-central Miami–Dade County, the change in hydraulic head in response to hydrologic stress (withdrawals, precipitation, and canal stage) in more deeply buried water-bearing strata usually mirrors those fluctuations that occur at the water table. Conversely, semiconfined hydrologic conditions within the well field are implied by the occurrence of a low-amplitude (0.003-m or 0.010-ft) diurnal change in water levels observed during both pumping and nonpumping well-field operation. Harmonic water-level change is commonly observed within coastal confined or semi-confined aquifers that are subject to mechanical (tidal) or

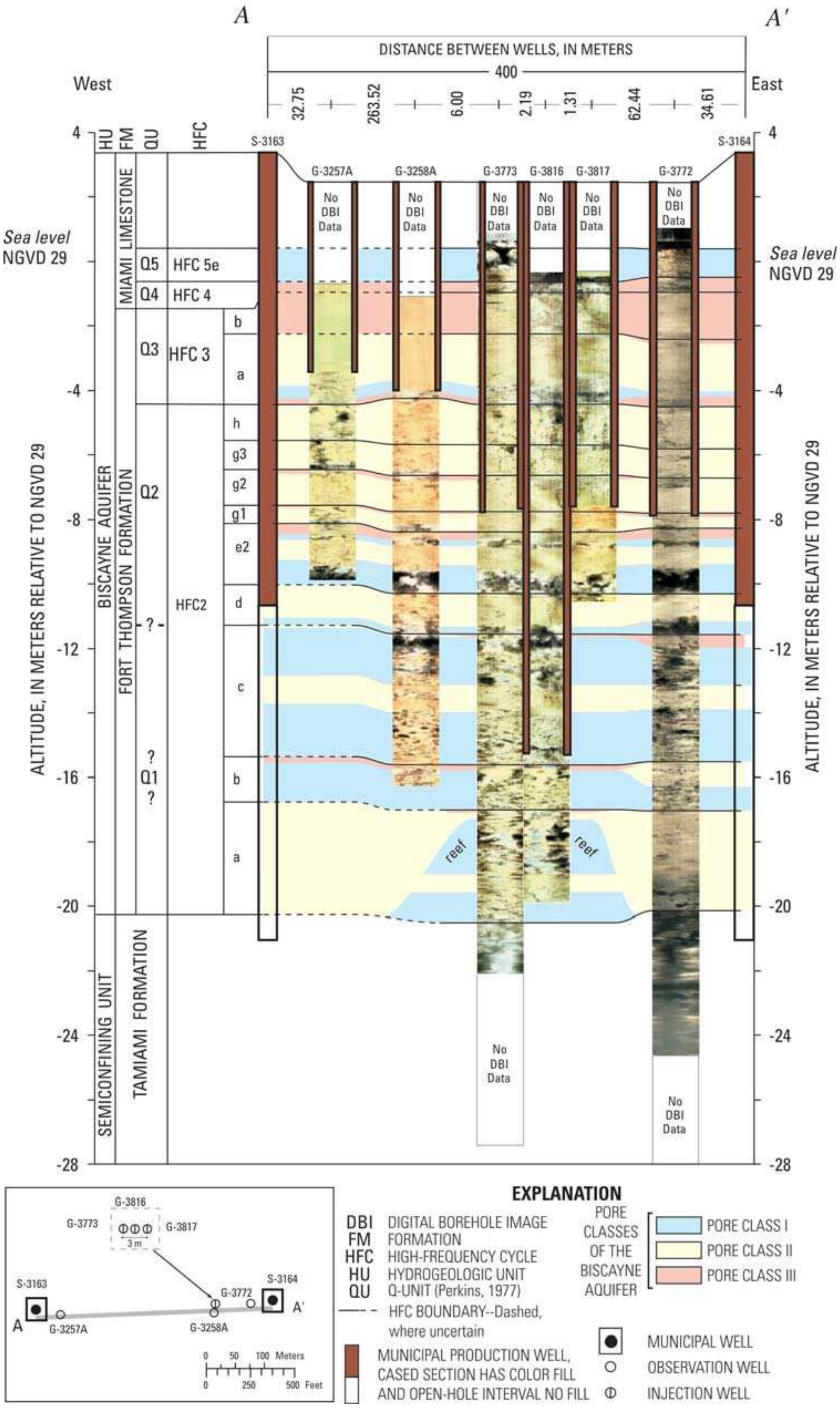

Figure 3. Line of section between S-3163 and S-3164 showing optical borehole image logs, relation between sequence stratigraphic units, and classification of ground-water flow within the Northwest well field.

Table 2. *Pore classes (I, II, III) related to aquifer attributes at the Northwest Well Field.*

Pore Class	Major Pore Type	Major Type of Ground-Water Flow and Relative Permeability
III	Separate vugs, including moldic and thin vertical solution pipes	Leaky (limited small-scale conduit flow), typically low permeability
II	Interparticle porosity and separate vugs	Diffuse-carbonate flow, moderate permeability
I	Touching vugs, including solution-enlarged molds of fossils, burrows, and roots; interburrow and inter-root vugs; and uncommon bedding plane vugs and cavernous vugs	Conduit flow, high permeability

pressure-forcing (barometric) influences. The effect of unconfined storage dampens water-table harmonic oscillations within several hundred meters of the coastline (Erskine, 1991). Specific mechanisms that control these low-amplitude fluctuations, including the possible effect of shallow water-table wetland evapotranspiration, have not been resolved.

A high-frequency, early-time, oscillatory hydraulic response was observed during the first minute of the aquifer test and was considered indicative of high transmissivity. A similar underdamped hydraulic response has been reported elsewhere in highly transmissive, fractured-rock carbonate aquifers, including the Floridan aquifer system and the Silurian dolomite in northeastern Illinois (Bredehoeft et al., 1966; Giffin and Ward, 1989; and Shapiro, 1989). Sensitivity of the Biscayne aquifer to hydrologic stress was exhibited during the course of the aquifer test, as demonstrated by the rapid change in ground-water levels in response to precipitation and canal stage. Canals represent important hydrologic boundaries, despite well-to-canal separation distances of 2.4 to 3.2 km (1.5–2.0 mi).

In southern Florida, effective or kinematic porosity of the Biscayne aquifer has been assumed to be approximately equivalent to specific yield by some researchers (Merritt, 1996, p. 46). Lohman (1972) defines effective porosity as a measure of the interconnected pore space available for the transmission of ground water. Kinematic porosity is defined as voids in pore space occupied by moving water relative to the total rock volume (de Marsily, 1986). Specific yield is the ratio of water drained by gravity from an aquifer to the total volume of the aquifer. The specific yield of the Biscayne aquifer is reported to range from 10 to 35 percent (Schroeder et al., 1958). Treating specific yield as an "equivalent" measure may be viewed as a reasonable assumption in granular media that lack isolated and dead-end (cul de sac) pore space, are not affected by capillary tension, and are not affected by the length of time provided for gravity drainage to occur. This equivalency premise does not consider a more complex condition that may occur, in which system porosity is divided into a dual-domain set of mobile and immobile parameters (van Genuchten and Wierenga, 1976; Reeves et al., 1991).

A detailed description of the spatial distribution of aquifer porosity is rarely available. Most commonly, a uniform distribution of porosity within the model domain is assumed. For example, a constant 20 percent specific yield has been applied to the uppermost layer of the model layer in north Miami–Dade County (Wilsnack et al., 2000) and in Northwest well-field ground-water flow models (CH2M-HILL, 2001). Backward-tracked flow pathlines were defined, assuming that the porosity of the Biscayne aquifer is 20 percent and uniformly distributed (CH2M-HILL, 2001; Guha, 2005). Ground-water flow in the Biscayne aquifer is broadly controlled by hydraulic gradient; however, preferential, high-velocity flow paths are likely constrained to the interconnected part of the pore system. For example, two equal-volume blocks of an aquifer, with equivalent permeability and boundary stresses, may have similar bulk porosity but different effective porosity. The volume of aquifer with a smaller effective porosity will transmit water at a higher velocity. Conversely, the volume of aquifer with larger effective porosity will transmit water at lower velocities. Biscayne aquifer equivalency assumptions for effective porosity and specific yield indicate that it is reasonable to anticipate differences between measured and simulated ground-water velocity.

3.4. Conservative and Colloidal Tracer Tests

A conservative tracer test was performed in April 2003 to obtain data on formation properties and transport parameters and to aid in the design of a particulate-tracer experiment. A forced-gradient tracer test was executed using a 50-kg (110-lb) mass of rhodamine WT (Liquid Acid Red 388 dye; Keystone Aniline Corporation, Chicago, IL) and a 15-kg (33-lb) mass of deuterium (^{2}H; Cambridge Isotope Laboratories, Andover, MA) (Table 1). A centrifugal pump was used to introduce tracer material into the injection well, G-3773, which was completed as an open borehole from approximately –7.7 m to –20.5 m (–25 to –67.3 ft) below sea level. A pipe extended from the pump into the borehole, with its opening located at the same depth as the flow zone, HFC 2e2 (Figure 4). Injection well G-3773 is located 100 m (328 ft) west of the production well, S-3164, which discharged at an average rate of 0.49 m^3/second (7,900 gpm). Following injection, gravity-fed formation water was used to flush the two conservative tracers from the borehole into the Biscayne aquifer. Borehole water

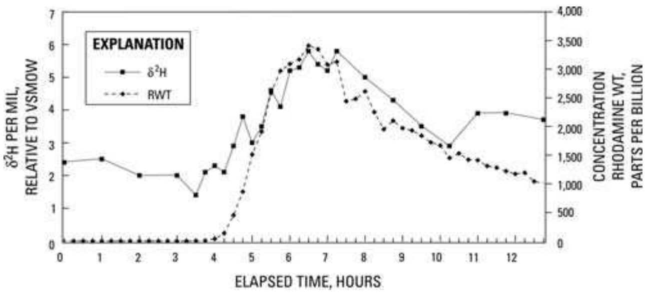

Figure 4. Rhodamine WT (RWT) and deuterium (δ^2H) breakthrough curves at production well S-3164 on April 22, 2003.

samples were collected at both the production and injection wells to assess tracer movement within the formation.

Peak tracer pulse breakthrough occurred in 6.5 hours (Figure 4). Between the point of injection and the production well, the apparent mean advective flow velocity observed during this test appears to be one to two orders of magnitude greater than previously measured (Table 1). Recovery of rhodamine WT is estimated to have been about 60 percent of the injected mass at the time the test was prematurely terminated at 12.75 hours. Comparison of mean tracer velocity during this test with previous determinations is not possible, however, because of differences in (1) test objectives, (2) distance and location of the point of injection and tracer recovery (production) well, (3) hydrologic conditions (hydraulic gradient, well-field operation, canal stage levels, and climate), (4) injection- and observation-well construction uncertainty, and (5) uncertainty regarding the geologic character of ground-water flow zones previously tested.

Horizontal flow-meter measurements and dye traces conducted previously (Miami–Dade Department of Environmental Resources Management, 1999, 2000a; Krupa et al., 2001; and Guha et al., 2003) were designed to assess the potential for contamination from existing borrow-pit lakes located, in a regional sense, downgradient of the supply wells. Tracer tests conducted during the present study were designed, in part, to also consider the potential adverse effect of lime-rock mines proposed for excavation in upgradient areas.

The April 2003 tracer test illustrates the difficulty and uncertainty associated with estimates of ''interconnected'' karst aquifer pore space. Before the test, a scoping effort was conducted to estimate the likely duration of a tracer test and the amount of tracer required in obtaining a peak concentration at the point of recovery that was three to four orders of magnitude greater than the detection limit. Aquifer porosity was assumed to be uniformly distributed, with a potential range between 5 and 40 percent. Before the April 2003 test, these estimates of aquifer effective porosity were regarded as reasonable in the Biscayne aquifer, largely because they were based on the visual inspection of cores, examination of borehole-image logs, and calculated values of vuggy porosity from these logs (Cunningham et al., 2004a).

An estimation of effective porosity between the points of injection and recovery can be made by applying a simple mass balance for a radially converging flow regime to the rhodamine WT breakthrough data (Javandel et al., 1984),

$$v = \frac{dr}{dt} = \frac{Q}{(2\pi rh)n} \tag{1}$$

where v is mean tracer velocity (m/day); Q is flow rate (m^3/day); r is radius from the pumping well (m); t is travel time (days); h is thickness of aquifer (m); and n is effective porosity (dimensionless).

With what is currently known about the heterogeneity of the Biscayne aquifer, Eq. 1 is obviously an over-simplification of the flow regime between the injection and production wells. Implicit in this equation is the assumption of a homogeneous formation, in which ground-water flow is laminar and radially oriented with respect to the production well. Ground-water flow is likely channelized through dissolution-enhanced vuggy features within the Biscayne aquifer, which may constitute a very small percentage of the overall aquifer volume. Nevertheless, Eq. 1 can be used to estimate effective porosity. Therefore, the effective porosity of the aquifer between the injection point and the withdrawal well can be more easily estimated by integrating and rearranging the result:

$$\int_0^r r\ dr = \int_0^t \frac{Q}{(2\pi h)n} dt$$
$$\frac{r^2}{2} = \frac{Q}{(2\pi h)n} t$$
$$n = \frac{Q}{(\pi h)r^2} t$$

where t is the mean time-of-travel between the injection point and the withdrawal well (distance r).

Using the time to peak rhodamine WT concentration as a conservative assessment of mean arrival time, an effective porosity of about 2 percent is estimated given a withdrawal rate of 43,063 m^3/day (11,376,000 gal/day), a peak arrival time of 6.5 hours, an aquifer thickness of 18 m (59 ft) below the base of the low-permeability unit, which is mostly contained in high-frequency cycles HFC 3b and HFC 4 (Figure 3), and an injection- to withdrawal-well distance of 100 m (328 ft). Effective porosity is estimated to be about 4 percent if thickness is limited only to the 9-m- (29.5-ft-) thick, stratiform, touching-vug pore system (pore class I) that extends below the low-permeability unit mostly contained in high-frequency cycles HFC 3b and HFC 4 (Figure 3).

In comparison to estimates of aquifer porosity of up to 40 percent from borehole-image logs and core examination, an estimate of 2 to 4 percent from the April 2003 tracer test indicates that movement of ground-water flow is nonuniform in the Biscayne aquifer at the Northwest well field. Dynamic movement of ground water is largely constrained to interconnected pore space contained within stratiform passageways formed by touching vugs. The unexpected rapid breakthrough associated with the April 2003 test provided an opportunity to make adaptive, cost-effective changes in the design of the February 2004 colloidal particle test.

The objective of the February and March 2004 tracer tests was to estimate formation properties for specific ground-water flow zones within both shallow and deep parts of the section that included the HFC 2e2, HFC 2b, and HFC 2a units (Figure 3). In the shallow ground-water flow zone at the base of high-frequency cycle HFC 2e2, carboxylated polystyrene microspheres and conservative tracers were simultaneously injected using submersible pumps and a single inflatable packer system, which is similar in design to the dual packer Multifunction Bedrock-Aquifer Transportable Testing Tool (BAT^3) system (Shapiro, 2001). The packer equipment was used to isolate a fluid-filled interval at the bottom of an injection borehole using an inflatable packer; to collect water samples for chemical analysis; to measure hydraulic head; and to inject and withdraw tracers. Transducers and flow meters were linked to a Campbell Scientific CR10X™ data logger to collect time-varying rate of pumping or fluid-injection and fluid-pressure responses. Data acquisition was integrated using a laptop computer to store and display data in real time. The procedure used to introduce a tracer into the formation consisted of injecting the tracer solution into a packed-off open-hole section of the well followed by flushing a formation water "chaser" to displace residual material from the well into the aquifer. Water samples were collected from the injection well after injection of chaser water had been completed to determine the residual tracer mass that remained within the open-hole injection interval.

In February 2004, deuterium, dissolved sulfur hexafluoride (SF_6), dissolved halon, and ~2-, ~3-, and ~5-μm size microsphere tracers were injected into the G-3817 open-hole section, which includes an approximately 0.80-m- (2.6-ft-) thick, high-permeability ground-water flow zone at the base of high-frequency cycle HFC 2e2 (–8.6 to –10.3 m or –28 to –33.8 ft) (Figure 3). Deuterium, halon, SF_6, and microsphere breakthrough data currently are being assessed in the context of a comprehensive evaluation of well-field hydraulics. However, preliminary field test data indicate that there has been limited attenuation of microspheres (Harvey et al., 2005), especially where they have advected at high velocities within a touching-vug stratiform flow zone. In March 2004, a 29-kg (64-lb) sodium bromide (21 kg or 46 lb bromide) tracer was injected into the packed-off open-hole section of injection well G-3816. This well is open, with mostly to highly porous, vuggy rocks of HFC 2a and HFC 2b (Figure 3) at a depth of –15.5 to –19.8 m (–50.9 to –65 ft). Whereas breakthrough data have been obtained from the shallow ground-water flow zone at the base of high-frequency cycle HFC 2e2 (Figure 3), a tracer pulse was not detected at production well S-3164. Currently, there are no plans to conduct a similar test within this lower zone using deuterium, halon, SF_6, or the microspheres. Potential factors that contributed to the inability to detect bromide at production well S-3164 include density differences resulting in downward movement of the tracer, dilution owing to an insufficient tracer mass, and the possibility that diffusive transport exceeds advective transport. Differences of connectivity of touching-vug, stratiform ground-water flow zones could represent a confounding geologic factor. Solution-enlarged burrow and interburrow vugs form a well-connected pore system of touching vugs in the shallow stratiform ground-water flow zone at the base of HFC 2e2, but only solution-enlarged burrow molds are well developed within the lower ground-water flow zone in HFC 2a and HFC 2b (Figure 3). More vugs observed on the digital borehole-image log are present as separate vugs. Limited horizontal continuity within a lowermost ground-water flow zone in HFC 2a could have further restricted movement of the bromide tracer toward production well S-3164 (Figure 3). The areal extent of touching-vug porosity in the upper part of HFC 2a is limited because that unit is, in part, a coral patch reef.

4. SUMMARY

The Northwest well field, Florida's largest municipal well field, is located on the eastern edge of an extractive limestone-rock mining district in north-central Miami–Dade County. Mining activities create artificial lakes that are, in places, the same depth as the supply-well production zone. These borrow-pit lakes are within a 247- to 914-m (810- to 3,000-ft) distance of active supply wells. Consequently, there is considerable concern that if mine expansion continues, withdrawals are more likely to be influenced by the quality of lake-mine surface water, and the well field will require use of enhanced disinfection and filtration treatment to remove protozoan pathogens, including *Cryptosporidium parvum*.

Laboratory and field tests have been coupled to examine potential pathways for solute and microbial contamination, filtration mechanisms that might impede microbial transport, and karst limestone well-field vulnerability issues. Intensive data-collection efforts have been completed and include laboratory column studies, detailed geologic site investigations, and hydraulic and field tracer tests. The assessment of some of these data is ongoing.

The Biscayne aquifer underlies the Northwest well field and is formed by vertically repeating assemblages of principally carbonate lithofacies that delineate a cyclostratigraphy. These lithofacies are each characterized by specific pore classes that are characterized by highly permeable, touching-vug stratiform flow zones and uncommon bedding plane vugs (pore class I); less-permeable matrix with mostly intergranular porosity and separate vugs (pore class II); and leaky, low-permeability layers (pore class III). Most ground-water flow occurs within touching-vug pore space (vuggy pores that coalesce into interconnected pore space), forming tortuous stratiform pathways for advective movement of solutes and pathogens. Diffuse-carbonate flow occurs within matrix-dominated carbonate-rock flow zones, mostly formed by interparticle pore space. Minor, leaky low-permeability flow characterizes micrite-rich limestone layers that behave, at least locally, as a semiconfining unit.

An underdamped hydraulic response was observed during aquifer tests, reflecting the highly transmissive nature of the Biscayne aquifer. Ground-water occurs under unconfined or semiconfined conditions. Hydraulic tests indicated that the aquifer underlying the Northwest well field is strongly influenced by stage levels in surrounding canals that are at a 2.4- to 3.2-km (1.5- to 2.0-mi) distance from supply wells.

Conservative tracers (rhodamine WT and deuterium) were introduced into an injection well located 100 m (328 ft) from a production well in April 2003. Mean velocity of the tracer pulse between the point of injection and recovery (supply well) seems to be one to two orders of magnitude greater than measurements obtained by Miami–Dade County in 1998–99. An assessment of the outcome of a suite of conservative and colloidal tracers (deuterium, halon, SF_6, and microspheres) has not been completed. However, preliminary field test data indicate there is limited attenuation of microspheres, especially where they are advected at high velocities within a stratiform ground-water flow zone characterized by touching-vug porosity.

The April 2003 tracer experiment indicated that interconnected pore space or effective porosity of the Biscayne aquifer near the point of injection and the production well is much smaller (2 to 4 percent) than previously considered. In the past, researchers simulated ground-water flow and developed time-of-travel well-field protection zones by treating the Biscayne aquifer as a single-porosity, equivalent continuum. On the basis of the 2003 test, however, it seems that specific yield is a poor equivalent measure of the effective porosity required in the continuum models to match field-measured velocities. Effective porosity is one of the formation parameters used to define time-of-travel protection zones. Although continuum models are well-suited to simulate regional flow conditions, very-near and near-field conditions may compare poorly, especially in a triple-porosity karst aquifer. As a result, there is greater uncertainty with regard to whether physical system complexities and high-velocity, preferential flow conditions within the well field have been correctly approximated.

Comparing the April 2003 tracer test with previous tests is problematic because of differences in test objectives, design, and methods; uncertainties in well construction; well-field operational conditions; climatic and hydrologic conditions; and the distance between the point of injection and recovery (production well). The ability to resolve well-to-well correlative relations and likely pathways for contamination played an important role in the outcome of the 2003 and 2004 tracer tests. Nevertheless, the April 2003 tracer test has demonstrated potential contamination risks in the Northwest well field that are far greater than previously considered, indicating the need for reassessment of existing rock-mine setback distances.

ACKNOWLEDGMENTS

The authors wish to acknowledge the administrative and field support during the 2003–04 tracer field experiments provided by Julie Baker, Hillol Guha, Theodore Harrison, and Liz Britt of the Miami–Dade Department of Environmental Resources Management and by Clint Oakley, Virginia Walsh, William Pitt, Arthur Baldwin, and other well-field operational staff of the Miami–Dade Water and Sewer Department. John Williams and Alton Anderson of the U.S. Geological Survey provided vertical borehole flow-meter technical support, and Marc Stewart, Dawn Edwards, and Adrian Castillo of the U.S. Geological Survey provided important field assistance during 2003 and 2004 tracer tests. Constructive reviews by Andrew O'Reilly, Ron Reese, Eve Kuniansky, and Sandra Cooper of the U.S. Geological Survey and by three anonymous peer reviewers for the journal helped to improve the final manuscript.

REFERENCES

Anderson, M. P. and Woessner, W. W., 1992, *Applied Groundwater Modeling—Simulation of Flow and Advective Transport*: Academic Press, San Diego, CA, 381 p.

Bear, J., 1993, Modeling flow and contaminant transport in fractured rocks. In Bear, J.; Tsang, C.-F.; and de Marsily, G. (Editors), *Flow and Contaminant Transport in Fractured Rock*: Academic Press, San Diego, CA, 560 p.

Bredehoeft, J. D.; Cooper, H. H.; and Papadopulos, I. S., 1966, Inertial and storage effects in well-aquifer systems: An analog investigation: *Water Resources Research,* Vol. 2, pp. 697–707.

Cacas, M. C.; Ledoux, E.; de Marsily, G.; Barbreau, A.; Calmels, P.; Gaillard, B.; and Margritta, R., 1990a, Modeling fracture flow with a stochastic discrete fracture network: calibration and validation—2. The transport model: *Water Resources Research,* Vol. 26, No. 3, pp. 491–500.

Cacas, M. C.; Ledoux, E.; de Marsily, G.; Tillie, B.; Barbreau, A.; Durand, E.; Feuga, B.; and Peaudecerf, P., 1990b, Modeling fracture flow with a stochastic discrete fracture network: calibration and validation—1. The flow model: *Water Resources Research,* Vol. 26, No. 3, pp. 479–489.

Camp, Dresser and McKee, Inc., 1982, *Wellfield Travel Time Model for Selected Well Fields in Dade, Broward, and Palm Beach Counties, Florida*: Consultant report for Dade County Department of Environmental and Resources Management, Broward County Planning Council, and Palm Beach County Area Planning Board.

Camp, Dresser and McKee, Inc., 1985, *Ground-Water Flow Model for the Northwest Wellfield, Dade County, Florida*: Consultant report prepared for Dade County Department of Environmental and Resources Management.

CH2M-HILL, 2001, *Risk Assessment and Ground-Water Flow Modeling of the Miami–Dade Northwest Well Field*: Consultant report prepared for Miami–Dade County Department of Environmental and Resources Management, 38 p.

Cunningham, K. J.; Carlson, J. L.; and Hurley, N. F., 2004a, New method for quantification of vuggy porosity from digital optical borehole images as applied to the karstic Pleistocene limestone of the Biscayne aquifer, southeastern Florida: *Journal Applied Geophysics,* Vol. 55, No. 1-2, pp. 77–90.

Cunningham, K. J.; Carlson, J. L.; Wingard, G. L.; Robinson, E.; and Wacker, M. A., 2004b, *Characterization of Aquifer Heterogeneity Using Cyclostratigraphy and Geophysical Methods in the Upper Part of the Karstic Biscayne Aquifer, Southeastern Florida*: U.S. Geological Survey Water Resources Investigations Report 03-4208, 66 p.

Cunningham, K. J.; Renken, R. A.; Wacker, M. A.; Robinson, E.; Zygnerski, M. R.; Shapiro, A. M.; and Wingard, G. L., 2006, Application of carbonate cyclostratigraphy and borehole geophysics to delineate porosity and preferential flow in the karst limestone of the Biscayne aquifer, SE Florida. In *Geological Society of America Special Paper*: Geological Society of America, Boulder, CO, in press.

Cunningham, K. J.; Wacker, M. A.; Robinson, E.; Gefvert, C. J.; and Krupa, S. L., 2004c, *Hydrogeology and Ground-water Flow at Levee-31N, Miami–Dade County, Florida, July 2003 to May 2004*: U.S. Geological Survey Scientific Investigations Map I-2846, 1 plate.

de Marsily, G., 1986, *Quantitative Hydrogeology*: Academic Press, New York, 440 p.

Erskine, A. D., 1991, The effect of tidal fluctuation on a coastal aquifer in the UK: *Ground Water,* Vol. 29, No. 4, pp. 556–562.

Federal Register Notice, October 11, 1979, Vol. 44, No. 198.

Federal Register Notice, May 10, 2000, Vol. 65, No. 91.

Fish, J. E. and Stewart, M., 1991, *Hydrogeology of the Surficial Aquifer System, Dade County, Florida*: U.S. Geological Survey Water-Resources Investigations Report 90-4108, 50 p.

Giffin, D. A. and Ward, D. S., 1989, Analysis of early-time oscillatory aquifer response. In *Symposium on New Field Techniques, National Water Well Association*: Dallas, Texas, March 20–23, 1989, pp. 187–211.

Guha, H., 2005, personal communication, Miami–Dade Department of Environmental Resources Management, Miami, FL.

Guha, H.; Kottke, H.; and Harrison, T., 2003, Dye tracer study near a high capacity public supply well system, Miami–Dade County, Florida, U.S.A. In *Proceedings, 2003 International Water Congress*: American Water Resources Association, Middleburg, VA, pp. 1–9.

Harvey, R. W. and Garabedian, S. P., 1991, Use of colloid filtration theory in modeling movement of bacteria through a contaminated sandy aquifer: *Environmental Science Technology,* Vol. 15, No. 1, p. 178–185.

Harvey, R. W.; Metge, D. W.; Shapiro, A. M.; Renken, R. A.; Osborn, C. L.; Ryan, J. N.; and Cunningham, K. J., 2005, Use of carboxylated polystyrene microspheres to assess the transport potential of *Cryptosporidium parvum* öocysts in karstic limestone of the Biscayne Aquifer (Northwest Well Field, Miami, FL): *American Chemical Society, 229th ACS National Meeting*, March 13–17, 2005, San Diego, CA: Electronic document, available at http://oasys2.confex.com/acs/229nm/techprogram/P816823.HTM

Jackson, J. A. (Editor), 1997, *Glossary of Geology,* 4th ed.: American Geological Institute, Alexandria, VA, 769 p.

Javandel, I.; Doughty, C.; and Tsang, C.-F, 1984, *Groundwater Transport—Handbook of Mathematical Models*: Water Resources Monograph Series 10, American Geophysical Union, Washington, DC, 228 p.

Kerans, C. and Tinker, S. W., 1997, *Sequence Stratigraphy and Characterization of Carbonate Reservoirs*: SEPM Short Course Notes 40, Society for Sedimentary Geology, Tulsa, OK, 130 p.

Kottke, H. and Harrison, T., 2005, personal communication, Miami–Dade Department of Environmental Resources Management, Miami, FL.

Krupa, S., 2005, personal communication, South Florida Water Management District, West Palm Beach, FL.

Krupa, S.; Hill, S.; and Bevier, C., 2001, *Miami–Dade County Northwest Well Field Groundwater Velocity Investigation*: Technical Publication WS-1, South Florida Water Management District, 36 p.

Lohman, S. H., 1972, *Ground-Water Hydraulics*: U.S. Geological Survey Professional Paper 708, 70 p.

Lucia, F. J., 1995, Rock-fabric/petrophysical classification of carbonate pore space for reservoir characterization: *American Association Petroleum Geologists Bulletin,* Vol. 79, p. 1275–1300.

Lucia, F. J., 1999, *Carbonate Reservoir Characterization*: Springer-Verlag, New York, 226 p.

Macler, B. A. and Merkle, J. C., 2000, Current knowledge on groundwater microbial pathogens and their control: *Hydrogeology Journal,* Vol. 8, pp. 29–40.

Martin, J. B. and Screaton, E. J., 2001, Exchange of matrix and conduit water with examples from the Florida aquifer. In Kuniansky, E. L. (Editor), *U.S. Geological Survey Karst Interest Group Proceedings, St. Petersburg, Florida, February 13–16, 2001*: U.S. Geological Survey Water-Resources Investigations Report 01-4011, pp. 38–44.

Merritt, M. L., 1996, *Numerical Simulation of a Plume of Brackish Water in the Biscayne Aquifer Originating from a Flowing Artesian Well, Dade County, Florida*: U.S. Geological Survey Water-Supply Paper 2464, 74 p.

Metropolitan Dade County, 1980, *Protection of Potable Water Supply Wells Program*: Department of Environmental Resource Management Technical Report 80-4, 176 p.

Metropolitan Dade County, 1981, *Resolution No. R-81-23 Adopting the Northwest Well Field Time-of Travel Protection Zones:* Board of County Commissioners, Metropolitan Dade County, Miami, FL.

Metropolitan Dade County, 1983, *Resolution No. R-83-82 Adopting the 30-Day Zone, 40-Ft Depth Rock-Mine Setback Limitation*: Board of County Commissioners, Metropolitan Dade County, Miami, FL.

Metropolitan Dade County, 1985a, *Resolution No. R-85-54, Adopting an Additional 30- Day Rock-Mine Setback Distance*: Board of County Commissioners, Metropolitan Dade County.

Metropolitan Dade County, 1985b, *Resolution No. R-1541-85,* *Adopting the Northwest Well Field Protection Plan*: Board of County Commissioners, Metropolitan Dade County, Miami, FL.

Miami–Dade Department of Environmental Resources Management, 1999, *Description and Analysis of Preliminary Tracer Trials Conducted at the Northwest Wellfield, Miami–Dade County, Florida*: Report, Miami–Dade Department of Environmental Resources Management, 16 p.

Miami–Dade Department of Environmental Resources Management, 2000a, *Description and Analysis of Full-Scale Tracer Trials Conducted at the Northwest Well Field, Miami–Dade County, Florida*: Report, Miami–Dade Department of Environmental Resources Management, 20 p.

Miami–Dade Department of Environmental Resources Management, 2000b, *Northwest Well Field Watershed Protection Plan*: Report prepared for the South Florida Water Management District, Miami–Dade Department of Environmental Resources Management.

National Research Council, 1993, *Ground Water Vulnerability Assessment—Predicting Relative Contamination Potential under Conditions of Uncertainty*: National Academy Press, Washington, DC, 224 p.

National Research Council, 1996, *Rock Fractures and Fluid Flow: Contemporary Understanding and Applications*: National Academy Press, Washington, DC, 551 p.

Osborn, C. L.; Ryan, J. N.; Harvey, R. W.; Metge, D. W.; Landkamer, L. L.; Renken, R. A.; Cunningham, K. J.; and Shapiro, A. M., 2004, Transport and attachment of *Cryptosporidium parvum* öocysts and microsphere analogs in karstic limestone of the Biscayne aquifer, Miami–Dade County, Florida: *Eleventh International Symposium on Water Rock Interaction,* Saratoga Springs, NY, 2 p.

Parker, G. G.; Ferguson, G. E.; and Love, S. K., 1955, *Water Resources of Southeastern Florida, with Special Reference to the Geology and Ground Water of the Miami Area*: U.S. Geological Survey Water-Supply Paper 1255, 965 p.

Perkins, R. D., 1977, Depositional framework of Pleistocene rocks in south Florida. In Enos, P. and Perkins, R. D. (Editors), *Quaternary Sedimentation in South Florida, Part II*: Geological Society of America Memoir 147, Geological Society of America, Boulder, CO, pp. 131–198.

Prickett, T. A. and Lonnquist, C. G., 1971, *Selected Digital Computer Techniques for Groundwater Flow Modeling*: Illinois State Water Survey Bulletin No. 55, 62 p.

Reeves, M.; Freeze, G. A.; Kelley, V. A.; Pickens, J. F.; Upton, D. T.; and Davies, P. B., 1991, *Regional Double-Porosity Solute Transport in the Culebra Dolomite under Brine-Reservoir-Breach Release Conditions: An Analysis of Parameter Sensitivity and Importance*: Report SAND89-7069, Sandia National Laboratories, 243 p.

Schroeder, M. C.; Klein, H.; and Hoy, N. D., 1958, *Biscayne Aquifer of Dade and Broward Counties, Florida*: Florida Geological Survey Report of Investigations No. 17, 56 p.

Shapiro, A. M., 1989, Interpretation of oscillatory water levels in observation wells during aquifer tests in fractured rock: *Water Resources Research,* Vol. 25, No. 10, pp. 2129–2137.

Shapiro, A. M., 2001, *Characterizing Ground-Water Chemistry and Hydraulic Properties of Fractured Rock Aquifers Using the Multifunction Bedrock-Aquifer Transportable Testing Tool (BAT^3):* U.S. Geological Survey Fact Sheet FS-075-01.

Vacher, H. L. and Mylroie, J., 2002, Eogenetic karst from the perspective of an equivalent porous medium: *Carbonates Evaporites,* Vol. 17, No. 2, pp. 182–196.

van Genuchten, M. T. and Wierenga, P. J., 1976, Mass transfer studies in sorbing porous media, I. Analytical solutions: *Soil Science Society America Journal,* Vol. 40, pp. 473–481.

Walker, F. R. and Stedinger, J. R., 1999, Fate and transport model of *Cryptosporidium*: *Journal Environmental Engineering,* Vol. 125, No. 4, pp. 325–333.

Walters, R. R., 1987, Dade County, Case Study. In Page, G. W. (Editor), *Planning for Ground Water Protection*: Academic Press, Orlando, FL, pp. 205–239.

Wilsnack, M. M.; Welter, D. E.; Nair, S. K.; Montoya, A. M.; Zamorano, L. M.; Restrepo, J. I.; and Obeysekera, J., 2000, *North Miami–Dade County Ground Water Flow Model:* Report, South Florida Water Management District, 40 p.

Wilson, J. T.; Mandell, W. A.; Paillet, F. L.; Bayless, E. R.; Hanson, R. T.; Kearl, P. M.; Kerfoot, W. B.; Newhouse, M. W.; and Pedler, W. H., 2001, *An Evaluation of Borehole Flowmeters used to Measure Horizontal Ground-Water Flow in Limestones of Indiana, Kentucky, and Tennessee, 1999*: U.S. Geological Survey Water Resources Investigations Report 01-4139, 129 P.

U.S. Geological Survey
U.S. Department of the Interior

News Release

Date: August 27, 2008

Contact: A.B. Wade (703) 648-4483 abwade@usgs.gov

Water Supply at Greater Risk than Expected

Scientists from the U.S. Geological Survey have concluded that the drinking water from the Miami-Dade Northwest Well Field (NWWF) is at risk of contamination due to the close proximity of existing lakes created from limestone rock mining activities. Scientists conducted experiments to show how chemical contaminants and pathogens would move through the Biscayne aquifer. Approximately 2 million residents in southeastern Florida rely on the Biscayne aquifer for drinking water.

The U.S. Geological Survey first studied the movement of groundwater in the Biscayne aquifer in April 2003 when they injected a harmless red dye into the limestone of the Biscayne aquifer, which was then pulled into the public water supply system by wells at the NWWF. The results of this test revealed that groundwater traveled through the limestone aquifer at rates much faster than anticipated.

These studies were conducted because of the potential contamination of a drinking water supply in areas where shallow karst limestone systems, such as the Biscayne aquifer, are the source of drinking water. Of particular concern is the potential movement of pathogens in the groundwater, such as *Cryptosporidium parvum,* from limestone-rock mine lakes to the production wells. *Cryptosporidium parvum* is commonly recognized as a pathogen of concern because of its resistance to chemical disinfection. *Cryptosporidium* has been known to survive the normal chlorination process that a drinking water facility uses. Current treatment of water drawn from NWWF production wells is not completely effective in removing these pathogens from the drinking water. In other parts of the country, *Cryptosporidium* outbreaks have been associated with drinking water. This organism causes severe intestinal infections and can be a significant health concern.

Fluorescent microscopic particles were used to mimic the transport behavior of *Cryptosporidium parvum* in the aquifer. They traveled through the aquifer about three times faster than predicted. USGS research microbiologist Dr. Ronald Harvey explained that “The fast transport of these particles, their low removal in the aquifer and the extensive nature of the highly porous zones of limestone suggest that chlorine-resistant, surface-water pathogens pose potential threats to the drinking water withdrawn from the Biscayne aquifer.”

In response to the red dye test, the Miami-Dade County Department of Environmental Resources Management and the Miami-Dade Water and Sewer Department requested the USGS conduct additional studies that included a complex series of tracer tests conducted in February 2004. The analyses and results of these tests, published in three articles in the scientific journal, *Water Resources Research,* show that the potential movement of chemical contaminants and pathogens within the Biscayne aquifer can occur very quickly, primarily through highly porous limestone. A complementary study by USGS and university scientists provides additional insight to the broad continuity of these highly porous flow zones. It is published in the journal *Geological Society of America Bulletin*.

Robert Renken, USGS hydrologist and one of the lead investigators of the study said, "The highly porous nature of the Biscayne aquifer presents significant water-management implications, especially as it relates to the inadvertent release of contaminants within or immediately outside the well field protection area."

Tests were conducted by injecting a tracer solution into the aquifer for a period of one hour. However, the tracer solution was still detected 160 hours later (about one week) at the NWWF production well. “This indicates that if a contamination event occurs in the Biscayne aquifer that continues for days, weeks, or months it has the potential to degrade water quality and could persist from years to decades,” said Dr. Allen Shapiro, USGS research hydrologist involved in the study.

Public-supply wells in the Miami-Dade area are required to have a designated distance or well-head protection zone around them to protect against contamination. Currently, the well-field protection zones are determined by numerical models that simulate groundwater travel-times. The tracer test results indicate that the numerical models are based on an oversimplified understanding of how groundwater moves through the Biscayne aquifer. Current protection zones are not sufficient to protect water supply wells from possible contamination from borrow-pit lakes (artificial lakes created by the mining activities) associated with nearby rock mining activities.

The risk of contamination to groundwater increases when groundwater is located close enough to surface water such that it receives direct surface-water recharge. Some borrow-pit mines are located as close as 800 ft from a municipal supply well. The Northwest Well Field is located in the Lake Belt area where open-pit rock mining activities excavate limestone from the Biscayne aquifer intersecting the same porous aquifer units as NWWF supply wells. The Lake Belt area is located between high-density urban development to the east and freshwater wetlands and water-conservation areas of the Everglades to the west.

The tracer tests demonstrate that existing and proposed rock mines near the NWWF in Miami-Dade County, Florida likely increase the risk of contaminating public drinking water sources. Miami-Dade County Department of Environmental Resources Management and the Miami-Dade Water and Sewer Department requested the study in response to County and public concern that rock mining activities near the NWWF presented much greater contamination risks than previously recognized. These findings will be used to support future water-management and land-use decisions.

The articles published in the journal ***Water Resources Research*** can be viewed at:
http://www.agu.org/pubs/crossref/2008/2007WR006058.shtml
http://www.agu.org/pubs/crossref/2008/2007WR006059.shtml
http://www.agu.org/pubs/crossref/2008/2007WR006060.shtml

The article published in the journal ***The Geological Society of America Bulletin*** can be viewed at:
http://www.gsajournals.org/perlserv/?request=get-abstract&doi=10.1130%2FB26392.1

Follow the path of water on a virtual 3-D tour traveling through a piece of limestone from the Biscayne aquifer. This animation was created using CAT-scan technology.
http://sofia.usgs.gov/people/cunningham.html

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For Discussion May 9, 2014
Sea Level Rise Task Force

From: Virginia Walsh, P.G., Ph.D.
Miami-Dade Water and Sewer Department
Planning Section

I participated in the April 28-29 USGS, CES and Florida Sea Grant Sponsored Technical Meeting, Recommendations for Everglades Restoration under a Future Climate Scenario Working Group: Water Management Response to Hydrology and Sea Level Rise *(Session Leaders: Jayantha Obeysekera, SFWMD & Glenn Landers, USACE)*, and as a result of the working group conclusions, we would like to recommend the below for inclusion in the final SLR Task Force Committee Report. The working group consisted of District, USACE, USGS and County Engineers and Scientists, and Water Managers, and the below represents the group's key action items.

Immediate Action:

- Integrate local-scale surface/groundwater flow modeling between southeast counties, building on existing Miami-Dade and Broward County efforts
- Request from SFWMD a comprehensive study and recommended plan to restore/improve flood damage reduction and protection against salt water intrusion. This should develop the District plan to address a +1 foot SLR, and is recommended to be completed within a 2-year time frame.
    - Provide County request for funding to FEMA and state agencies, along with a cost sharing by the County for rainfall and storm surge future predictions modeling, higher resolution LIDAR data, and development of better models that incorporate the complex coastal geomorphology of South Florida (identified as major data gaps in above session*)*

Long term Goal:

- Support the development of a regional assessment that integrates natural system and built environment exposure to a broad range of sea level rise and climate scenarios.
- Develop a coordinated water management response at the federal, state, and local levels that will be used to guide private and public sector decision making

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June 30, 2014

VIA E-MAIL MAYORW@MIAMIDADE.GOV

Wilbur Mayorga, M.S.,P.E., Chief
Environmental Monitoring and Restoration Division
Miami-Dade County Division of Environmental Resources Management
701 NW 1st Court
Miami, Florida 33136

Re: Comments of Kendall Properties and Investments ("KPI") on Proposed Amendments to Wellfield Protection Ordinance (the "Proposal")

Dear Mr. Mayorga:

This letter is being written on behalf of KPI, a Florida General Partnership that owns approximately 1920 acres located in Miami-Dade County to the east of Krome Avenue and south of Tamiami Trail (the "Property"), most of which is located within the current wellfield protection area for the West Wellfield ("Protection Area"). This letter is also written on behalf of Krome Mining Partners, a Florida General Partnership that owns 300 acres immediately to the south of the Property. Berger Singerman represents both entities. Although the following comments are stated as coming from KPI, Krome Mining Partners shares the same concerns, because the Proposal would expand the Protection Area boundaries to include the property that Krome Mining Partners owns.

As you know, KPI filed a lawsuit against Miami-Dade County (the "Lawsuit") challenging the constitutionality of the current Wellfield Protection Ordinance ("Ordinance") and the Lawsuit is currently in abeyance while KPI and the County are exploring settlement opportunities. We very much appreciate your efforts to facilitate settlement, and we are hopeful that our discussions with the County will result in a mutually agreeable resolution to the litigation.

In the Lawsuit KPI has challenged the constitutionality of the Ordinance, facially and as applied to KPI by the Miami-Dade County Division of Environmental Resources Management ("DERM"), and has asserted, among other things, that the Ordinance imposes an undue burden on KPI that violates KPI's equal protection and substantive due process rights under Article I, Sections 2 & 9, of the Florida Constitution, is unduly vague and burdensome, lacks any rational basis, and is overbroad, arbitrary, and discriminatory towards KPI. While we very much appreciate DERM's efforts to update and improve the Ordinance, we find that the Proposal in its current form does not accomplish these results, or address KPI's constitutional concerns. We therefore welcome the opportunity to submit these comments and work with you to redraft the Proposal in a way that provides significant wellfield protection while protecting KPI's right to be able to have economically viable uses of its Property.

PROPOSAL STRUCTURE

KPI would like to discuss structural rather than substantive issues first, because the complicated way in which the Proposal is organized makes it very difficult for KPI to determine how DERM intends to continue to regulate activities within the Protection Area. In the Lawsuit we discussed structural problems with the Ordinance that have created ambiguities in enforcement and compliance. We continue to be concerned with how the Proposal intends to regulate "hazardous materials" as that term is defined in Code Sec. 24-5. The regulatory provisions are currently contained primarily in Code Sec. 24-43(5) through Code Sec. 24-43(10). The Proposal would eliminate the intermediate subsections (6) through (9).

Subsection (5) of the Proposal, like the Ordinance, begins with two lengthy, unnumbered sentences, each of which is shown as a separate, free-standing paragraph and each of which treats rockmining in conflicting ways. The first paragraph specifically excludes rockmining from the requirement to obtain a Director's written approval, whereas the second imposes that approval requirement for rockmining where hazardous materials are being used. These two sentences are followed by a third free-standing, unnumbered paragraph that imposes conditions on the Director's approval. Some numbered (as letters or roman numerals) subparagraphs are then listed, interspersed with unnumbered subparagraphs, making all it very difficult, if not impossible, to figure out how all of the paragraphs, sections and subsections relate to each other.

The third unnumbered paragraph in subsection (5), for example, provides an exception for fuels and lubricants required for rockmining operations, but its application to rockmining remains unclear in light of the disparate treatment of rockmining operations in the previous two unnumbered paragraphs. The confusion is compounded by the structure of subsection (5) as a whole. There are two unnumbered paragraphs, then a paragraph (5)(a) and (5)(b), followed by another unnumbered paragraph, followed by paragraphs (5)(e) through (5)(f).

The confusion is compounded by the language beginning at the end of subsection (5)(d) to the rest of subsection (5), which is then followed by subsection (10). Subsection (5)(e) rewrites the current covenant requirements to require compliance with subsections (5)(a)-(c), but then ends on a mid-sentence "or," followed by two more subsections, (e) and (f), continuing for several pages, also connected by "or"s but interspersed with complete sentences. It is not clear how the "or"s all fit together, or how those provisions fit with any other part of subsection (5).

It is standard practice in legislative drafting to number all paragraphs and subparagraphs. This enables the reader to understand how all parts of the legislation relate to each other, and forces the drafter to organize systematically. The failure to number all paragraphs is an indication that such systematic organization cannot be readily accomplished without reorganization of the legislation. That needs to be done here. As an example of what might be doable, there could be separate sections explaining what the general regulatory structure is, what specific activities are regulated, and what exceptions or additions apply to particular activities. There may be a variety of other ways to do this, but to lump all the requirements together and then from time to time provide exceptions and additions, often in unnumbered paragraphs, from or to the various regulations, and then provide some exceptions and additions to those exceptions and additions, results in confusion as to the overall intent of the regulation.

WEST WELLFIELD DELINEATION

Since the County approved an "Interim" Protection Area in 1989, scientists from the United States Geological Service, the South Florida Water Management District ("SFWMD"), and the County have spent considerable time and effort to refine their knowledge of the hydrogeology in Miami-Dade County and use that knowledge to develop increasingly complex multi-layer models with smaller and smaller model cells. As our experts have advised us, if the proper models are used, and withdrawal assumptions are based upon actual permitted levels (15 mgd), most of KPI's property would not even be within the Protection Area. Instead, the Protection Area boundary that DERM is now proposing appears to rely upon a single layer model that is both outdated and oversimplified, and eliminates DERM's obligation to evaluate and update the model as new information becomes available.

The Ordinance now imposes a .1 foot draw down assumption exclusively on the Protection Area, not on any other wellfield protection areas. The Proposal would continue the inequity of that assumption in relationship to other protection areas through the application of a composite 95% confidence interval for the Protection Area. This assumption relies upon a computer model to make an uneducated random selection of hydrogeologic parameters, rather than using an updated model based upon decades of Biscayne aquifer studies and guided by more advanced professional analysis.

The modeling in the Proposal reduces the assumed withdrawal rate from 145 to 25 mgd, still above the permitted amount of 15 mgd, but that reduction is offset by the imposition of other unnecessarily restrictive model assumptions. These model assumptions include basing the model period upon the lowest water level for the period and using it as the dry steady-state condition with no rainfall recharge. The modeling also uses an "average" effective porosity value based on averaging the result from one "prematurely terminated" tracer with the value used by the USGS and SFWMD in all previous modeling. This results in the assumption in the Proposal of a 0.12 "average" effective porosity on travel distances, as compared to 0.20 used in other USGS models. This is the average of the 0.04 partial tracer test result and 0.20 value used previously. The model then uses a Monte Carlo approach to evaluate uncertainty in hydraulic conductivity and effective porosity. The presented composite result then selects a dry and wet season scenario that is not an accurate reflection of current scientific knowledge. The intent, as explained in the supporting USGS technical report, is to "[ensure] that the greatest possible capture area is estimated" The overall effect, however, is an unscientifically supportable expansion of the size of the area being regulated with no added wellfield protection benefit.

There are other flaws in the Proposal's delineation methodology as well. The net effect of all this is to expand the boundaries of the Protection Area to include even more of KPI's property than what currently exists, even though more accurate modeling should have the opposite effect. Particularly given the increased regulatory burdens being recommended under the Proposal, as explained below, by expanding the Protection Area to include most of the remaining portions of the KPI property, the Proposal would impose even greater burdens upon KPI's ability to use its property for otherwise lawful purposes than those that are currently being imposed upon KPI, with even less scientific justification.

DEFINITION OF HAZARDOUS MATERIALS

The definition of "hazardous materials" is a key component to determining what the Ordinance regulates. Though without being incorporated into the Code, DERM now apparently relies upon long list of constituents identified simply by name, without any consideration of how the constituents are stored, used, or disposed of, and with no consideration of the likelihood that the particular constituent would or even ever could end up in groundwater, much less within the cone of influence of the intake of the wells of the West Wellfield. The definition in the Proposal would incorporate constituents into the Code, but in a way that is not workable.

The definition in the Proposal creates a rebuttable presumption that "hazardous materials" include anything that contains a chemical that "is present in the waste, product, substance, combination, or breakdown product in concentration levels that exceed" the levels the County and the Florida Department of Environmental Protection ("FDEP") have established by ordinance and rule, respectively, as Groundwater Cleanup Target Levels ("GCTLs"), and the FDEP has established as Maximum Contaminant Levels ("MCLs") and Secondary Standards. The GCTLs are used to determine whether specified contaminants are in groundwater in concentrations that would trigger the need to undertake contamination site assessments and remedial action. The MCLs set minimum levels for determining whether public drinking water systems meet the standards set forth in the Florida Safe Drinking Water Act. The Secondary Standards set standards under the Florida Safe Drinking Water Act for determining the organoleptic quality of drinking water (color, odor, taste).

Neither FDEP nor the County adopted the GCTL, MCL, and Secondary Standard concentration level criteria for application to media other than groundwater or drinking water, and the criteria have not yet been so applied, for good reason. There is no rational basis for applying those concentration levels as a regulatory tool to determine whether the same concentration levels of the particular constituents, when contained, for example, in commercial products or raw materials, often within buildings with concrete floors, should thereby be treated as hazardous materials. A groundwater guidance concentration should not be used as a surrogate concentration in another (liquid) medium that would be, for example, stored at the land surface in a wellfield protection area. Groundwater guidance criteria (GCTLs, MCLs) are established based not only on the inherent toxicity of a chemical, but also on conservative assumptions regarding the extent to which exposure to such chemicals at particular concentration levels might cause toxicity as the result of human contact from groundwater through ingestion, inhalation, and dermal contact (depending upon the material). These assumptions include, among other things, ingestion of groundwater at a rate of two liters per day. It is completely inappropriate to assume that these assumptions would be relevant to a product such as a pesticide stored at the land surface in dry form in a wellfield protection area. In addition, the extent to which a chemical even in liquid form would be likely to contaminate groundwater to a level that exceeds the corresponding groundwater guidance criterion depends primarily on the location where stored, the concentration of that chemical and the quantity of the product which contains the chemical that may come in contact with the groundwater, if released at the surface.

In addition, it is not possible to compare chemical concentrations in liquids measured in units of milligrams per liter (mg/L) or micrograms per liter (ug/L) with solids measured in units of milligrams per kilogram (mg/kg) that may be stored or used at the land surface. For example, the active chemical in a pesticide formulation would be measured in mg/kg of the dry pesticide product to be used for the formulation. For such use, that pesticide may need to be dissolved in a carrier fluid, such as water. The concentration of active pesticide chemical in the resulting liquid, in mg/L or ug/L, would depend on the amount of pesticide and the volume of liquid used. There is no way to equate in any direct manner the dry concentration of a chemical with a liquid (e.g., groundwater) guidance concentration.

The problem with using these concentration levels as a regulatory tool is illustrated, for example by the proposed exclusion of a "de minimis quantity" in the Proposal, which is expressed in terms of liquid volume (i.e., one quarter U.S. gallon, equivalent to 946.4 milliliters). There is no equivalent definition of what constitutes a de minimis quantity of a solid material, which would be expressed in units of, for example, pounds or kilograms. This is an important oversight, given that so many of the listed chemicals can be stored in dry form.

A similar problem can be shown with the Proposal's exclusion from regulation of certain types of prepackaged products, because the exclusion only applies if the products are kept within certain types of buildings and only for personal or retail use. This approach does not take into consideration more logical potential pathways for contamination, such as the building's imperviousness to possible spills, how the products are packaged, whether the products are stored in liquid or dry form, and whether the products are soluble. Furthermore, the exception does not even allow for the delivery of the prepackaged products to a building or their removal from it, only their storage within the building, which essentially renders the exception unattainable.

In any event, the mere appearance of a chemical name on the lists used to define a term such as "hazardous materials" is of no value in assessing how or under what conditions such a material may (or may not) represent a potential hazard. It is not the presence of a chemical which poses a hazard, but the concentration, or the quantity, or the formulation of it that is of importance, as well as its use. Chemical reportable quantity thresholds and criteria must be based on reasonable considerations of amount, concentration, and formulation, and those will be further influenced by assumptions regarding wellfield characteristics for a specific wellfield, including the size of its cone of influence. If the assumptions are inappropriately large, then projected areas of pumping influence, and thus the associated permissible chemical quantities, concentrations, or formulations will be inappropriately restrictive. In order to be predictive of potential hazards, and thus to be protective against such potential hazards, some information regarding physical/chemical properties of relevant chemicals, as well as significant quantities, and/or significant concentrations is important. Dilute concentrations of chemical materials inherently pose a lesser hazard in comparison to highly concentrated forms, and at sufficiently low concentrations a de minimis condition is reached, wherein no meaningful hazard exists.

The aggregate quantity of a material that is "used, generated, handled, disposed of, discharged or stored" at a location will greatly influence the risk that may be posed by that material in terms of contamination of groundwater or other environmental media. That conclusion is an important concept underlying development of "reportable quantities" in specific programs such as the Community Right-to-Know provisions established under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, Superfund), and the Superfund Amendments and Reauthorization Act (SARA). As a practical example, implementation of an individual reportable quantity for a chemical of interest would provide a limit below which that chemical which is "used, generated, handled, disposed of, discharged or stored" would not be of regulatory interest. Other jurisdictions in Florida and elsewhere have implemented similar systems of reportable or threshold quantities for use in wellfield protection. We suggest that you should consider approaches that have proven to work elsewhere rather than a unique, untested one.

If DERM does not develop such a different approach, a property owner within a wellhead protection area will continue to be required to comply with prohibitions against using hazardous materials based upon a definition that is too ambiguous to understand, thereby leaving the Ordinance, once amended, to be the subject of future challenges. While the proposed definition creates a "rebuttable presumption" regarding what is a hazardous material, the definition provides no guidance or explanation as to how that presumption can be overcome. As indicated by KPI's own experience to date, particularly as it has involved DERM's treatment of KPI's proposal to store on the Property native Everglades muck that contains naturally-elevated levels of insoluble arsenic, DERM will likely continue to require that a property owner seek relief before the Environmental Quality Control Board ("EQCB") to be able to overcome the presumption. KPI went through this process without the benefit of any standards or guidance being provided in the Ordinance regarding what regulatory criteria should be followed to obtain that relief. Since the Proposal continues to offer no process for overcoming the presumption, the logical expectation is that initiating EQCB review would remain the only means for doing so, with no basis to expect any consistency as to the regulatory results.

REGULATORY PROVISIONS

Once the Proposal's regulatory structure and definition of hazardous materials are combined, the overall treatment of hazardous materials continues to be ambiguous, lacking a sufficient rational basis, and at times unequally applied. Because of the structural ambiguities previously described, it is hard if not impossible to identify all of the problems with the Proposal. KPI is therefore offering comments on only a few critical issues.

The Covenant

The requirement for execution of a covenant running with the land has been an essential component of the regulatory structure for the Ordinance, and would continue to be so under the Proposal. KPI's concerns with the current covenant requirements have been explained in detail in the Lawsuit. The Proposal does not solve these concerns, and may make them even greater.

There is no rational basis for requiring a covenant, as one is neither necessary nor useful as an enforcement tool. As currently required by DERM, recording of covenants results in restrictions on the use of property within a wellfield protection area that currently are or may become inconsistent with the requirements themselves, and will become more inconsistent as the Ordinance changes from time to time, whether by the Proposal or by other amendments. A recorded covenant may even become inapplicable, because the encumbered property may not remain within the protection area when the County adopts a new map,

A covenant is also unnecessary. Wellfield protection areas are already regulated by the Ordinance generally, and specifically through any provisions of a Director's authorization. Both the boundaries of the protection area and the details of any Director's authorization on a particular parcel of property are easily available to anyone doing even a modicum of due diligence, no more so than a property records search to find a covenant, and likely more easily. To the extent a Director's authorization covers less than the entire parcel, the smaller area would be spelled out in the authorization, as well as any conditions for or restrictions on use, as modified from time to time.

This is particularly problematic given the inherent ambiguity of determining what a hazardous material is. The covenant requirement thereby creates an unnecessary and harmful cloud upon the title to the property. Because the definition of hazardous materials is so vague, it will be very difficult, at best, for a prospective purchaser to understand what further regulation a covenant may impose upon the property beyond any specific requirements and restrictions imposed by a Director's authorization, or why that additional layer of regulation is even required.

The Proposal would worsen one already problematic aspect of the existing Ordinance. Under the Ordinance, the County Commission has to approve the form of the language for the covenants, which places at least some level of review on what activities might be proscribed, under what circumstances. The Proposal would eliminate the Commission approval requirement. As a result, there would be nothing to constrain DERM from imposing whatever additional requirements in a covenant that it might, in its exclusive discretion, wish to include. This would eliminate a clear existing constraint upon the ability of DERM staff to place additional use or other legal restrictions on impacted property that are beyond those expressly authorized by County Commission Ordinance or Resolution.

There are two simple ways to solve these problems. The first and best, as already noted, would be to eliminate the requirement altogether. The second would be to adopt into the Code a form or forms for covenants, and limit the form requirements so that a covenant would do only two things: place the public on notice that the property is within a wellfield protection area, and identify by reference number the existence and location of a Director's authorization describing what uses are authorized and how those or any other uses are constrained in any way. That way, if either the authorized uses or restrictions change or the Ordinance is amended, the covenant notice will remain accurate without having to be refiled as amended.

The Elimination of KPI's Available Uses

The Ordinance now provides guidance to property owners as to how particular activities can be allowed by including in subsection (10) a "Table E-1" that provides specific land uses that can be approved within a Protection Area. The Proposal would eliminate that list of uses, and replace that list with some criteria in subsection (1) that are applicable only to the Northwest Wellfield.

This leaves KPI with no list and great uncertainty over what might otherwise be authorized by the Director, if anything. As previously explained, the Proposal would restructure subsection (5) in a manner that is extremely difficult if not impossible to understand as to the scope of regulation. Even with regard to rockmining, the Proposal provides substantial uncertainty as to what may be authorized. As has already been discussed, the first two paragraphs of Subsection (5) treat rockmining differently. Assuming the second paragraph overrules the first, then, as indicated by the second unnumbered paragraph after paragraph (b), any storage or use of hazardous materials would be prohibited not just within a 210-day travel time of the West Wellfield, but also within what little else of the Property is in the new Protection Area, since KPI is outside the Urban Protection Boundary, with the possible exception of fuels and lubricants, though it is not clear what the conflicting provisions within that paragraph are intended to do with regard to fuels and lubricants.

Even assuming the fuel and lubricant exception would apply to rockmining, it appears from the Proposal that the exception would not apply for any other purpose. As a result, even if KPI is allowed to store or use fuel and lubricants for rockmining machinery, it would not be allowed to use fuels and lubricants and fuels for any other purpose, which could substantially reduce, if not eliminate, any other possible uses for the Property. There is no rational basis, at least from the standpoint of wellfield protection, for allowing the very same fuels to be used for rockmining but not for any other purposes, regardless of the quantity or method of storage of those fuels, and regardless of the intensity of the use of the Property.

The Proposal's treatment of small quantity generators of hazardous waste reinforces KPI's concerns regarding the elimination of uses other than, possibly, rockmining. The exception for small quantity generators excludes any such generators outside of the Urban Development Boundary, which would exclude KPI from being able to take advantage of the exception, while allowing those closer to a wellfield, including the West Wellfield to take advantage of the exception if they are located within an Urban Development Boundary. The only bearing the exception has upon wellfield protection is the opposite of such protection, since KPI's property is further away from the West Wellfield than other property within the Protection Area. There is no rational basis for applying this requirement in such a discriminatory manner.

Overall, even more so than the Ordinance, the Proposal focuses almost exclusively on what activities are prohibited rather than what activities are allowed, and what exceptions, and exceptions to exceptions, exist for those prohibitions. This leaves any comprehensive understanding of what are those exceptions entirely to the discretion of the EQCB, for which no criteria for approval have been established beyond the EQCB's general authority. For a protection ordinance to be workable, and not deprive affected property owners of reasonable uses of their lands, the focus of the regulations should be on how activities are regulated, not what activities are prohibited, subject to what exceptions apply and what exceptions to those exceptions. For activities that are regulated, the focus should be on how those regulations should be applied, with what best management practices. In the end, a workable Ordinance can exist only if there is a fundamental revision of the Ordinance that regulates wellfield protection areas in a simple, straightforward and coherent manner that provides all interested parties with a clear idea of what is being regulated and how.

CONCLUSION

Once again, many of our problems with the Proposal, as with the Ordinance as currently drafted, are based upon the ambiguous way in which it is written, but the parts we do understand do not, in our view, satisfy the constitutional rational basis test, which requires legislation to bear a rational and reasonable relationship to a legitimate state objective, and prohibits the legislation from being imposed in an arbitrary and capricious manner. *See, e.g., Dep't of Corr. v. Fla. Nurses Ass'n*, 508 So.2d 317, 319 (Fla. 1987). In addition, if the Proposal is implemented by the County in the way we read it, the governmental ends implemented by the Proposal, as with the current Ordinance, would lack an essential nexus and rough proportionality to the protection that the County seeks to achieve, and thereby result in an unconstitutional taking by the County of KPI's property. *Koontz v. St. Johns River Water Mgmt. Dist.,* 133 S. Ct. 2586 (2013).

Rather than to continue to raise these constitutional issues or otherwise litigate with the County over the Ordinance, we look forward to the opportunity to work with DERM to come up with a more workable, reasonable and scientifically-based Ordinance. Thank you for your consideration.

Sincerely,

Mitchell W. Berger

Berger Singerman LLP

cc: Kendall Properties and Investment Partners

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Date: 11 August 2014

To: Wilbur Mayorga, P.E.
Chief, Environmental Monitoring and Restoration Division
Department of Regulatory and Environmental Resources
Miami-Dade County

From: David A. Chin, Ph.D., P.E., BCEE
Professor of Civil and Environmental Engineering

Subject: USGS Delineation of Travel-Time Contours in NWWF and WWF

I would like to alert you to a serious issue relating to the wellhead protection regulations that are being developed by your office. The travel-time contours that are being proposed as boundaries of the wellhead protection areas in the Northwest Wellfield (NWWF) and West Wellfield are significantly underestimated due to a major shortcoming in the USGS methodology. This shortcoming is briefly explained below.

The travel time of groundwater from any given location to a production well is equal to the sum of the travel time through the aquifer plus the travel time through intermediate lake(s), if present. To account for uncertainty in the aquifer-portion of the travel time, the USGS has used an elaborate Monte Carlo approach, however, the uncertainty in the lake-portion of the travel time is neglected; the travel time in all lakes are simply taken as being equal to their mean value. In reality, travel times through well-mixed lakes under ideal circumstances are quite uncertain, travel times in well-mixed lakes can be approximated by an exponential probability distribution, and the mean travel time in such lakes are exceeded more than 60% of the time. By neglecting the uncertainty in the lake-portion of the travel time, the calculated uncertainty in the total travel time (lake + aquifer) is in error. This error is largest for particle tracks that are mostly through lakes.

To illustrate the magnitude of the problem, consider a parcel of land on the north shore of Lake 22 in the NWWF. According to the USGS travel-time contours, this parcel of land lies on the 210-day contour, assuming as 95% confidence interval as per the Varljen and Schafer algorithm. This USGS result is obtained since the mean travel (i.e., residence) time in Lake 22 is assumed to be 239 days and the aquifer-

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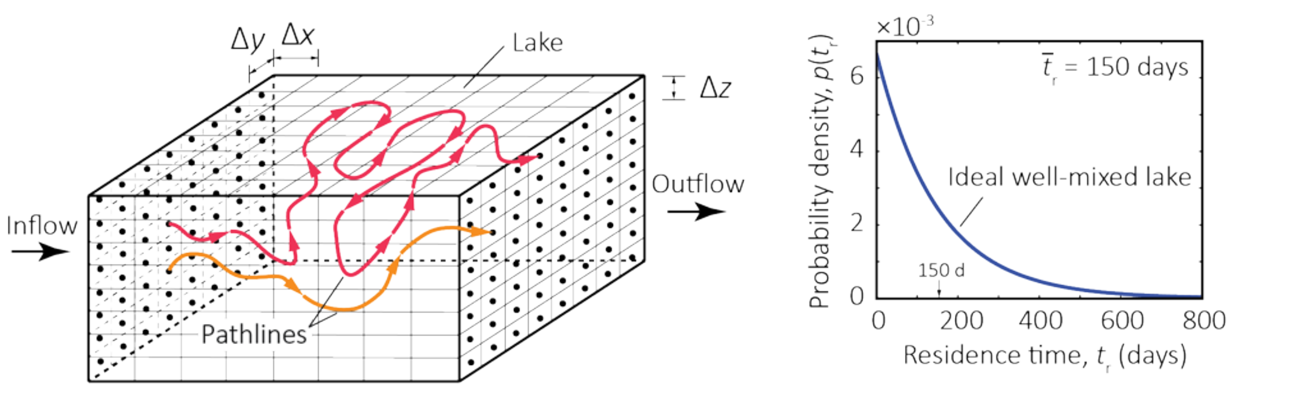
portion travel time is less than 10 days. However, if the residence time in Lake 22 is (more correctly) taken as having an exponential probability distribution with a mean of 239 days, and the aquifer residence time is assumed to have a mean of 10 days, then the aforementioned parcel of land on the north side of Lake 22 has around a 20-day travel time corresponding to the 95% confidence interval. Taking the regulatory travel time as 210 days when the actual travel time is around 20 days (for the same confidence interval) should be a major concern.

There are a few other technical issues of concern, however, the aforementioned issue is the most severe and the one that must be addressed before the proposed contours are adopted and enforced. This is an urgent issue. Knowing the professionalism and technical expertise of my colleagues at USGS, I anticipate that they will be eager to make the appropriate revisions in their calculations. If you decide not to change the proposed contours, please let me know when and where this item is to be publicly presented for adoption.

Thank you for your urgent attention to this matter.

P.S. The following diagram might be helpful in understanding the issue. This diagram shows the theoretical probability distribution of residence times in a well-mixed lake that has a mean residence time of **150 days**. In reality, there is a **63%** probability that the travel time is less than 150 days. If it is desired to select a travel time that is only exceeded 5% of the time (which would normally be desirable), then a travel time of **8 days** should be used in particle tracking through the lake, not 150 days.



(a) Pathlines through lake (b) Probability distribution of residence times

Cc: Lee N. Hefty, Assistant Director, RER
Tom Robertson, Assistant County Attorney for EQCB

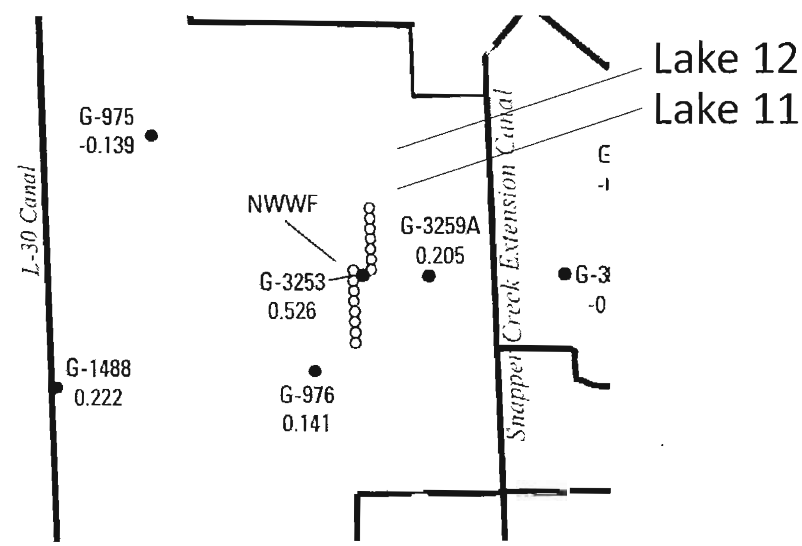
<u>Major</u> shortcomings of the USGS Model of Travel Times through Lakes in Miami-Dade County

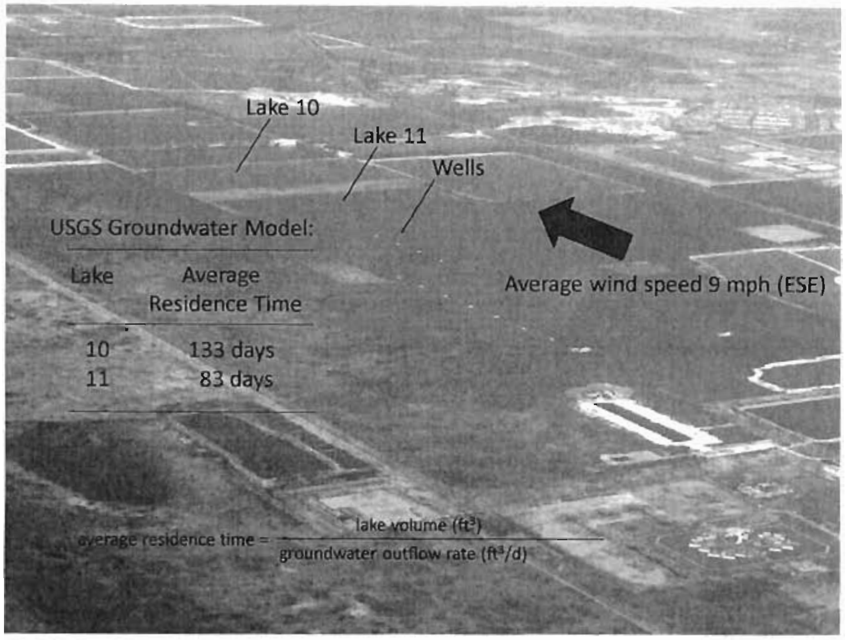
Issues and answers

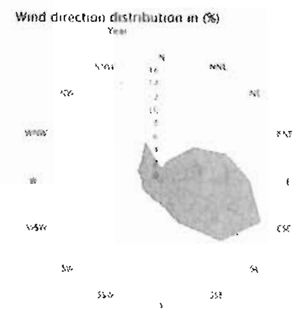
Presentation at RER on March 12, 2015

David A. Chin, Ph.D., P.E., BCEE
Professor of Civil and Environmental Engineering

<u>Lakes in Northwest Wellfield:</u>

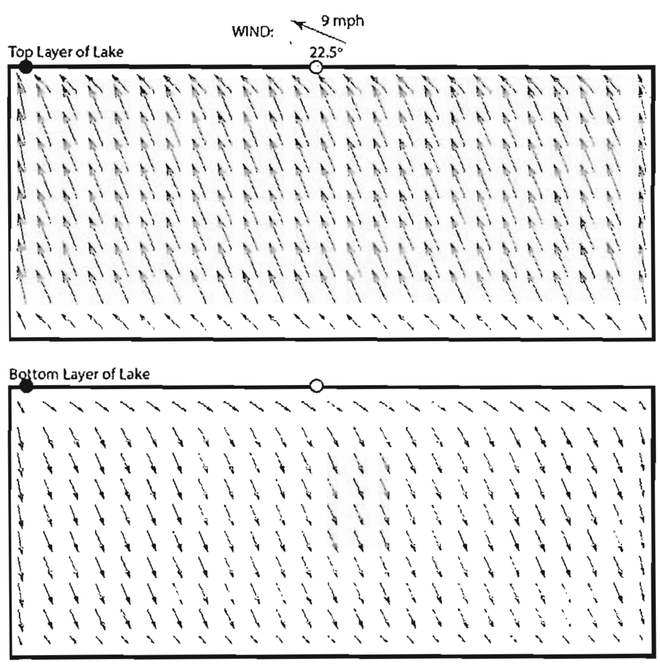






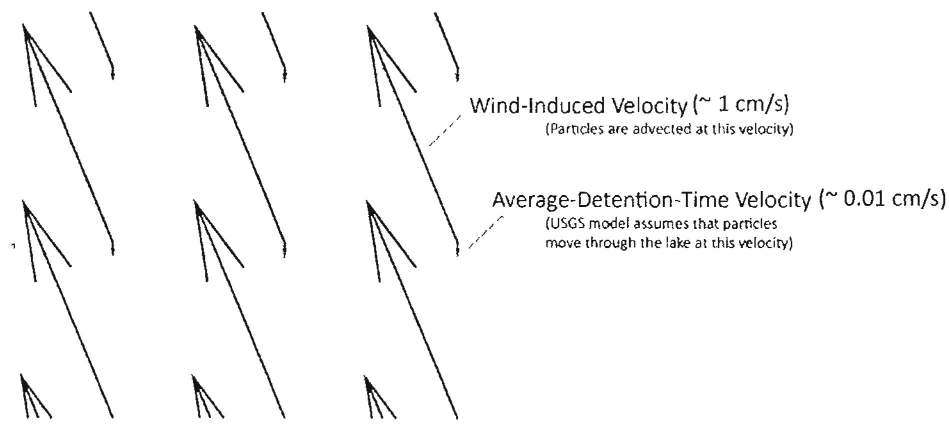
MIAMI

Wind-Induced Circulation in Lake 11:



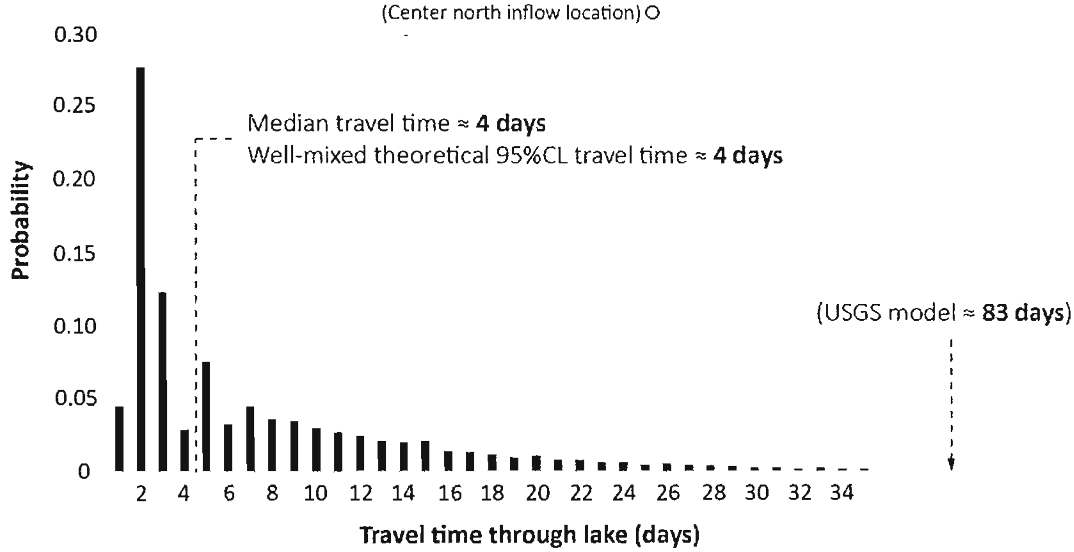
MIAMI

Actual Velocities in Lake Compared with Detention-Time Velocity assumed by USGS

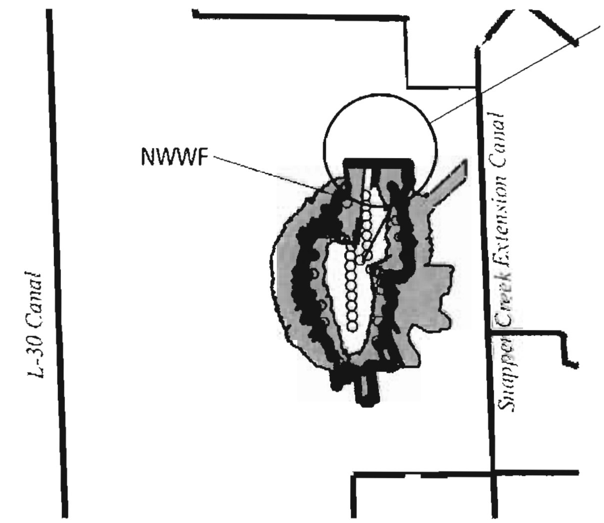


Lake 11

(Center north inflow location) O



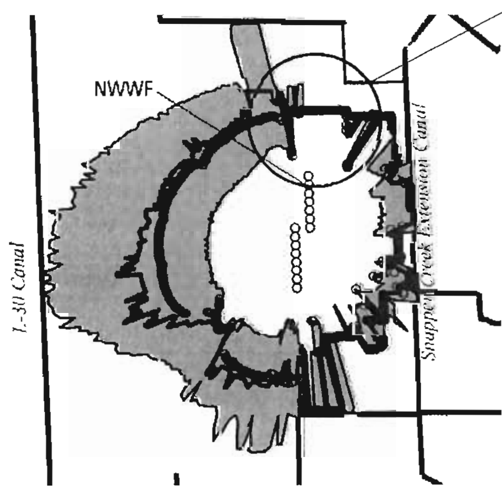
Major Error #1a: 30-day travel time contours



USGS model: ~83 days to travel through Lake 11

Reality: ~4 days to travel through Lake 11

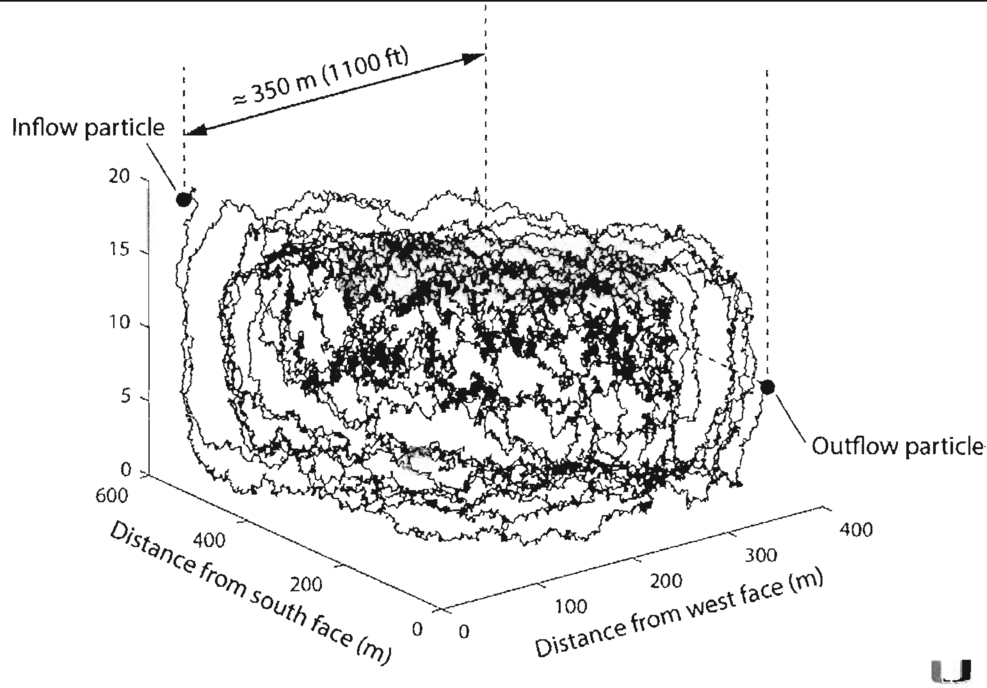
Major Error #1b: 210-day travel time contours



USGS model: More than **210 days** to travel through 2 lakes

Reality: Probably **~10-15 days** to travel through 2 lakes

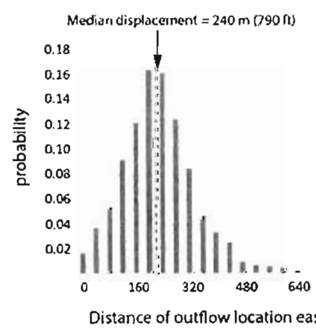
Example of actual particle track through Lake:



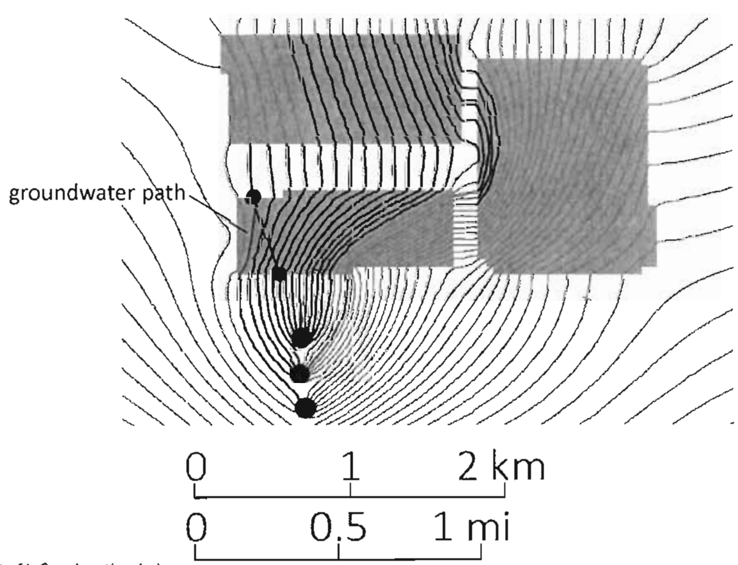
<u>Major Error #2:</u> In USGS model particles in lakes follow groundwater paths

(Lake circulation, which dominates the particle trajectory, is not taken into account.)

Actual path displacement:



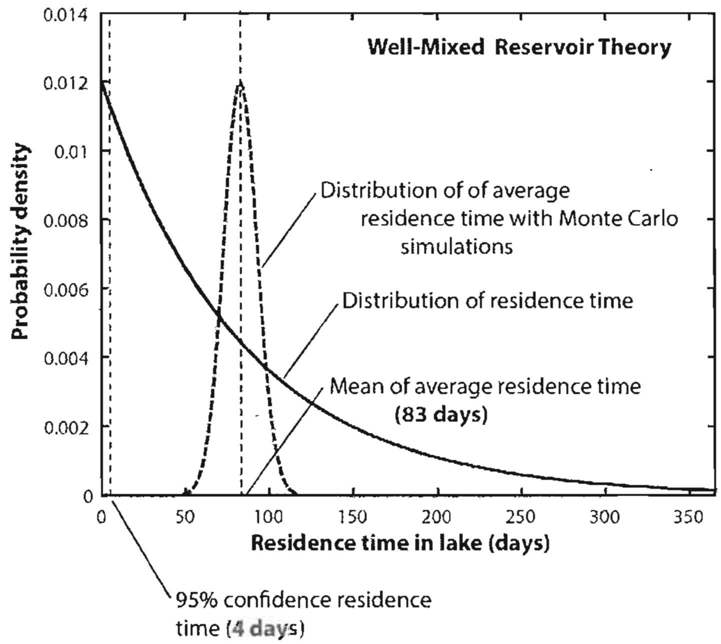
USGS Model:



Major Error #3: Inconsistent application of well-mixed reservoir theory

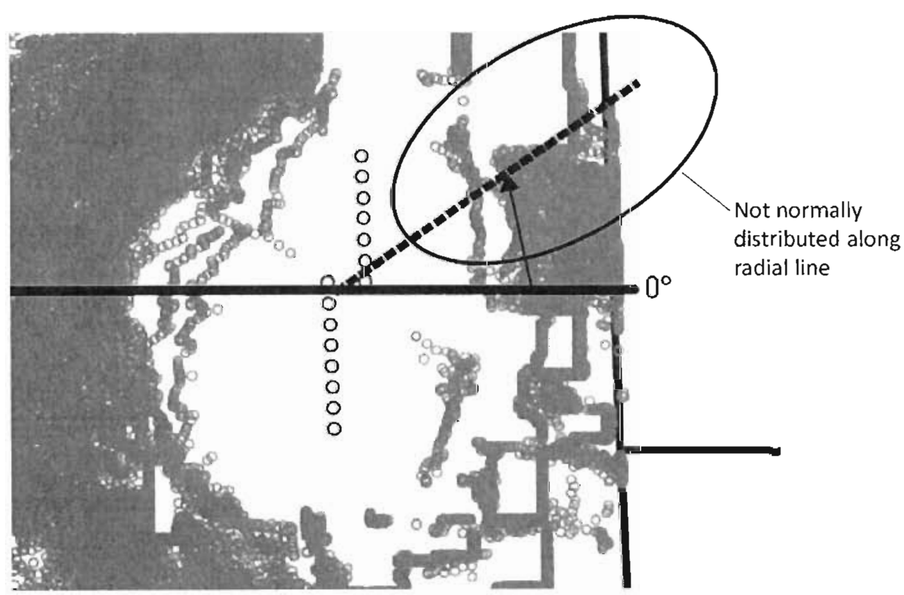
(Monte Carlo simulations only vary the average residence time in the lake.)

This is inconsistent with the calculation of travel-time contours with 95% confidence.



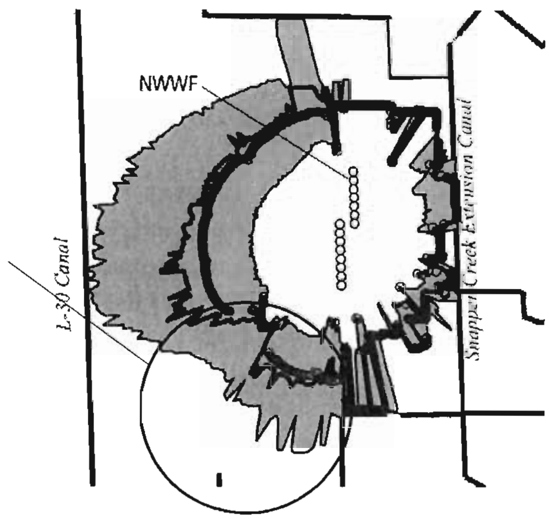
Concern #1: Inappropriate Location of Confidence Interval:

[Varljen and Schafer (1991) method not appropriate]



Concern #2: **Ragged Confidence Intervals:**

Unrealistic, due to insufficient number of particles



Conclusions

- **Major Errors:**
  - Travel-times through lakes (which ignore lake circulation) are very inaccurate.
    (e.g., USGS Report: "In general near the NWWF, the capture zones in areas with lakes were smaller in areal extent than capture zones in areas without lakes.")
  - Particle outflow locations and particle trajectories within lakes are very inaccurate.
  - Inconsistent application of theory, assumed lake residence time exceeded ~50% of the time.

- **Concerns:**
  - Inappropriate location of confidence intervals (uses radial classification, but very little radial symmetry).
  - Unrealistic ragged confidence intervals.

- **Where to go from here:**
  - Assertions presented here could be easily validated by dye tests, if assertions are disputed.
  - Use lake-specific probability distributions of travel times in the USGS groundwater model.
  - (Possibility: USGS/UM work together on final model, avoid conflict of interest.)
  - Fix must be made, since both existing and proposed wellhead protection areas are inaccurate.

United States Department of the Interior

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August 25, 2014

To: Wilbur Mayorga, P.E.
Chief, Environmental Monitoring and Restoration Division
Department of Regulatory and Environmental Resources
Miami-Dade County

From: Dorothy Sifuentes, Ph.D.
Supervisory Hydrologist, South Florida Hydrologic Studies Section
U.S. Geological Survey Florida Water Science Center

Thank-you for forwarding comments received from Professor Chin. We appreciate both the comments and the opportunity to respond. Although we cannot address how the study results will be used by MDRER for the proposed well-field ordinances, we hope to clarify some misconceptions. Below we present an excerpted comment from Professor Chin in italics, and our response follows in plain text.

"The travel time of groundwater from any given location to a production well is equal to the sum of the travel time through the aquifer plus the travel time through intermediate lake(s), if present. To account for uncertainty in the aquifer-portion of the travel time, the USGS has used an elaborate Monte Carlo approach, ***<u>however, the uncertainty in the lake-portion of the travel time is neglected; the travel time in all lakes are simply taken as being equal to their mean value</u>****. In reality, travel times through well-mixed lakes under ideal circumstances are quite uncertain, travel times in well-****<u>mixed</u>*** *lakes can be approximated by an exponential probability distribution, and the mean travel time in such lakes are exceeded more than 60% of the time. By neglecting the uncertainty in the lake-portion of the travel time, the calculated uncertainty in the total travel time (lake + aquifer) is in error. This error is largest for particle tracks that are mostly through lakes. "*

The statement that the uncertainty in the lake-portion of the travel time is neglected is not correct. Uncertainty of the lake-portion of the travel time of each particle was quantified in two ways:

1) **Residence-time uncertainty:** The residence time of each lake was a stochastic parameter altered in each of the 10,000 realizations of the model. The way this was implemented was through calculation of the steady-state outflow of the lake into the aquifer from the steady-state model and then the mean residence-time was calculated (also using an estimate of the

lake volume) using the equation $t_r = \frac{V}{Q}$ where t_r is the residence time (in days), V is the estimated volume of the lake (in cubic feet) and Q is the steady-state volumetric flow rate of the lake into the aquifer (in cubic feet per day). In effect, this calculation in the stochastic process used in the study allowed implementation of 10,000 different residence times for each lake in the model to be evaluated. Lake residence time data are not available for the deep, man-made mining-pit lakes in the Lake Belt Region and as a result there is considerable uncertainty for this parameter. The residence-time calculation used in this study for each lake permitted incorporation of lake residence-time uncertainty in estimated capture zones. In summary, a unique mean residence-time of each lake was calculated for each realization and the assemblage of 10,000 unique mean residence-times for each lake was used to estimate capture zones for the NWWF and WWF.

2) **Path uncertainty:** In well-mixed lakes, particles could take a variety of different paths to get through the lake which can be conceptualized through implementation of an exponential probability distribution approximation of particle travel time. In this study, we calculated travel-times using 10,000 unique realizations of hydraulic conductivity fields which resulted in 10,000 unique aquifer flow fields. The directions and velocities of the particles used in MODPATH are controlled by this flow field (along with the value of effective porosity). Therefore, within each lake, which is represented by MODFLOW cells of high hydraulic conductivity and an effective porosity of 1.0, each particle could potentially take 10,000 different paths through that lake based on each unique flow field. The simulation of the particle pathlines in this manner allows for another estimate of the uncertainty of model input parameters on travel-time based capture zones. We believe that use of the stochastic approach used in this study to quantify travel-time is a more defensible approach than use of a single deterministic model given the uncertainty of hydraulic parameters and hydrologic conditions and processes in the study area.

It is understood that there are numerous approaches that could be used to represent transport of dissolved constituents in this modeling effort. It is also understood that any approach will have unique assumptions and limitations. A more complicated approach and (or) model may have represented the lake mixing processes in a more physically-based manner but would likely have limited the ability to quantify capture zone uncertainty. We believe the selected approach is a defensible approach for simulating not only the potential particle pathways, but also the residence times of these lakes. The compilation of 10,000 model runs allows for quantification of the uncertainty inherent in many of the aquifer input parameters and processes; the 95% confidence interval calculation (specifically the upper bound 97.5 percentile contour) was determined to be a conservative estimate for decision-making support for water resource managers.

Regarding the model yielding a conservative estimate of drawdown contours and travel-time capture zones, the capture zone model was specifically designed to calculate conservative capture zones and drawdowns for resource protection. As a result, parameter distributions intentionally included values within the range of possible values but also those that would result in conservative estimates of capture zones and travel times. For example, effective porosity values implemented in the model were as low as 4%. Hydraulic conductivity values for the one-layer model were up to

250,000 ft/day. The dry-day model run effectively had no rainfall for steady-state conditions (which is very conservative). Canal-stage values used in the MODFLOW river package were some of the lowest on record for the dry-day model run. Design-capacity pumping rates were used for the wells and exceed historical pumping rates. The selected modeling approach and assumptions were made early on in the study and were agreed upon by both USGS scientists and county water-resource managers as defensible and necessary for a conservative estimate of drawdown and travel-time based capture zones. The modeling approach and assumptions and model results were also technically reviewed by independent hydrologists (internal USGS and external reviewers) with significant experience quantifying model uncertainty and prediction uncertainty.

MIAMI-DADE COUNTY
Carlos A. Gimenez, Mayor

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November 3, 2014

Kathy Aterno
Florida Director
Clean Water Action/Clean Water Fund
7300 North Federal Highway, Suite 200
Boca Raton, Florida, 33487

Re: Comments dated June 30, 2014 submitted on behalf of Joint Comments from Clean Water Action, Everglades Law Center, Florida Wildlife Federation, National Parks Conservation Association, Sierra Club Miami Group, Tropical Audubon Society, regarding the USGS Delineation of Travel Time Contour in the Northwest Wellfield and West Wellfield Protection Areas

Dear Ms. Aterno:

The Department of Regulatory and Economic Resources–Division of Environmental Resources Management (DERM) is committed to working with stakeholders to ensure that Miami-Dade County's wellhead protection program represents a technically sound and balanced approach to protecting the county's drinking water resources. To this end DERM appreciates your input into the process.

On August 11, 2014 DERM requested that the USGS review and provide a response to the technical comments provided in your referenced correspondence. Please find attached the USGS's response.

If you have any questions concerning the foregoing please contact me via email at mayorw@miamidade.gov or at (305) 372-6700.

Sincerely

Wilbur Mayorga, P.E., Chief
Environmental Monitoring and Restoration Division

Attachment
pc: Jack Osterholt, Deputy Mayor (josterholt@miamidade.gov)
Lourdes Gomez, Deputy Director, RER (lgomezt@miamidade.gov)
Tom Robertson, CAO (ROBERT@miamidade.gov)
Sara Fain, Everglades Law Center (sara@evergladeslaw.org)
Manley Fuller, Florida Wild Life Federation, (wildfed@gmail.com)
John Adornato, National Parks Conservation Association (jadornato@npca.org)
Stephen Mahoney, Sierra Club Miami (stephen.mahoney@florida.sierraclub.org)
Laura Reynolds, Tropical Audubon Society (director@tropicalaudubon.org)
Lee Hefty, DERM Director

United States Department of the Interior

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August 25, 2014

To: Wilbur Mayorga, P.E.
Chief, Environmental Monitoring and Restoration Division
Department of Regulatory and Environmental Resources
Miami-Dade County

From: Dorothy Sifuentes, Ph.D.
Supervisory Hydrologist, South Florida Hydrologic Studies Section
U.S. Geological Survey Florida Water Science Center

Thank-you for forwarding comments received from Clean Water Action, Everglades Law Center, Florida Wildlife Federation, National Parks Conservation Association, Sierra Club Miami Group, and Tropical Audubon Society. We appreciate both the comments and the opportunity to respond. Although we cannot directly address comments about how the study results are used by MDRER for the proposed well-field ordinances, we can address technical comments about the model and model results. Below we present the excerpted stakeholder comments in italics, and our response follows in plain text.

"Since the main objective of the model was to determine travel times, the model should have been calibrated based on travel times determined through tracer studies rather than observed groundwater levels. The USGS MODFLOW model utilized by the County incorporated the 2003 tracer tests of the Northwest Wellfield into the effective porosity parameter; however, with this method of calibration, potential errors in water levels would lead to greater errors in travel times."

The model was not calibrated to the tracer-test travel times for three reasons: 1) the scale of the model needed to estimate capture zones is much larger than the scale of the tracer tests and therefore is not feasible, 2) tracer tests are sensitive to hydrologic conditions present during the test and therefore the exact antecedent and ambient conditions in the aquifer would need to be known and simulated for a local-scale model calibration (for which no local-scale model exists) and most importantly 3) there is considerably uncertainty regarding the effective porosity estimate from the local-scale tracer tests which hinges on whether one assumes flow contribution from only the main preferential flow zone versus all the flow zones. From Renken and others (2008):

"If it is assumed that the majority of the tracer mass and the peak concentration associated with the breakthrough curve is attributed solely to the 0.9 m-thick touching-vug flow zone at the −9.5 m depth, the transport porosity is estimated to be 0.41. This estimate of the porosity is consistent with the range of the porosity in the touching-vug intervals reported by Cunningham et al. [2006b] from inspection of cores and borehole image logs. In contrast, if it is assumed that all touching-vug flow zones within the open-hole interval of the injection well contributed to tracer migration and the time of the peak concentration, the porosity estimate is reduced by an order of magnitude to 0.04. Under this assumption, the cumulative thickness of all touching-vug porosity is approximately 9 m. This estimate should be considered a lower bound because the total mass of the tracer was not recovered, which would have resulted in a much larger mean arrival time. A larger mean arrival time when accompanied by a larger formation thickness in equation (1) would result in a larger estimate of the porosity."

Therefore, even on the relatively small scale of this 2003 tracer test, considerable uncertainty exists as to the estimated effective porosity of this area. It can be surmised that at the scale of the capture zone model, the uncertainty of values and the spatial variability of effective porosity would be even greater.

In order to best consider and quantify the effects of effective porosity on estimated capture zones, the effective porosity was sampled from a Gaussian distribution and varied stochastically in each of the 10,000 model runs to get a composite confidence interval for NWWF and WWF capture zones and travel time contours. The effective porosity values of 0.04 and 0.41, as reported in Renken and others (2008) for the NWWF 2003 tracer test, were included within the Gaussian distribution that was sampled during the stochastic runs. Therefore, these values were directly used in the modeling effort (along with other values between 0.04 and 0.5, with a mean expected value of 0.12, as discussed in the report).

"Moreover the inherent heterogeneity and anisotropy of the aquifer is not taken into account."

The inherent heterogeneity, and more importantly uncertainty of the heterogeneity in regards to hydraulic conductivity is, in fact, explicitly taken into account using the stochastic approach applied in this study, and is the primary reason for taking the stochastic approach. The stochastic approach applied in this study also allowed quantification of capture zone uncertainty resulting from the uncertainty of model boundary conditions (canal leakages), effective porosity, and lake residence times.

"No tracer studies have been conducted for the West Wellfield and should be obtained in order to make informed decisions of travel time in that area"

Additional tracer tests were discussed and recommended during and following tracer tests conducted in the late 1990s – early 2000s, and were ultimately not conducted. It should be noted that performing a successful quantitative tracer test is difficult, time-consuming and costly. From a technical standpoint, a tracer test is best performed when the test is not likely to be confounded by influential hydrologic processes, e.g. precipitation, local groundwater withdrawals, changes in canal operations, etc. Even under the best of hydrologic conditions, results have limited certainty, and may not provide the desired information. For example, different tracers used in tests during 2003-04 produced different results. In the absence of tracer test data for the WWF, interpretations made from tracer test data for the NWWF can be reasonably assumed at the WWF.

"The report was not subjected to the necessary and appropriate levels of review. The USGS report is an open-file report, indicating that it did not go through the highest level of review associated with USGS reports. The County should use reports subject to the highest level of review in making significant decisions related to the region's water supply."

This statement is incorrect. USGS Open File reports receive the same level of technical review as any other USGS interpretive product, for example Scientific Investigation reports, Professional Papers, or Scientific Investigation Maps. These include at least two technical peer reviews (this report had three technical peer reviews), as well as several levels of supervisory and technical expert reviews and approvals, and ultimate Bureau Approval by the Bureau Approving Official. The primary difference between an Open File report and any of these other interpretive reports is the editorial standards. In this case, the report was released as an Open File report to avoid delays in report layout and map and illustration formatting. Because of the anticipated scrutiny of the findings of the study, we can assure Miami-Dade County that this report received a thorough technical review, and has been held to the highest technical standards. While a Scientific Investigation Report is being prepared to supersede this report, the interpretation and information in the maps and figures will remain unchanged.

"The MODFOW model does not indicate the ultimate source of the water coming into the West Well field. Because it creates an artificial western boundary in its model, the USGS model does not answer questions about the water that will be pulled into the well fields, nor about the potential impacts to Everglades National Park."

The purpose of the study and report were not to answer questions about impacts to ENP, but to describe the area of influence of the well fields within the regulatory influence of the county, which is east of the L-30 Canal, or as stated on p. 51 "the goal of the study was to estimate capture zones within urban areas…". As it is designed to do, the L-30 Canal exhibits strong influence on recharge into the aquifer, and was appropriately simulated using a head-dependent flux boundary condition. Nonetheless, to address uncertainties about quantities of underflow from the Everglades beneath the L-30 Canal into the simulated area, sensitivity tests were conducted with the model extending the boundary to the west, and results were provided in Appendix 3. Results showed that if the boundary is moved westward, the boundary condition at the L-30 Canal still controls the water levels near the NWWF (fig. 3-1).

"MODFLOW is too simplified to assess flows in this area. Renken et al. (2008) states that given the complexity of water flow through karstic aquifers, water resources management "cannot be undertaken using simplified conceptual models of groundwater flow regimes based on estimates of bulk hydraulic properties." "

The complete statement by Renken and others (2008), referring to tracer test studies, is, "The purpose of this investigation is to demonstrate the inherent complexity of characterizing chemical and pathogen transport in karst aquifers. Water resources management in karst aquifers cannot be undertaken using simplified conceptual models of groundwater flow regimes based on estimates of bulk hydraulic properties. Characterization of karst aquifers requires the integration of data and interpretations from various hydrogeologic disciplines, including geologic mapping, geophysics, geochemistry, and hydrologic testing, including well-designed in situ tracer experiments conducted over the physical dimensions of interest". Groundwater-flow models are inherently simplified representations of complex systems, intended to represent the most important aspects of the system to answer specific questions, and are constrained by data availability, time and resources. That the system is complex is known, but the degree of complexity is often unknown and time and resources must be balanced against analysis complexity. In fact, the subject report describes a rather complex groundwater flow model. One can always argue that more field data collection and analysis would improve our understanding, and hence management, of the system. While some aspects of the conceptual model represented by the groundwater flow model may be simplified, the approach is designed to capture the necessary degree of complexity and quantify the effects of parameter uncertainty to address travel-time based capture zones and drawdown at the Northwest and West Well Fields.

"The USGS report does not appropriately use the data it has, does not reflect efforts to obtain additional needed data,"

The authors here do not explicitly state how the USGS report does not appropriately use available data, so it is unclear what the expectations are. This objective of this particular study was an analysis using available data, and there was no data collection component to the study. The report documents spatially variable hydraulic properties, stressors, and calibration data used to construct the model. The considerable uncertainty in the distribution of hydraulic properties is addressed using a stochastic approach with 10,000 unique realizations of the system. All of the data are described and referenced in the report.

Reference:

Renken, R.A., Cunningham, K.J., Shapiro, A.M., Harvey, R.W., Zygnerski, M.R., Metge, D.W., and Wacker, M.A., 2008, Pathogen and chemical transport in the karst limestone of the Biscayne aquifer: 1. Revised conceptualization of groundwater flow: Water Resources Research, v. 44, W08429, doi: 10.1029/2007WR006058

MEMORANDUM

DATE: 26 June 2015

TO: Julie Dick, Everglades Law Center

FROM: Dr. Rajendra Paudel, Hydrologist
Aida Arik, Ecological Engineer

SUBJECT: Suggested hydrogeological investigation and groundwater model improvements for designating Miami-Dade West Wellfield and Northwest Wellfield Protection Areas

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This letter to Everglades Law Center is in response to Section 6 of the Ordinance Amending 24-43 of the Code of Miami-Dade County Relating to Potable Water Supply Wells and Potable Water Wellfield Protection dated April 21, 2015, calling for "further scientific investigation of the proposed wellfield protection areas."

The Everglades Foundation reviewed the USGS Open-File Report 2013-1086, which was the basis for the proposed update to the wellfield protection areas, as well as other related literature. We suggest the following refinements to the USGS groundwater model to establish a robust basis for the protection of the West Wellfield (WWF) and Northwest Wellfield (NWWF) areas in Miami-Dade County:

1. Conduct further field tracer tests for improved representation of aquifer properties in the model

The Biscayne aquifer is a karstic aquifer consisting mainly of highly permeable limestone and less-permeable sandstone and sand. The highly permeable rocks of the Biscayne aquifer make it readily susceptible to contamination. Conducting field tracer tests are essential to assess the heterogeneity and anisotropy of the aquifer. The heterogeneity reflects the variability of the pore sizes in the rock matrix that hold water. The anisotropy reflects the different directions and speeds in which water is conveyed through the various connections of pores within the aquifer.

The USGS model simulates groundwater flow in an area covering 1,550 square miles using a mean effective porosity derived from 1) previous localized set of tracer tests conducted near the NWWF reporting a mean value of 0.04 and 2) previous USGS studies that reported an average value of 0.2 used to calibrate Biscayne aquifer models. To characterize the uncertainty in estimating the effective porosity, a stochastic approach was used with 10,000 random values over a lognormal distribution of porosity values with a mean value of 0.12 (average of 0.04 and 0.2). This uniform distribution of effective porosity was used throughout the model domain. Since the karstic Biscayne aquifer is known to be highly heterogeneous and anisotropic, with the presence of high-porosity and high permeability flow zones

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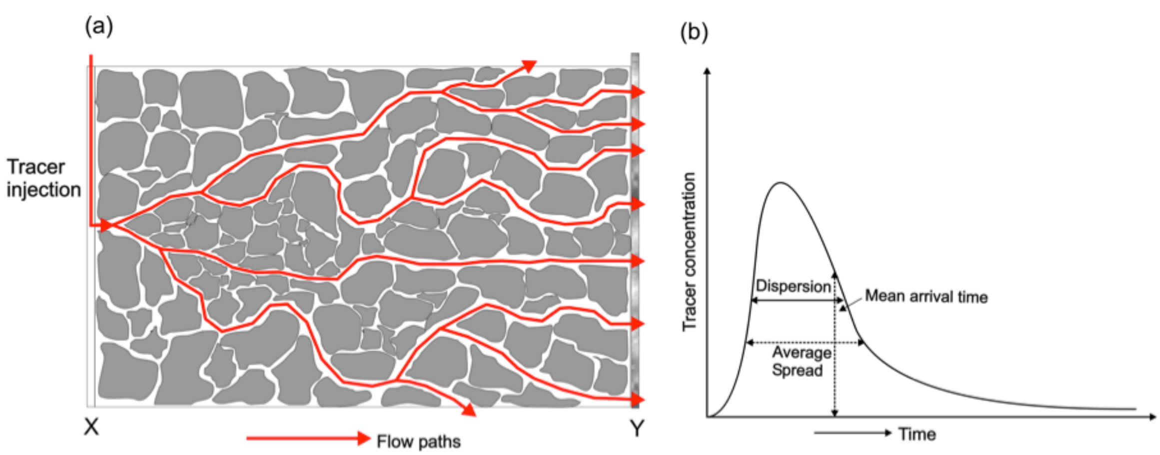
near the NWWF and WWF (Shoemaker et al., 2008), the distribution of porosity values used in the model may not be truly representative of the entire modeled area, especially near the WWF.

Therefore, we suggest conducting further tracer tests during different hydrologic conditions (i.e., wet and dry seasons) to collect more data for improved characterization of the porosity distribution of the Biscayne aquifer, especially near WWF where there were no prior tracer tests.

2. Account for the dispersive transport mechanism

The USGS model assumes advection as the primary transport mechanism for the tracers; the effect of dispersive transport mechanism is not accounted for in the model. Renken et al. (2008) estimated the dispersive transport to be small based on the tracer tests near NWWF compared to advective transport at a scale of about 100 m. However, the dispersive rate significantly depends on the spatial scale of the experiment (Dullien, 1992; Ho et al., 2009).

The following schematic diagram conceptualizes the dispersion mechanism caused by variations in groundwater local velocities. Figure (a) shows a side view cross-sectional area of an aquifer, in which a conservative tracer was injected at location X and recovered at location Y. The red lines represent the flow paths in the aquifer. Some tracer particles reach location Y faster than others especially through conduits and mega pores. Figure b shows the tracer concentration recovered at location Y over a period of time, which is also known as tracer breakthrough curve. The variable groundwater velocities are causing the spread in tracer arrival time, a phenomenon known as the dispersive transport.



The effect of dispersion could be considerable in the study site covering an area of 1,550 square miles, due to the inherent heterogeneities in the karstic Biscayne aquifer that could cause a wide range of local velocities. Therefore, we suggest that it is critical to also include the dispersive transport mechanism in the model.

3. Quantify the uncertainty of the residence time in the quarry lakes

The estimation of the groundwater travel time through existing quarry lakes in the USGS study has significant uncertainty, which may translate to a substantial risk to the protection of the groundwater resources. The USGS study does not explicitly account for lake-mixing processes with the assumption that the lake mixing occurs over the residence time period. The significance of mixing processes in these lakes is, however, acknowledged on Page 28 of the USGS report, described as introducing "substantial uncertainty as to whether an introduced-chemical constituent in a lake will reach a well field within 10 days if the lake is within a 10-day capture zone." The uncertainties associated with the estimation of the travel time through the quarry lakes could be high, mainly since the values are based on a single residence time for each quarry lake. Although uncertainty in travel time through the aquifer is taken into consideration, the uncertainty in travel time through the quarry lakes has been neglected in the model.

We suggest assessing the uncertainties of the residence time and travel time in the quarry lakes in the model in order to better quantify the uncertainty in the estimation of the protection zone.

4. Use maximum withdrawal rates to delineate respective wellfield protection areas

The WWF and NWWF provide a significant amount of the drinking water supply for Miami-Dade County, and will continue to be critical inland sources of potable water. Even though the 1996 to 2004 volumetric daily pumping rates for the NWWF were consistently less than the maximum design capacity, the maximum withdrawal capacity for the respective wellfields is recommended to be used in the groundwater model for the purpose of maintaining the highest level of protection of the groundwater resources. For the NWWF, the pumping rate of 225 Mgal/d represents the maximum design capacity. For the WWF, a pumping rate of 40 Mgal/d represents the maximum allowable withdrawal for the protection of the Everglades natural area, according to a 1993 MOU between the US Department of Interior, the Governor of the State of Florida, the South Florida Water Management District, and Metropolitan Dade County.

We suggest updating the simulations with a pumping rate of 40 Mgal/d for the WWF instead of 25Mgal/d used in the USGS study, as well as using the design capacity of 225 Mgal/d for the NWWF.

References:

Dullien F.A.L., 1992, Porous Media: Fluid Transport and Pore Structure. 2nd Edition, Academic Press.

Ho, D.T., Engel, V.C., Variano, E.A., Schmieder, P.J., Condon, M.E., 2009, Tracer studies of sheet flow in the Florida Everglades. Geophys. Res. Lett. 36, L09401, doi:10.1029/2009GL037355.

Renken, R.A., Cunningham, K.J., Shapiro, A.M., Harvey, R.W., Zygnerski, M.R., Metge, D.W., and Wacker, M.A., 2008, Pathogen and chemical transport in the karst limestone of the Biscayne aquifer: 1. Revised conceptualization of groundwater flow: Water Resources Research, 44, W08429, doi: 10.1029/2007WR006058.

Shoemaker, W.B., Cunningham, K.J., Kuniansky, E.L., and Dixon, J.F., 2008a, Effects of turbulence on hydraulic heads and parameter sensitivities in preferential groundwater flow layers: Water Resources Research, 44, W03501, doi:10.1029/2007WR006601.

GT GreenbergTraurig

Kerri L. Barsh
Tel. 305-579-0772
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June 30, 2014

VIA ELECTRONIC MAIL AND HAND DELIVERY

Wilbur Mayorga, P.E., Chief
Environmental Monitoring & Restoration Division
Regulatory and Economic Resources
701 NW 1st Court, 4th Floor
Miami, Florida 33136-3912

Re: Proposed Amendment to the Miami-Dade County Public Wellfield Ordinance (Sections 24-5 and 24-43 of the Miami-Dade County Code) dated May, 9, 2014[1] / Public Comments by the Miami-Dade Limestone Products Association

Dear Mr. Mayorga:

I am writing on behalf of the Miami-Dade Limestone Products Association (M-DLPA) and its member companies (Cemex Construction Materials Florida, LLC; Vecellio & Grogan, Inc. (doing business as White Rock Quarries); Vulcan Materials Company (and its lessee, Florida Rock Industries, Inc.); Titan Florida LLC; and Oldcastle Southern Group) in response to Miami-Dade County's request for public comments regarding the proposed Wellfield Protection Ordinance Amendment.

Comment 1: *Lines 42 through 47.* We propose the following revisions to lines 42 through 47 of the proposed amendment.

> *De minimis quantity* shall mean a volume of one quarter U.S. gallon (946.4 milliliters) or less stored in a closed container~~; or~~ except in the case of lubricating oils or hydraulic fluids~~; or~~. ~~i~~In the case of lubricating oils or hydraulic fluids, de minimis quantity shall mean either a volume of one U.S. gallon stored in a closed container or, the volume inside a gear box, a hydraulic reservoir, or a crankcase. Items that individually meet the volumetric requirements of *de minimis quantity* shall not be considered *de minimis* if the aggregated volume of such items exceeds 5 gallons.

We think the suggested revision improves the definition's clarity.

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[1] These comments are based upon the draft language of the amendment posted on the Miami-Dade County website at www.miamidade.gov/environment/library/guidelines/2014-05-19-proposed-wellfield-protection-ordinance.pdf (Accessed June 3, 2014 at 12:15 pm).

Comment 2: *Lines 106 through 119.* We propose the following revisions to lines 106 through 119 of the proposed amendment to improve its clarity.

> The omission of any chemical contained in any waste, product, substance, combination or break-down product, from the list of contaminants in Section 24-44(2)(f)(v) Table 1 and Table 2, Section 24-43.3(2)(h) or Chapter 62-550, FAC., Table 1, Table 2, Table 3, Table 4, Table 5 and Table 6, as same may be amended from time to time, shall not create any presumption that the chemical, waste, product, substance, or combination containing that chemical, or any breakdown product of that chemical ~~containing the non-included chemical~~ is not a hazardous material.

Comment 3: *Lines 123 through 138.* We suggest the insertion of a provision that would expressly state that property owners, lessees, and operators may seek relief from the requirements of the wellfield ordinance by application to the Environmental Quality Control Board (EQCB). This provision would further specify that the EQCB may grant such relief upon a demonstration that site-specific conditions or the implementation of hydrological barriers or other technology safeguards adequately protect the public health, safety and welfare to the same or a greater extent that the wellfield protection ordinance.

Comment 4: *Lines 255 through 256.* We propose the following revisions to lines 255 through 256 of the proposed amendment.

> For uses ancillary to rock mining as defined in Section 33-422 of this Code. ~~necessary for extracting and processing subsurface material~~

This suggested revision will ensure that that the determination of ancillary rockmining uses remains consistent with Section 33-422 of the Code and will help avoid any potential conflict. Furthermore, proposed addition of "For uses ancillary to rock mining necessary for extracting and processing subsurface material" is ambiguous.

Comment 5: *Lines 784 through 788.* We propose the following revisions to lines 784 through 788 of the proposed amendment.

> The aforesaid covenant shall substantially be in a form prescribed by the Director and shall incorporate the requirements and prohibitions of Section 787 24-43(5)(a), (b) and (c).

This suggested revision provides the County's administration with some flexibility in making non-substantial modifications to the form that may provide greater clarity given the context of a particular property or proposed use.

Comment 6: *Lines 784 through 788.* We propose that the County make the required form available on Municode for convenient reference. The covenant could be included as part of the Code text of a link to the County website could be imbedded into the Code text as it appears on Municode's website.

Comment 7: *Lines 1139 through 1142.* We propose the following revisions to lines 1139 through 1142 of the proposed amendment.

> Limestone quarrying, rock crushing and aggregate plants ancillary to ~~section in connection with~~ limestone quarrying (~~no o~~On-site fuel storage shall be prohibited. ~~except that t~~The use of fuel, ~~and~~ lubricants, and LP, and ~~natural gas storage~~ the storage of natural gas are permitted)

We think that this revision improves the provision's clarity.

Comment 8: Proposed New Amendment. We propose adding a new section to the proposed amendment that would create a section of the Code, Section 24-43(7)(d). The new section would read as follows:

> The excavation: a) has received a valid unusual use or certificate of use for excavation pursuant to section 33-423 of the Code (or municipal equivalent), which was obtained prior to [effective date of the new wellfield protection ordinance], or b) has occurred or is to occur on property within Increments I, II, and III as indicated in the attached Figure XX, whose potential impacts on groundwater quality were evaluated by the U.S. Army Corps of Engineers in the 2009 Final Supplemental Environmental Statement on Rock Mining in the Lake Belt Region of Miami-Dade County, Florida, with the U.S. Environmental Protection Agency, the Florida Department of Environmental Protection and Miami-Dade County as reviewing agencies.

Section 24-43(7) of the Code currently provides regulations pertaining to excavations and permitted depths within each of the travel time bands (*e.g.*, 30-day, 100-day, *etc.*) listed on the wellfield protection area maps. As currently proposed, the amendment to the wellfield ordinance does not address section 24-43(7). The proposed amendment would, however, incorporate new maps that modify the location of travel time bands. In some instances, these new bands would conflict with the vested rights of the holders of certificates of use for excavation and similar permits, property owners, and holders of various entitlements. The suggested provision would formally grandfather these property owners and permit holders and eliminate any doubt as to the preservation of their already vested mining rights.

Thank you for the opportunity to comment on the proposed amendment to the wellfield protection ordinance. We look forward to continuing to work with the County on this matter. If you have any questions or would like to discuss the above comments, please contact me at 305-579-0772 or at barshk@gtlaw.com.

Very Truly Yours,

Kerri L. Barsh

Attachment

cc: Cliff Kirkmyer, M-DLPA President
James M. Hurley, IV, M-DLPA Sec'y/Treasurer
Scott McCaleb, M-DLPA Executive Comm. Member
George Pantazopoulos, M-DLPA Executive Comm. Member
Vicky Tomas, Executive Director
Tom MacVicar, P.E.
Edward O. Martos, Esq.

ACOE (2009) Final SEIS - Alternative 4 Proposed Mining Plan

GT GreenbergTraurig

Kerri L. Barsh
Tel. 305-579-0772
barshk@gtlaw.com

June 30, 2014

VIA ELECTRONIC MAIL AND HAND DELIVERY

Wilbur Mayorga, P.E., Chief
Environmental Monitoring & Restoration Division
Regulatory and Economic Resources
701 NW 1st Court, 4th Floor
Miami, Florida 33136-3912

Re: Proposed Amendment to the Miami-Dade County Public Wellfield Ordinance (Sections 24-5 and 24-43 of the Miami-Dade County Code) dated May, 9, 2014[1] / Public Comments by Kendall Investments 172, LLC

Dear Mr. Mayorga:

I am writing on behalf of Kendall Investments 172, LLC in response to Miami-Dade County's request for public comments regarding the proposed Wellfield Protection Ordinance Amendment.

Comment 1: *Lines 42 through 47.* We propose the following revisions to lines 42 through 47 of the proposed amendment.

> *De minimis quantity* shall mean a volume of one quarter U.S. gallon (946.4 milliliters) or less stored in a closed container~~; or~~ except in the case of lubricating oils or hydraulic fluids~~; or~~. ~~i~~In the case of lubricating oils or hydraulic fluids, de minimis quantity shall mean either a volume of one U.S. gallon stored in a closed container or, the volume inside a gear box, a hydraulic reservoir, or a crankcase. Items that individually meet the volumetric requirements of *de minimis quantity* shall not be considered *de minimis* if the aggregated volume of such items exceeds 5 gallons.

We think the suggested revision improves the definition's clarity.

Comment 2: *Lines 106 through 119.* We propose the following revisions to lines 106 through 119 of the proposed amendment to improve its clarity.

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[1] These comments are based upon the draft language of the amendment posted on the Miami-Dade County website at www.miamidade.gov/environment/library/guidelines/2014-05-19-proposed-wellfield-protection-ordinance.pdf (Accessed June 3, 2014 at 12:15 pm).

> The omission of any chemical contained in any waste, product, substance, combination or break-down product, from the list of contaminants in Section 24-44(2)(f)(v) Table 1 and Table 2, Section 24-43.3(2)(h) or Chapter 62-550, FAC., Table 1, Table 2, Table 3, Table 4, Table 5 and Table 6, as same may be amended from time to time, shall not create any presumption that the chemical, waste, product, substance, or combination containing that chemical, or any breakdown product of that chemical ~~containing the non-included chemical~~ is not a hazardous material.

Comment 3: *Lines 123 through 138.* We suggest the insertion of a provision that would expressly state that property owners, lessees, and operators may seek relief from the requirements of the wellfield ordinance by application to the Environmental Quality Control Board (EQCB). This provision would further specify that the EQCB may grant such relief upon a demonstration that site-specific conditions or the implementation of hydrological barriers or other technology safeguards adequately protect the public health, safety and welfare to the same or a greater extent that the wellfield protection ordinance.

Comment 4: *Lines 784 through 788.* We propose the following revisions to lines 784 through 788 of the proposed amendment.

> The aforesaid covenant shall substantially be in a form prescribed by the Director and shall incorporate the requirements and prohibitions of Section 787 24-43(5)(a), (b) and (c).

This suggested revision provides the County's administration with some flexibility in making non-substantial modifications to the form that may provide greater clarity given the context of a particular property or proposed use.

Comment 5: *Lines 784 through 788.* We propose that the County make the required form available on Municode for convenient reference. The covenant could be included as part of the Code text of a link to the County website could be imbedded into the Code text as it appears on Municode's website.

Comment 6: *Lines 663 et seq.* The constraints on the use of hazardous materials (particularly petroleum products) outside the 30-day travel line of the West Wellfield Protection area should be more flexible to allow for property-specific considerations, including the use of best management practices and other measures (such as secondary containment and the like) to protect against the release and migration of hazardous materials.

Thank you for the opportunity to comment on the proposed amendment to the wellfield protection ordinance. We look forward to continuing to work with the County on this matter. If you have any questions or would like to discuss the above comments, please contact me at 305-579-0772 or at barshk@gtlaw.com.

Very Truly Yours,

Kerri Barsh

Kerri L. Barsh

June. 30, 2014

Wilbur Mayorga
Chief, Environmental Monitoring and Restoration Division

Miami Dade County Department of Regulatory and Economic Resources
Division of Environmental Resources Management
Overtown Transit Village North
701 NW 1st Court
Miami, Florida 33136

RE: Comments for the Proposed Amendments to the Wellfield Protection Ordinance (Section 24-5 Definitions and 24-43 Protection of Potable Water Supply Wells)

Mr. Mayorga,

Florida Power and Light Company (FPL) is appreciative of the opportunity provided to meet with Department of Regulatory and Economic Resources (RER) on June 17 and discuss our questions and concerns related to the proposed amendments to the Miami Dade County Wellfield Protection Ordinance. As stated, FPL has some concerns that the proposed amendments could be interpreted in such a way as to hamper FPL's ability to maintain and operate the electric service infrastructure that exists in the designated wellfield areas. One of the chief concerns was the potential application of additional restrictions to current operations that are within the 210 day boundaries. Following our discussion on June 17th, it is our understanding that RER did not intend to subject these facilities to such restrictions. While it was not clear to FPL prior to our meeting, RER was clear that the intent was that existing facilities, such as our existing infrastructure, were "grandfathered" to the extent the facility meets the current wellfield protection requirements and any issued permit conditions.
The following comments are provided, as requested, with the intent of preserving FPL's ability to operate, maintain and improve current or future electric distribution and transmission facilities and equipment needed to service the County's needs.

The Hazardous Materials definition in Sec.24-5, page 2, lines 80-115 of the draft ordinance, appear overly complex by referencing all of the remediation tables when the common limiting factor is section 24-44 (2) (f) (v) (1) (lines 85-87). Unless the added references create some specific modification, FPL suggest simplifying this section by eliminating the references following "product" on line 81 to the word "shall" on line 84, the references beginning on line 103 following "Table 2" through line 104 "Table 6", and the references beginning on line 110 following "Table 2" through line 111 "Table 6" . The result of the new language would be:

> (lines 80 – 87) There shall be a rebuttable presumption that any waste, product, substance, combination, or breakdown product ~~containing any chemical listed as a contaminant in Section 24-44(2)(f)(v) Table 1 and Table 2 , 24-43.3(2)(h) or Chapter 62-550, FAC., Table 1, Table 2, Table 3, Table 4, Table 5 and Table 6, as same may be amended from time to time,~~ shall constitute a hazardous material if the chemical is present in the waste, product, substance, combination, or breakdown product at concentrations which exceed the groundwater cleanup target level set forth in Section 24-44(2)(f)(v)1.

(Lines 100-105) >>Non-inclusion of any chemical contained in any waste, product, substance, combination, or breakdown product, as a contaminant in Section 24-44(2)(f)(v) Table 1 and Table 2, ~~Section 24-43.3(2)(h) or Chapter 62-550, FAC., Table 1, Table 2, Table 3, Table 4, Table 5 and Table 6~~, as same may be amended from time to time<< shall not create any presumption that the waste, product, substance, combination, or breakdown product >>containing the non-included chemical is not a hazardous material. To determine whether or not a chemical,

(Lines 108-115) not included as a contaminant in Section 24-44(2)(f)(v) Table 1 and Table 2, ~~Section 24-43.3(2)(h) or Chapter 62-550, FAC., Table, 1, Table 2, Table 3, Table 4, Table 5 and Table 6~~, as same may be amended from time to time, is a contaminant, the cleanup target level (s) for that chemical may be established using the procedures, equations and input parameters set forth in the DERM Technical Report: "Development of Clean-up Target Levels (CTLs) for Chapter 24 of the Code of Miami-Dade County, Florida" (dated September, 2005).<<

Additionally, the definition assumes knowledge or available information to the regulatory community of constituents that are not active ingredients of a formulation. Safety Data Sheets and product engineering sheets generally provide information at a concentration that is required by law, 1% or 0.1% for carcinogens (1,000 -10,000 PPM), or that are required for product performance, typically 0.01 - 0.1% (10 - 100 PPM). The referenced CTLs in the tables are often significantly below these published levels for many chemical products in use by industry. FPL suggest that in place of an overly restrictive definition based strictly on an assumption related to levels equivalent to the Clean-Up Target Levels for chemical products or generated waste, the definition establish qualifying statement such as based on "readily available information" be inserted on line 86 following the word concentrations. The line may then read:

(line 86) or breakdown product at concentrations<u>, from readily available information,</u> which exceed the groundwater cleanup

While the language for determining if a non-included material is to be considered a hazardous material appears permissive, using the form "may" (p3, line 112) no alternative basis of determination is given. This absence implies the only accepted method of determination when a non-inclusive chemical is present, is that a CTL is to be determined using the procedures, equations and input parameters set forth in DERM's Technical Report dated September, 2005. This process may involve costly time consuming studies to establish the CTL. The performances of these types of studies are typically not consistent and may generate some uncertainty in the results. Therefore, two entities utilizing the same chemical within a well field may employ slightly different methodologies and assumptions to determine if a chemical is (or is not) a contaminant. Also, since there is no limitation on the type of chemical to which this applies and is in effect requiring the regulated community to apply this test to any chemical product in use in the wellfield.

FPL believes that requiring the regulated community to determine and apply remediation cleanup standards to in-use materials as a threshold or end point is significantly more restrictive than is required to protect surface and groundwater. To avoid any misunderstandings on whether a non-inclusive chemical is (or is not) a contaminant, FPL suggests the ordinance simply rely on the use the groundwater cleanup target level set forth in Section 24-44(2)(f)(v)1 as the primary standard, which is more restrictive, and retain the language that non-inclusion does not create any presumption that the waste, products substances or combination thereof are not a hazardous material, while striking the new determination language beginning on line 108-115. The regulated community would then rely on the information and testing provided by their suppliers or required by existing law to identify materials that are hazardous to employees, the public and the environment.

While the definition for Hazardous Material states there is a "rebuttable presumption" (page 2, line 80-87), it provides no basis for demonstrating that the presumption does not apply. FPL suggests that additional language be included to clearly define what would constitute sufficient information to rebut the presumption.

The prohibition of "Small Quantity Generators" of hazardous waste (p. 17, line 728-729) initially raised some concerns that it would potentially impede FPL's ability to maintain electrical equipment and facilities. Hazardous waste includes small quantity materials such as aerosols for lubrication, cleaning electrical contact, to larger applications such as paints and coatings used to prevent corrosion. Based on the June 17 meeting it is FPL's understanding that RERs intent was to address regular manufacturing or commercial process that generate waste as well as the areas for storage and management of hazardous waste and not the typical deminimis generation from maintenance at substations or line transmission-distribution activities conducted by FPL. While deminimis quantities may be used in the field, FPL removes any wastes to the local service center. Therefore, the wastes are not stored or managed in the wellfield. FPL suggests that an exception be provided for conditionally exempt small quantity generators as defined in the state solid waste rules that do not store or manage hazardous waste in the Northwest Wellfield or basic protection area of the west wellfield. FPL also request that the limitation of the exclusion or electrical transformers to "nonresidential" land uses (p17, lines 736 -751 be revised to include all utility owned transformers on lines and in substations.

FPL requests the Department consider a change to the existing allowance for "electrical transformers serving nonresidential land uses" (page 17, line736). FPL is unclear on the purpose of restricting the allowance to units serving only nonresidential land us and believes it could contribute to confusion. Unless there is a compelling reason or concern, FPL suggests the language be modified as "all utility owned electric transformers". If there is a concern for nonutility owned transformers FPL recommends "all utility owned transformers; other nonutility transformers serving nonresidential land uses;".
FPL noted that the elimination of the table "Allowable Land Uses Within the Northwest Wellfield Protection Area and Within the West Wellfield Interim Protection Area" (pages 27-38, lines 1159 -1427) coupled with the addition of limiting criteria of (10) (e)(v) (pag26, lines 1111 – 1128) electrical substations have been removed. Since, electrical substations are present in the wellfields due in part to engineering requirements and service of these facilities is critical to providing electrical service for the county, FPL requests either a change to the limitation or an exception for the construction, operation and maintenance of the power delivery infrastructure. Such a change could be effected by adding "electrical transmission and distribution" to the "Utilities" land use on page 27, lines 1152-1154.

Respectfully submitted,

Tomey E Tuttle, MA, CHMM, CPEA
Environmental Project Manager,
Florida Power and Light, Company

ATTACHMENT B

Evaluation of the USGS Model for Estimating the Capture Zones
and Drawdowns at the Northwest and West Wellfields
Miami-Dade County, Florida
(Draft 2.0, July 2016)
Dr. David Chin

Evaluation of the USGS Model for Estimating the Capture Zones and Drawdowns at the Northwest and West Wellfields, Miami-Dade County, Florida

(Draft 2.0, July 2016)

1 The USGS Model

The USGS model was constructed using the MODFLOW-2005 code (Harbaugh, 2005) with a 1730-row $\times$ 930-column $\times$ 1-layer grid. Each cell within the model domain had horizontal dimensions of 50 m $\times$ 50 m, and a vertical dimension equal to the local depth of the Biscayne aquifer. Bounding canals and bounding portions of Biscayne Bay were represented as head-dependent-flux and constant-head boundaries, respectively. Quarry lakes were simulated as very-high-hydraulic-conductivity cells. The model was calibrated under transient conditions to measured piezometric heads, water-table elevations, and canal seepage flows using the 1999 lake configuration; the period of calibration was 1996-2004. Calibration was done using hydraulic conductivities within the model cells assigned based on measured hydraulic conductivities, and kriged estimates at intermediate locations. The kriged estimates of log-transformed hydraulic-conductivity field were based on an assumed exponential semivariogram, with a correlation length scale of 5 km and a variance of 0.3. Subsequent to the transient calibration, single days within the calibration period were selected to represent dry, average, and wet conditions, and the 1999 lake configuration was replaced by the 2004 lake configuration. Drawdown and travel-time contours were calculated for each of these three reference conditions. Monte-Carlo simulations were used to generate perturbations of the calibrated hydraulic-conductivity and effective-porosity fields. Perturbations in the calibrated hydraulic-conductivity field were simulated using a random multiplicative adjustment factor having an exponential semivariogram with a correlation length scale of 4 km and a log-transformed variance and nugget of 0.1 and 0.01, respectively. For each realization of the hydraulic-conductivity field, the synoptic effective porosity within the model domain was assumed to be constant throughout the domain, and drawn from a lognormal distribution with a geometric mean of 0.12 and a log-transformed variance of 0.16. A total of 10,000 realizations of the synoptic hydraulic-conductivity and effective-porosity fields were generated within the model domain. For each of these realizations, the spatial distribution of the water-table elevation was calculated using a single (steady-state) model run, and the drawdown was calculated in each cell by subtracting the calculated water-table elevation from the no-pumping water-table elevation. Also for each realization, the MODPATH 5.0 post-processor (Pollock, 1994) was applied along with a post-processor algorithm suggested by Chin et al. (2010) for estimating the average travel time of conservative contaminants through quarry lakes. Contaminant particles were backtracked from the wellheads to give particle distributions corresponding to 10-, 30-, 100-, and 210-day travel times to a wellhead. This procedure for estimating the drawdown and particle locations at designated travel times was repeated for each of the 10,000 realizations of synoptic hydraulic-conductivity and effective-porosity fields. The 95% confidence intervals were calculated for drawdowns of 0.25 ft and 0.1 ft, and the distribution of 10-d, 30-d, 100-d, and 210-d travel-time contours were estimated from the ensemble distribution of particle locations for the given travel times.

2 Key Limitations of the USGS Model

The primary limitation of the USGS model is that the model does not adequately simulate the movement of contaminants through quarry lakes. This limitation has a dominant effect on the delineation of travel-time zones surrounding the wellheads in the NWWF and WWF, and the travel times delineated by the USGS model are likely to be very inaccurate. Other key limitations are: (1) delineation of wellhead protection areas should be based on build-out scenarios for the quarry lakes, and (2) the method used to estimate travel-time contours from particle tracks was not adequately validated. These limitations are discussed in more detail below.

Limitation # 1: Tracking Contaminants Through Lakes

The USGS model does not appropriately simulate the movement of contaminants through quarry lakes. The algorithm used in the USGS model for calculating travel times through quarry lakes is that for each realization of the hydraulic conductivity field the travel time through a lake is taken as being equal to the (deterministic) residence time in the lake. The residence-time approach, which was originally suggested by Chin et al. (2010), defines the average travel time through a well-mixed lake as the quotient of the lake volume and the volumetric flow rate through the lake. The USGS model further assumes that the pathline of a contaminant particle through a lake is the same as the pathline of a groundwater particle as it moves through a high-hydraulic conductivity zone occupying the same volume as the lake. In reality, for any given realization of the hydraulic conductivity field, the travel time of a contaminant through a lake must be described stochastically using a probability distribution of travel times, rather than deterministically using a single value such as the mean residence time. Furthermore, the assumption that contaminant particles follow groundwater pathlines through a lake is unrealistic, since contaminant particles will follow a path that is controlled by the wind-driven circulation within the lake. Lake circulation cannot be simulated using a groundwater flow model. Notably, the assumed mean currents in quarry lakes corresponding to the residence-time approximation (~ 0.01 cm/s) are two orders of magnitude smaller than actual wind-induced currents (~ 1 cm/s). If a lake is well mixed, then for any given realization of the hydraulic conductivity field, the probability distribution of travel times through the lake will theoretically follow an exponential probability distribution. Over multiple realizations of the hydraulic conductivity field the mean travel time through a given lake will vary because the volumetric flow rate through the lake will vary and therefore a distribution of mean travel times through the lake will be generated. However, the probability distribution of the mean travel times through a lake will generally have a much smaller variance than the distribution of actual travel times. The movement of contaminants through quarry lakes has been demonstrated by Chin (2016) who showed that the conditional probability distribution of particle tracks through a typical quarry lake will depend on the lake dimensions and wind velocity, and such lakes cannot generally be assumed to be well mixed for all wind directions. Taking individual lake-mixing characteristics into account is essential for accurately modeling contaminant tracks and travel times through quarry lakes. Lake-mixing characteristics were simply not taken into account in the USGS model.

Limitation # 2: Assumed Lake Configuration

The USGS model calculates the travel-time and drawdown contours based on the 2004 lake configuration. Hence, the calculated results from the USGS model are strictly valid only for the 2004 lake configuration, and are not valid for any subsequent configuration of lakes. Since the lake configuration has changed since 2004 and will continue to change, the travel-time contours generated by the USGS model would need to be continually updated to keep pace with the current lake configuration. This situation is clearly undesirable, particularly since under 2004 conditions the lake surface area near both the NWWF and WWF wellheads was around 17 mi^2, and under buildout conditions the lake surface area in the immediate vicinity of wellheads would be around 40 mi^2. The limitation of conditioning the travel times on the 2004 lake configuration is further exacerbated by the fact that the existing regulatory travel-time zones in the NWWF were delineated in 1985, and do not account any of the existing lakes. As a consequence, the existing travel-time contours are very inaccurate, overestimate the actual travel times at any given location, and are underprotective of the wellheads when these existing travel-time zones are applied to land-use regulations stated in terms of travel times. Based on the aforementioned considerations, it would be prudent to update the regulatory travel-time contours based on lake-build-out scenarios for both the NWWF and the WWF, and to perform these updates expeditiously.

Limitation # 3: Method of Estimating Travel-Time Contours

The USGS model uses a method proposed by Varljen and Schafer (1991) to estimate the spatial distribution of particle locations for any given travel time. This method assumes that the particle locations are normally distributed within all radial sectors that originate at a fixed point within the wellhead array. Since there is no radial symmetry relative to the selected reference point, a normal distribution of particles within each sector would not be expected and such an approach would need to be validated. The USGS model report does not document any hypothesis-test results to support the approximation of normality as required to apply the Varljen and Schafer (1991) approach, and in fact, several of the particle tracks shown in the model report do not appear to support the assumption of normality.

3 Concerns

Several additional modeling issues were discussed by the TWG. Whereas these additional issues might not be necessarily limiting by themslves, they represent opportunities for improving the delineation of both the regulatory travel-time zones and the 0.25-ft drawdown contour within the NWWF and WWF. The additional issues of concern are: (1) Monte Carlo simulations are not essential for estimating the probability distributions of travel times within the NWWF and the WWF, (2) using a likelihood function could improve the estimation of travel-times and drawdowns in both wellfields; and (3) contaminant transport through canals should be considered.

Concern # 1: Monte-Carlo Simulations are not Essential

The motivation for Monte Carlo simulations in the USGS model was to generate a probability distribution of particle tracks that corresponds to a random hydraulic conductivity field and a random effective-porosity field. However, stochastic particle tracks can be equivalently generated using macrodispersion coefficients. The macrodispersion coefficient in each cell can be expressed directly in terms of the variance of the probability distribution of the (log-)hydraulic conductivity and effective-porosity distribution within the cell. The required variance in each cell can be estimated using the variogram model, the correlation length scale within the cell can be taken as a characteristic lateral dimension of the cell, and a conventional formulation such as that described in Dagan (1989) and validated by Chin and Wang (1992) could be used to estimate the local macrodispersion coefficient. Particle tracks in this random hydraulic-conductivity/effective-porosity field can then be simulated using the macrodispersion coefficient and mean seepage-velocity field as described in Chin et al. (2010). The advantage to using macrodispersion coefficients instead of Monte Carlo simulations is the significant saving in computer time, since the groundwater model only has to be run once using the calibrated hydraulic-conductivity and effective-porosity fields, instead of running the model 10,000 times for random perturbations of the hydraulic-conductivity/effective-porosity field as was done in the USGS model. The simulation of 10,000 particle tracks will still be necessary, however, the computer-time demand will be significantly reduced.

Concern # 2: Unconstrained Realizations

By using unconstrained Monte Carlo simulations the USGS model gives the same weight to results from hydraulic-conductivity and effective-porosity fields that are very unlikely as to those fields that are very likely. Using a classical likelihood function formulation (e.g., Chin, 2013), the likelihood of the results from any given field realization can be measured by the sum of the squares of the differences between simulated and measured water-table and canal-seepage fluxes. This approach makes the conventional assumption that the model errors are normally distributed. Using a likelihood-function post processor, the more plausible model outcomes would be given more weight. A likelihood-function approach for modeling particle tracks in wellfields has been described by Enzenhoefer et al. (2014). In this approach, model parameters such as the hydraulic conductivity and porosity used in Monte Carlo simulations are constrained to be selected from physically plausible ranges as determined by the parameter covariances derived from the likelihood function of the parameters. Application of a likelihood function to give appropriate weight to model outcomes from unconstrained realizations could have a significant effect on the model results for both travel times and drawdowns. For the scenarios considered in the USGS model, it is recognized that 0.25-ft drawdowns in the NWWF and the WWF are dominated by specified-head boundary conditions, and hence the effect of applying a likelihood function could be minimal when applied to drawdowns. This would need to be confirmed by simulations.

Concern # 3: Consideration of Contaminant Transport in Canals

In cases where a travel-time contour intersects a canal, contaminants can potentially move from a source location in the intersected canal to a wellhead. In such cases, the additional travel time is roughly equal to the travel time of the contaminant from its source to the point of intersection of the travel-time contour and the canal. Flow pathways and times of travel within canals should also be considered, and appropriate wellhead protection areas delineated along canals to protect the wellheads that are fed by the canals.

4 Other Considerations

In the course of reviewing the USGS model, several modeling issues were considered that did not result in a recommendation for modifications to the model. These considerations were within the context of identifying acceptable aspects of the model, and understanding model approximations when applying the results of the model simulations. These additional considerations are summarized below.

Adequacy of simulated drawdowns. The drawdowns simulated by the USGS model were calculated appropriately for the specified model configuration and boundary conditions. For purposes of calculating the drawdown distributions in the NWWF and WWF, representation of the lakes as high-hydraulic-conductivity zones is appropriate. However, some consideration should be given to using the LAK package in any future revisions of the USGS model, since this package gives a more realistic representation of quarry lakes. Both of the aforementioned approaches are adequate.

Adequacy of a two-dimensional (1-layer) model. Representation of groundwater flows as being two-dimensional within the model domain relies in the validity of the Dupuit-Forcheimer (D-F) approximation. The D-F approximation assumes that vertical variations in piezometric head at any given location are negligible, which corresponds to seepage flows being horizontal. The D-F approximation is likely to be valid over the majority of the model domain containing the NWWF and the WWF, since the horizontal dimension of the flow domain greatly exceeds the vertical dimension. However, following conventional guidance, the D-F approximation cannot be assumed valid within at least two aquifer depths ($\sim 50\,\text{m}$) from partially penetrating features such as canals and pumping wells (Chin, 2013). Since the horizontal dimensions of cells in the USGS model are $50\,\text{m} \times 50\,\text{m}$, this agreement of scales provides support for applying the D-F approximation within the portion of the model domain containing the wellfields. Of some relevance to concerns relating to the proper representation of canal seepage, particularly in the vicinity of primary canals that are model boundaries, previous field work on the L-31N Canal (Chin, 1990) has provided validation that the D-F approximation is applicable beyond two aquifer depths from the canal. Work has also been done on estimating the seepage under the L-30 canal (Sonenshein, 2001). Application of these field results could be used to estimate the underflow of groundwater from Everglades National Park (ENP) into the wellfields. In the current USGS model, the leakage to and from the bounding canals cannot be distinguished from canal-underflow seepage between the wellfields and ENP.

5 Calculation of Travel Times

The two major shortcomings of the USGS method of calculating through lakes are: (1) the USGS method unrealistically assumes that each particle follows a groundwater-flow streamline through a lake, and (2) the travel time along each groundwater-flow streamline within a lake is assumed to be the same and equal to the mean residence time in the lake. In reality, each particle entering the lake is mixed by the lake circulation generated by the wind, the lake currents cannot be calculated using a groundwater-flow model, and the travel times along particle paths in the lake between entrance and exit locations are variable between paths and are dependent on the mixing characteristics in the lake. A more realistic particle-tracking strategy is described below.

Analytical formulation. The key probability distributions that are bases for estimating the travel times of groundwater "particles" between source locations within a wellfield and wellheads are as follows:

$p_{\mathrm{a}}(\mathbf{x}_2, t|\mathbf{x}_1)$ = probability that a particle travels through the aquifer from a source location $\mathbf{x}_1$ to a destination location $\mathbf{x}_2$ in time t;

$p_{\ell}(\mathbf{x}_2, t|\mathbf{x}_1)$ = probability that particle travels through the lake from an entrance location $\mathbf{x}_1$ to an exit location $\mathbf{x}_2$ in time t;

Let T be the travel time from a source location ($\mathbf{X}_1$) to the any of the wellheads (collectively represented by $\mathbf{X}_{\mathrm{w}}$) such that

$$T = t_1 + \tau + t_2 \tag{1}$$

where t_1 is the travel time from the source to the lake, τ is the travel time through the lake, and t_2 is the travel time from the lake to the wellhead(s). The travel times t_1, t_2, and T are illustrated in Figure 1.

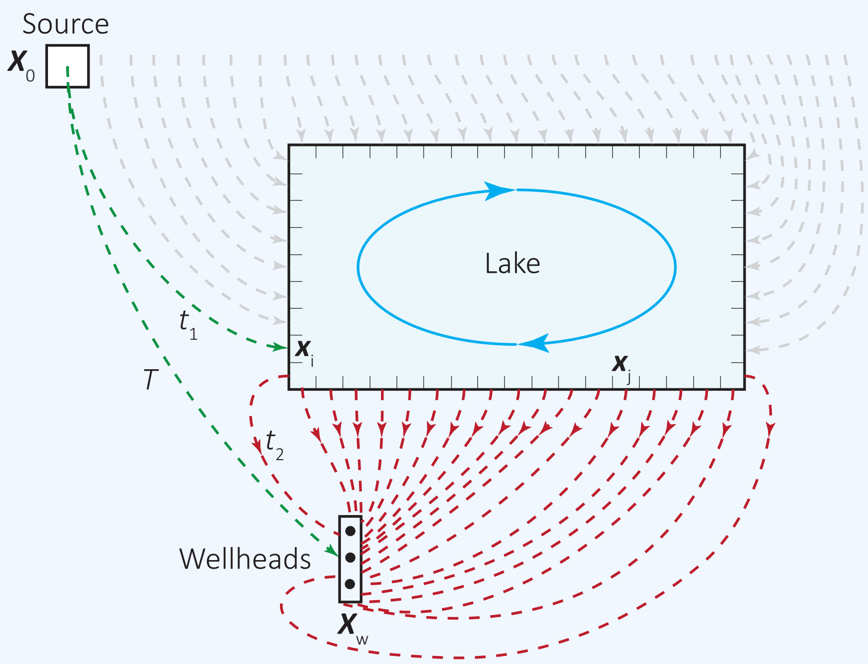

Figure 1: Particle tracks from source to wellheads

Using the defined variables, the probability ($p_{\mathrm{a}\ell}$) that a particle originating at source-location $\mathbf{X}_0$ is transported through both the aquifer and the lake and is at the wellhead location, $\mathbf{X}_{\mathrm{w}}$, after a time T is given in terms of the fundamental particle-track probability distributions,

$p_{\mathrm{a}}(\mathbf{x}_2, t|\mathbf{x}_1)$ and $p_\ell(\mathbf{x}_2, t|\mathbf{x}_1)$ as:

$$p_{\mathrm{a}\ell}(\mathbf{X}_{\mathrm{w}}, T|\mathbf{X}_0) = \sum_{i=1}^{I}\sum_{j=1}^{J}\left\{\int_0^T p_\ell(\mathbf{x}_j, T - t_{12}|\mathbf{x}_i)\left[\int_0^{t_{12}} p_{\mathrm{a}}(\mathbf{x}_i, t_1|\mathbf{X}_0)p_{\mathrm{a}}(\mathbf{X}_{\mathrm{w}}, t_{12} - t_1|\mathbf{x}_j)\,\mathrm{d}t_1\right]\mathrm{d}t_{12}\right\} \tag{2}$$

where the dummy variable t_{12} is equal to t_1+t_2; the quantity in square brackets in Equation (2) is the probability density of t_{12}. The subscript "aℓ" in Equation (2) indicates that the particle travels through both the aquifer and the lake. It is apparent from Figure 1 that a particle can also travel to the well without passing through the lake; the probability of this occurrence is represented by $p_{\mathrm{a}}(\mathbf{X}_{\mathrm{w}}, T|\mathbf{X}_0)$, where the subscript "a" indicates that the particle travels only through the aquifer. The probability, $p(\mathbf{X}_{\mathrm{w}}, T|\mathbf{X}_0)$, of a particle traveling from a source location $\mathbf{X}_0$ to the wellhead location $\mathbf{X}_{\mathrm{w}}$ in time T is therefore given by

$$\boxed{p(\mathbf{X}_{\mathrm{w}}, T|\mathbf{X}_0) = p_{\mathrm{a}\ell}(\mathbf{X}_{\mathrm{w}}, T|\mathbf{X}_0) + p_{\mathrm{a}}(\mathbf{X}_{\mathrm{w}}, T|\mathbf{X}_0)} \tag{3}$$

where $p_{\mathrm{a}\ell}(\mathbf{X}_{\mathrm{w}}, T|\mathbf{X}_0)$ is calculated from the translational probability distributions, $p_{\mathrm{a}}(\mathbf{x}_2, t|\mathbf{x}_1)$ and $p_\ell(\mathbf{x}_2, t|\mathbf{x}_1)$, using Equation (2). The relationship given by Equation (3) is the fundamental equation for calculating the probability distribution of travel time, T, between $\mathbf{X}_0$ and $\mathbf{X}_{\mathrm{w}}$ in terms of the base translational probability distributions of travel times in the aquifer and through the lake. Equation (3) can also be generalized to the case where $\mathbf{X}_{\mathrm{w}}$ is any destination point, not necessarily a wellhead location. Such a formulation would be utilized in cases where multiple lakes are involved.

Particle-tracking formulation. The travel-time probability distribution $p(\mathbf{X}_{\mathrm{w}}, T|\mathbf{X}_0)$ given by Equation (3) can be approximated using a particle-tracking approach. This probability density function can be expressed in terms of the following particle counts:

N = number of particles released from $\mathbf{X}_0$;

n_{0ik} = number of particles released from $\mathbf{X}_0$ and arrive at $\mathbf{x}_i$ in time step k;

n_{0wk} = number of particles released from $\mathbf{X}_0$ and arrive at $\mathbf{X}_{\mathrm{w}}$ in time step k without passing through the lake;

M = number of particles released from $\mathbf{x}_i$ on the lake boundary;

m_{ijk} = number of particles released from $\mathbf{x}_i$ and arrive at $\mathbf{x}_j$ in time step k;

O = number of particles released from $\mathbf{x}_j$ on the lake boundary;

m_{jwk} = number of particles released from $\mathbf{x}_j$ and arrive at $\mathbf{X}_{\mathrm{w}}$ in time step k;

Using these particle counts, the probability density function given by Equation (3) can be estimated by the following relation

$$p(\mathbf{X}_\mathrm{w}, K\Delta t|\mathbf{X}_0)\Delta t = \sum_{j=1}^{J}\sum_{i=1}^{I}\sum_{\beta=1}^{K}\left\{\frac{m_{ij(K-\beta)}}{M}\left[\sum_{\alpha=1}^{\beta}\frac{n_{0i\alpha}}{N}\cdot\frac{o_{jw(\beta-\alpha)}}{O}\right]\right\} + \frac{n_{0wK}}{N} \tag{4}$$

where I is the number of lake-inflow surface elements, J is the number of lake-outflow surface elements, Δt is the time-step, and K is the total number of time steps corresponding to the travel time T, where $T = K\Delta t$.

Estimation of regulatory travel time from a source location. The probability densities given by Equations (3) and (4) give the probability that the travel time from the source location to the destination location is between T and $T - \Delta t$, where Δt is the time step in the particle tracks. A typical probability density function resulting from this calculation is shown in Figure 2(a), and the corresponding cumulative probability distribution is shown in Figure 2(b).

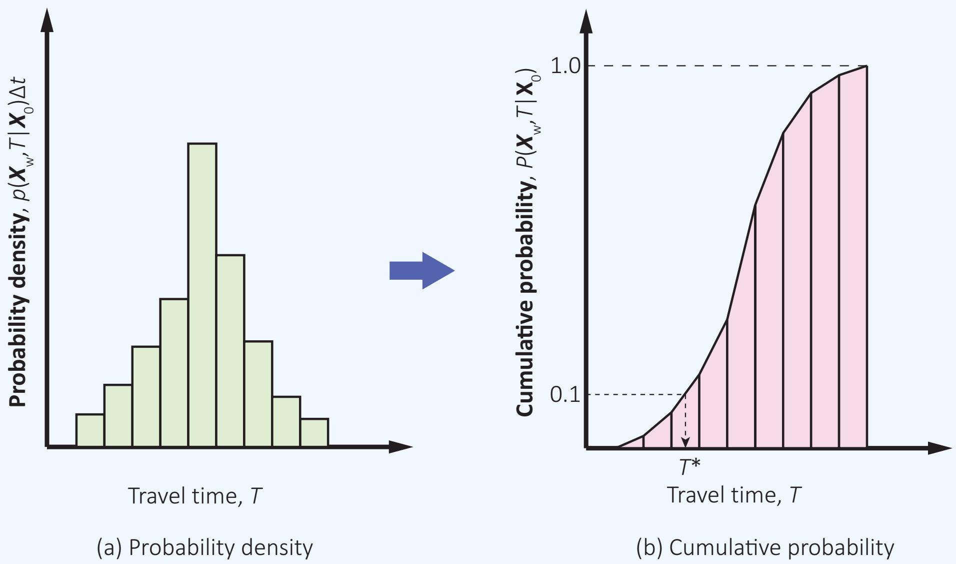

Figure 2: (a) Probability density function, and (b) Corresponding probability distribution

If the regulatory travel time at any source location is defined as having a 90% exceedance probability, then the regulatory travel time, T^*, corresponds to the travel time with a cumulative probability of 0.1 as shown.

Particle tracking and dispersion in the aquifer. For any time step Δt, the incremental distance Δx_i traveled by a groundwater particle in the x_i coordinate direction is given by

$$\Delta x_i = \left[\bar{v}_i + N(0,1)\sqrt{\frac{2D'_i}{\Delta t}} \right] \Delta t \tag{5}$$

where $\bar{v}_i$ is the mean seepage velocity in the x_i direction (i.e., the seepage velocity estimated from the groundwater-flow model), $N(0,1)$ is a random normally distributed number with a mean of zero and a standard deviation of 1, and D'_i is the component of the dispersion coefficient in the x_i direction. In accordance with first-order stochastic theory, the principal components of the dispersion coefficient, D'_i can be estimated by (Chin, 2013)

$$D'_1 = \sigma_Y^2 \lambda |\mathbf{v}| + \alpha_\mathrm{L}, \qquad D'_2 = 0.1(D'_1 + \alpha_\mathrm{L}), \qquad D'_3 = 0.01(D'_1 + \alpha_\mathrm{L}) \tag{6}$$

where σ_Y^2 is the variance of the (natural) logarithm of the hydraulic conductivities in the porous formation, λ is the (spatial) correlation length scale of the hydraulic conductivities, $|\mathbf{v}|$ is the magnitude of the local seepage-velocity vector, and α_L is the longitudinal component of the hydrodynamic dispersivity. The magnitude of α_L, is typically on the order of the size of the pores within the solid matrix (presumably ~ 1 cm at the sites being considered here), in which case $\alpha_\mathrm{L} \ll D'_1$ in typical field-scale dispersion models. Application of the dispersion coefficient $\mathbf{D}'$ calculated using Equation (6) is appropriate whenever: (1) the particle track in the aquifer significantly exceeds the correlation length scale, λ, and (2) the standard deviation of the log-hydraulic conductivity, σ_Y, is less than around 1.5.

Aquifer dispersion parameters in NWWF and WWF. The hydraulic conductivity variance, σ_Y^2, in the NWWF and WWF can be estimated from local hydraulic conductivities derived from APTs. Based on hydraulic-conductivity data summarized in Brakefield et al. (2013), where the hydraulic-conductivity data were derived mostly from Fish and Stewart (1991), it has been reported that $\sigma_Y^2 = 1.6$ is representative of APT data in the NWWF and WWF. It should be noted that Brakefield et al. (2013) used a $\log_{10}$ transformation of the hydraulic conductivity which yielded a variance of 0.3 after transformation; this corresponds to a variance (σ_Y^2) of 1.6 using a $\log_e$ transformation, which is the usual transformation associated with σ_Y. It is important to note that $\sigma_Y = \sqrt{1.6} = 1.3$ satisfies the requirement that $\sigma_Y < 1.5$ for the use of the first-order stochastic theory being applied here (Chin and Wang, 1992). The support scale of APT data analyzed using the classic Theis et al. (1963) methodology (as done by Fish and Stewart, 1991) is typically on the order of the effective radius of the pumping well. Field-scale dispersion data have been reported by Gelhar et al. (1992), and more recent comprehensive analyses have been reported by Zech et al. (2015). Based on these data, if a groundwater-flow model with a cell size of 50 m is used to estimate the seepage-velocity field, then it would be appropriate to estimate the local longitudinal macrodispersivity as $D'_1/|\mathbf{v}| = \sigma_Y^2 \lambda \sim 10$ m, which in this case would put the correlation length scale of the APT-derived hydraulic conductivity field on the order of $\lambda = 6$ m. This estimate of the correlation length scale is reasonably consistent with the support scale of the hydraulic conductivities derived from specific-capacity measurements as reported by Brakefield et al. (2013). Based on the aforementioned justifications, using a cell size of 50 m in the groundwater-flow model and taking $\sigma_Y^2\lambda = 10$ m in Equation (6) is justified by both field data reported in the open technical literature and local measurements.

Particle tracking and dispersion in lakes. Particle tracking through the seepage lakes[a] can be done using the particle tracking model described in detail by Chin (2016). This seepage-lake particle-tracking model has a formulation similar to that given by Equation (5), with the main differences being that $\bar{v}_i$ is derived from the lake hydrodynamic model, which can be developed using the EFDC, (Tetra Tech, 2002), and D_i is the turbulent diffusion coefficient within the lake. The algorithm suggested by Chin (2016) for determining the conditions under which a lake-water particle exits the lake and enters the aquifer can also be used.

[a] In *seepage lakes* inflow and outflow are predominantly via groundwater seepage.

6 Recommendations

Based on the limitations and concerns described in the previous sections of this report, the the following assessments and recommendations are offered:

- Travel times through quarry lakes were not appropriately calculated and do not properly account for the wind-driven circulation within lakes. A more appropriate particle-tracking approach that takes into account wind-driven circulation in the quarry lakes should be used.
- The ultimate build-out configuration for lakes should be used in delineating the travel-time contours. This approach will avoid the need to realign travel-time contours as additional lakes are quarried.
- A more robust technique should be used to estimate the probability distribution of contaminant-particle locations for given travel times, or the assumed technique should be statistically validated.
- Consider using the much more time-efficient stochastic particle-tracking approach based on dispersion coefficients rather than time-consuming Monte-Carlo simulations.
- If unconstrained Monte Carlo simulations continue to be used, then a likelihood function should be used to give the results from more-plausible hydraulic-conductivity and effective-porosity field realizations more weight relative to less-plausible realizations.
- In cases where regulatory travel-time contours intersect flowing canals, wellhead protection areas should include areas adjacent to the contributory flowing canals that could be sources of wellhead contamination with travel times in canals taken into account.

References

[1] Brakefield, L., J. Hughes, C. Langevin, and K. Chartier. 2013. Estimation of Capture Zones and Drawdown at the Northwest and West Well Fields, Miami-Dade County, Florida, Using

an Unconstrained Monte Carlo Analysis: Recent (2004) and Proposed Conditions. Open File Report No. 20131086. Reston, VA : U.S. Geological Survey.

[2] Chin, D. 1990. A method to estimate canal leakage to the Biscayne aquifer, Dade County, Florida. Water-Resources Investigations Report No. 90-4135. : United States Geological Survey.

[3] Chin, D. 2013. *Water-Quality Engineering in Natural Systems.* Hoboken, New Jersey : John Wiley & Sons Second edition.

[4] Chin, D. 2013. *Water-Resources Engineering.* Upper Saddle River, New Jersey : Pearson Third edition.

[5] Chin, D. 2016. Tracer transport through seepage lakes. *Journal of Hydrologic Engineering* 21(7):06016004(6).

[6] Chin, D., J. Iudicello, K. Kajder, P. Kelly, D. Porzilli, and H. Guha 2010. Lake Effect in Wellhead Protection. *Journal of Water Resources Planning and Management* 136(3):403–407.

[7] Chin, D. and T. Wang 1992. An investigation of the validity of first-order stochastic dispersion theories in isotropic porous media. *Water Resources Research* 28(6):1531–1542.

[8] Dagan, G. 1989. *Flow and Transport in Porous Formations.* New York, New York : Springer-Verlag.

[9] Enzenhoefer, R., T. Bunk, and W. Nowak 2014. Nine Steps to Risk-Informed Wellhead Protection and management: A Case Study. *Groundwater* 52:161–174.

[10] Fish, J. and M. Stewart. 1991. Hydrogeology of the surficial aquifer system, Dade County, Florida. Water-Resources Investigations Report No. 90-4108. : United States Geological Survey.

[11] Gelhar, L., C. Welty, and K. Rehfeldt 1992. A critical review of data on field-scale dispersion in aquifers. *Water Resources Research* 28(7):1955–1974.

[12] Harbaugh, A. 2005. MODFLOW-2005, the U.S. Geological Survey modular ground-water modelThe ground-water flow process. USGS Techniques and Methods 6-A16 no.. Reston, Virginia : U.S. Geological Survey.

[13] Pollock, D. 1994. User's Guide for MODPATH/MODPATH-PLOT, Version 3: A particle tracking post-processing package for MODFLOW, the U.S. Geological Survey finite-difference ground-water flow model. Open file report 94-464 no.. Reston, Virginia : U.S. Geological Survey.

[14] Sonenshein, R. 2001. Methods to Quantify Seepage Beneath Levee 30, Miami-Dade County, Florida. Water-Resources Investigations Report No. 01-4074. : U.S. Geological Survey.

[15] Tetra Tech, Inc. 2002. Draft User's Manual for Environmental Fluid Dynamics Code Hydro Version (EFDC-Hydro) Release 1.00.

[16] Theis, C., R. Brown, and R. Meyer. 1963. Estimating the transmissivity of aquifers from the specific specific capacity of wells. Water Supply Paper No. 1536-I. Reston, Virginia : U.S. Geological Survey.

[17] Zech, A., S. Attinger, V. Cvetkovic, G. Dagan, P. Dietrich, A. Fiori, Y. Rubin, and G. Teutsch 2015. Is unique scaling of aquifer macrodispersivity supported by field data? *Water Resources Research* 51:76627679.

ATTACHMENT C

Memorandum of Understanding 1994

MEMORANDUM OF UNDERSTANDING

BETWEEN

THE U.S. DEPARTMENT OF INTERIOR,
THE GOVERNOR OF THE STATE OF FLORIDA,
THE SOUTH FLORIDA WATER MANAGEMENT DISTRICT
AND METROPOLITAN DADE COUNTY

This Memorandum of Understanding (hereinafter sometimes referred to as the "Agreement"), made and entered into this 26th day of October, 1994, by and between the U.S. Department of the Interior, hereinafter called the "SECRETARY", the Governor of the State of Florida, hereinafter called the "GOVERNOR", the South Florida Water Management District, a public corporation of the State of Florida, hereinafter called the "DISTRICT", and Metropolitan Dade County, a political subdivision of the State of Florida, hereinafter referred to as the "COUNTY",

ARTICLE I. <u>BACKGROUND AND OBJECTIVES</u>

WHEREAS, the COUNTY proposes to construct a West Dade Wellfield, hereinafter referred to as the "Wellfield", and has applied to the DISTRICT for a Water Use permit (application #890731-12), requesting in said application to withdraw up to 40 million gallons per day from the Biscayne Aquifer and an allocation from the Floridan Aquifer System consistent with the Water Use permit, and

WHEREAS, the parties hereto desire to enter into this Agreement in order to provide adequate assurances that, in the event said Water Use permit is issued, withdrawals of water pursuant to said permit shall not cause adverse impacts to the hydrologic resources of the Everglades National Park, and

WHEREAS, the Everglades National Park Protection and Expansion Act of 1989, 16 U.S.C. secs. 410r-5 et seq., hereinafter referred to as the "Act" (Appendix "A"), provides that no Federal license, permit, approval, right of way or assistance shall be granted or issued with respect to the West Dade Wellfield (to be located in the Bird Drive Drainage Basin, as identified in the Comprehensive Development Master Plan for Dade County, Florida) until the SECRETARY, the Governor of the State of Florida, the South Florida Water Management District and Dade County, Florida enter into an agreement providing that any Water Use permit issued by the South Florida Water Management District for the Wellfield must include certain limiting conditions, which limiting conditions are ~~included within this Agreement;~~

NOW THEREFORE, in consideration of the mutual covenants hereinafter set forth, the parties hereto agree as follows:

ARTICLE II. TERMS AND CONDITIONS

A. The foregoing recitals are true and correct and are incorporated herein by this reference.

B. Conditions to be Incorporated if Water Use Permit is Issued by DISTRICT.

(1) If the DISTRICT issues any Water Use permit for the Wellfield pursuant to Application #890731-12, the Wellfield's peak pumpage shall not exceed the forty (40) million gallons per day from the Biscayne Aquifer. The appropriate allocation from the Floridan Aquifer System will be addressed in the permit based on DISTRICT Water Use Criteria and demonstrated hydraulic characteristics of the Floridan Aquifer System.

(2) Notwithstanding anything to the contrary herein, if the DISTRICT issues any Water Use permit for the Wellfield, the withdrawals authorized by the permit shall be limited to an amount which meets the applicable water use permitting criteria of the DISTRICT in Chapter 373, Florida Statutes, and Chapter 40E-2, F.A.C., which criteria shall in no event be applied to permit an allocation of water which would allow water withdrawals or pumpage rates which exceed the limitations set forth in the Act;

(3) If the DISTRICT issues a Water Use permit for the Wellfield, the permit shall include the following additional conditions regarding DISTRICT-declared water shortages:

(a) Reasonable, enforceable measures to limit demand on the Wellfield in times of water shortage, which shortage impacts the South Dade Water Use Basin, as defined in Chapter 40E-21, F.A.C., or the Everglades National Park, hereinafter called the "PARK". During such times of water shortage, the District has been authorized to declare areas of critical water supply pursuant to Chapter 373, Florida Statutes, and Chapter 40E-21, F.A.C.

(b) If, during times of a declared water shortage, the DISTRICT fails to limit demand on the Wellfield pursuant to Article II, Sec. B (3)(a) above, or if the DISTRICT limits demand on the Wellfield pursuant to Article II, Sec. B (3)(a) above, but the SECRETARY or the GOVERNOR certifies that operation of the Wellfield is still causing Adverse Impacts (see Article II, Sec. G herein) on the hydrologic resources of the PARK, as determined by the monitoring program described in Appendix "B", the ~~GOVERNOR may require the DISTRICT to take necessary~~ actions to alleviate the Adverse Impacts, includinG temporary reduction or cessation in pumpage from the Biscayne Aquifer from the Wellfield, use of alternative sources of water from the Floridan Aquifer System or additional reductions in demand. This certificate issued by the SECRETARY or the GOVERNOR shall specify what temporary corrective measures shall be required in the by the SECRETARY or the GOVERNOR shall specify what temporary corrective measures shall be required in the event of a disagreement regarding Adverse Impacts. In the event of such a disagreement, the COUNTY agrees to implement the corrective measures specified in the certificate pending outcome of the dispute resolution or correction of the Adverse Impacts, whichever occurs first. In the event that the COUNTY does not agree that Adverse Impacts have occurred in a particular case, the dispute mechanism set forth in Article II, Sec. D of this Agreement shall apply. The term "Adverse Impacts", as used herein, shall have the meaning set forth in Article II, Sec. G of this Agreement. The DISTRICT and the COUNTY shall abide by the order of the Governor to alleviate Adverse Impacts as permitted by Chapter 373, F.S., or its successor.

(c) Nothing herein shall be construed to limit the ability of the SECRETARY or the GOVERNOR to declare that Adverse Impacts to the hydrologic resources of the PARK have occurred when no water shortage has been declared by the DISTRICT.

C. The COUNTY agrees to comply with all conditions contained in any Water Use permit issued by the DISTRICT for the Wellfield.

D. The COUNTY agrees to operate the Wellfield in a manner which will not result in Adverse Impacts to hydrologic resources of the PARK. Upon notification by the SECRETARY or the GOVERNOR of Adverse Impacts to PARK hydrologic resources pursuant to the protocol developed in accordance with Article II, Sec. G herein, the COUNTY shall take necessary actions to alleviate the Adverse Impacts, including temporary reduction or cessation in pumpage from the Biscayne Aquifer from the Wellfield, use of alternative sources of water from the Floridan Aquifer System, or additional reductions in demand. In the event that the COUNTY does not agree that Adverse Impacts have occurred, the COUNTY shall only be required to implement the temporary corrective measures indicated in the certificate of Adverse Impacts pending resolution of the dispute pursuant to the dispute resolution procedure set forth in this Section. In the event of such a dispute, the COUNTY shall serve notice of the dispute upon the party which certified the Adverse Impacts. Upon notification of a dispute, the Key Officials indicated in Article IV, shall convene (by whatever communication device is expedient) within seventy-two (72) hours to determine whether Adverse Impacts have occurred. If the Key Officials substantiate that Adverse Impacts have occurred, they shall then decide what final action must be taken to alleviate the Adverse Impacts, and the COUNTY shall be required to take such action. If the Key Officials determine that Adverse Impacts have not occurred, the COUNTY shall not be required to continue corrective actions. If the Key Officials are unable to reach a unanimous resolution of the issue, then the decision of the SECRETARY shall be determinative.

E. If the DISTRICT issues a Water Use permit for the Wellfield, then, prior to the operation of the Wellfield, the COUNTY shall fund development of the following:

(1) the plan entitled, "Hydrologic Monitoring Program for the West Dade Wellfield" (Appendix "B"); and

(2) a stochastic hydrologic model (hereinafter "the model"), which model will be developed in cooperation with the DISTRICT and the PARK, and which will be used to develop an operation schedule for the Wellfield.

F. If the DISTRICT issues a Water Use permit for the Wellfield then, prior to the operation of the Wellfield, the COUNTY shall, with the cooperation of the PARK and the DISTRICT, implement the plan entitled, "Hydrologic Monitoring Program for the West Dade ~~Wellfield" (Appendix "B"). The parties to this Agreement agree~~ that this monitoring plan shall be implemented for a minimum of one (1) calendar year prior to operation of the Wellfield, in order to obtain a sufficient data base to allow for the calibration of the stochastic hydrologic model. All data, models and model output pertaining to the monitoring or determination of impacts related to the planning, development, implementation, or operation of the Wellfield shall be made available to all parties to this Agreement upon request.

G. Upon development and calibration of the model, the SECRETARY shall provide a protocol for timely notification to the GOVERNOR, the DISTRICT and the COUNTY when Adverse Impacts to the hydrologic resources of the PARK have occurred. The term "Adverse Impacts", for purposes of this Agreement, shall be defined as negative changes in water levels or flows in the L-31N canal and shall be equal to (a) specified hydrologic unit(s) of measurement which can reliably be detected by the monitoring network, and which can reasonably be linked by the model as being caused by the Wellfield. After collection of the base data as set forth in Article II, Sec. F herein, said unit(s) of measurement shall be determined by agreement of the parties hereto and incorporated as the standard(s) by which said "Adverse Impacts" shall be determined by inclusion in an appendix hereto (Appendix "C"), which appendix, upon approval of all parties to this Agreement, shall automatically be made a part of this Agreement without need for amendment hereto.

H. Nothing herein shall be construed to restrict the DISTRICT from exercising its authority under Chapter 373 of the Florida Statutes, or its implementing rules and permit conditions, to prevent or mitigate any adverse water resource impacts or impacts to existing legal uses and land uses.

I. Nothing herein shall be construed to restrict the COUNTY from applying for any other permit(s), or for modifications to any permit(s), if issued, provided, however, that this Agreement, unless amended, shall not pertain to any such application(s). If the COUNTY applies for a modification of (a) permit(s), or (an) additional permit(s) for this Wellfield, then this Agreement shall be modified, or a new agreement shall be entered into between the four parties hereto.

J. The DISTRICT agrees that it shall consider the feasibility of a water control structure on the C-4 canal (which structure would be located near the intersection of the C-4 Canal and the Dade-Broward Levee) as part of the revaluation of the Central and Southern Florida Flood Control Project or the first update of the Lower East Coast Regional Water Supply Plan.

K. Notwithstanding anything to the contrary herein, the DISTRICT does not warrant or guarantee in any way that it shall issue any Water Use permit to the COUNTY.

ARTICLE III. TERM OF AGREEMENTS; RENEWAL

A. Initial Term. This Agreement shall become effective upon the issuance of a Water Use permit for the Wellfield and shall have an initial term of fifty (50) years (which is the statutory maximum period of time for which a consumptive use permit may be issued by the South Florida Water Management District) or that period of time during which the Wellfield remains in operable condition, whichever is less.

B. Renewal Term. In the event that the initial term of this Agreement is fifty (50) years, this Agreement shall be automatically renewed for one (1) additional term of fifty (50) years, unless, prior to ninety (90) days before the expiration of said initial term, any of the parties to this Agreement notifies all other parties of its intent not to renew this Agreement.

C. Effect On Permit(s). Any permit issued by the DISTRICT shall be for the period of time which is stated in the permit, which time period need not coincide with the effective term of this Agreement. Similarly, the failure to renew this Agreement shall not affect the validity of any applicable Water Use ~~permit(s) in existence at the time of said failure to renew.~~

ARTICLE IV. KEY OFFICIALS

The following key officials (the "Key Officials") are authorized to act on behalf of the parties hereto in all matters undertaken pursuant to the terms of this Agreement:

THE U.S. DEPARTMENT OF INTERIOR: The Superintendent of the PARK, or authorized delegate, will provide review and approval of terms of all agreements, will be the authorized representative for service as required herein of all notices on the SECRETARY and participation in the dispute resolution mechanism set forth in Article II, Sec. D herein, and will exercise the authority to approve conduct of cooperative projects with regards to the conditions contained herein. The Assistant Director of the South Florida Research Center shall act as the authorized technical representative for the PARK with regard to the technical scope of this Agreement.

THE GOVERNOR OF THE STATE OF FLORIDA: The Secretary of the Florida Department of Environmental Protection is hereby designated as the Governors' authorized delegate. The Secretary of the Florida Department of Environmental Protection (DEP), or an employee assigned by the Secretary, will provide review and approval of terms of all agreements, will be the authorized representative for service as required herein of all notices on the GOVERNOR and participation in the dispute resolution mechanism set forth in Article II, Sec. D herein, and will exercise the authority to approve conduct of cooperative projects with regards to the conditions contained herein. In the event that Florida Statutes are amended respecting the position, powers, or status of the Secretary of the Florida Department of Environmental Protection, the Governor shall have the option to revoke this designation without amendment of this contract. The Director of the Division of Environmental Resources Permitting shall act as the authorized technical representative for DEP with regard to the technical scope of this Agreement.

THE SOUTH FLORIDA WATER MANAGEMENT DISTRICT: The Executive Director, or authorized delegate, will provide review and approval of terms of all agreements, will be the authorized representative for service as required herein of all notices on the DISTRICT and participation in the dispute resolution mechanism set forth in Article II, Sec. D herein, and will exercise the authority to approve conduct of cooperative projects with regards to the conditions contained herein. The Director of the Water Use Division's Regulation Department shall act as the authorized technical representative for the DISTRICT with regard to the technical scope of this Agreement.

METROPOLITAN DADE COUNTY: The Director of the Miami Dade Water and Sewer Authority Department, or authorized delegate, will provide review and approval of terms of all agreements, will be the authorized representative for service as required herein of all notices on the COUNTY and participation in the dispute resolution mechanism set forth in Article II, Sec. D herein, and will exercise the authority to approve conduct of cooperative projects with regards to the conditions contained herein. The Director of DERM, or authorized delegate, shall act as the authorized technical representative for the COUNTY with regard to the technical scope of this Agreement.

Written notice shall be provided to all parties of any change in Key Officials within four (4) weeks of such change.

ARTICLE V. AMENDMENT

This Agreement may be modified by amendment upon mutual written agreement of all parties.

ARTICLE VI. NOTICES

All notices required or permitted to be given under the terms and provisions of this Agreement by a party to the other parties shall be in writing and shall be sent by registered or certified mail, return receipt requested, to the parties as follows:

Department of the Interior
Richard S. Ring, Superintendent (Attn: Robert F. Doren)
Everglades National Park
40001 State Road 9336
Homestead, FL 33034-6733

The Governor of the State of Florida
c/o Secretary of the Department of Environmental Protection
2600 Blair Stone Road
Tallahassee, Florida 32399-2400
Attn: Director, Division of Environmental Resources Permitting

South Florida Water Management District
c/o Executive Director
P.O. Box 24680
West Palm Beach, Florida 33416-4680

Metropolitan Dade County
c/o Director, Miami Dade Water and Sewer Dept.
P.O. Box 330316
Miami, Florida 33133

or to such other address as may hereafter be provided by the parties in writing. Notices by registered or certified mail shall be deemed received on the delivery date indicated by the U.S. Postal Service on the return receipt.

ARTICLE VII. VENUE

Any litigation hereunder shall be brought in the appropriate state or federal court in Dade County, Florida.

ARTICLE VIII. HEADINGS

Captions and headings in this Agreement are for ease of reference only and do not constitute a part of this Agreement and shall not affect the meaning or interpretation of any provisions herein.

ARTICLE IX. RIGHTS OF OTHERS

Nothing in this Agreement express or implied is intended to confer upon any person other than the parties hereto any rights or remedies under or by reason of this Agreement.

ARTICLE X. WAIVER

There shall be no waiver of any right related to this Agreement unless in writing signed by the party waiving such right. No delay or failure to exercise a right under this Agreement shall impair such right or shall be construed to be a waiver thereof. Any waiver shall be limited to the particular right so waived and shall not be deemed a waiver of the same right at a later time, or of any other right under this Agreement.

ARTICLE XI. INVALIDITY OF PROVISIONS

The invalidity of one or more of the phrases, sentences, clauses, or Articles contained in this Agreement shall not affect the validity of the remaining portion of the Agreement, provided that the material purposes of this Agreement can be determined and effectuated.

ARTICLE XII. AUTHORITY OF PARTIES TO ENTER INTO AGREEMENT

A. Authority of the SECRETARY. The SECRETARY represents that (1) this Agreement has been duly authorized, executed and delivered by the Superintendent, Everglades National Park, pursuant to the authority vested in him by 16 U.S.C. secs. 1 and 1a-1 and 16 U.S.C. sec. 410r-8(i), as the duly authorized representative of the U.S. Department of the Interior for purposes of this Agreement, and (2) the U.S. Department of the Interior has the required power and authority to perform this Agreement.

B. Authority of the GOVERNOR. The GOVERNOR represents that (1) this Agreement has been duly authorized, executed and delivered by the Governor of the State of Florida, and (2) he has the required power and authority to perform this Agreement.

C. Authority of the DISTRICT. The DISTRICT represents that (1) this Agreement has been duly authorized, executed and delivered by the Governing Board of the South Florida Water Management District, and (2) it has the required power and authority to perform this Agreement.

D. Authority of the COUNTY. The COUNTY represents that (1) this Agreement has been duly authorized, executed and delivered by the Board of County Commissioners as the governing body of the County, and (2) it has the required power and authority to perform this Agreement.

ARTICLE XIII. ALLOCATION OF NATIONAL PARK SERVICE FUNDS

Nothing in this Agreement shall be construed to require the National Park Service to expend funds that have not been lawfully appropriated and administratively allocated for such purposes.

ARTICLE XIV. NONDISCRIMINATION

During the performance of this Agreement, the participants agree to abide by the terms of Executive Order 11246 on nondiscrimination and will not discriminate against any person because of race, color, religion, sex or national origin. The participants will take affirmative action to ensure that applicants are employed without regard to their race, color, religion, sex or national origin.

ARTICLE XV. CONGRESSIONAL PARTICIPATION RESTRICTION

No member or delegate to Congress, or resident Commissioner, shall be admitted to any share or part of this Agreement, or to any benefit that may arise therefrom, but this provision shall not be construed to extend to this Agreement if made with a corporation for its general benefit.

IN WITNESS WHEREOF, the parties hereto have caused this Agreement to be executed by their duly authorized representative(s) on the latest day and year noted below.

WITNESSES:

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DEPARTMENT OF THE INTERIOR

By: ______________________
Superintendent
Everglades National Park

WITNESSES:

____

____

THE STATE OF FLORIDA

By: ______________________
Governor

WITNESSES:

____

____

SOUTH FLORIDA WATER MANAGEMENT DISTRICT

By: ______________________
Chairman, Governing Board

ATTEST:

By: ______________________
Clerk

Approved as to form and legal sufficiency: ______

METROPOLITAN DADE COUNTY

By: ______________________
County Manager

APPROVED as to form and legal sufficiency this 3rd day of October, 1994

BY: ______________________
Assistant General Counsel
Office of the Governor

ATTACHMENT D

Water Supply Facilities Work Plan - Miami-Dade County

Section 6

Section 6
Climate Change and Sea Level Rise Plan

This section details MDWASD evaluation and planning for sea level rise and climate change over the planning horizon in this document. The primary concern to MDWASD water supply is salt water intrusion into the freshwater Biscayne aquifer, the primary source of drinking water in Miami-Dade County. Results of evaluation and data analysis completed to date indicate that within the next thirty years MDWASD will be able to operate our wellfields and water treatment facilities as designed, as groundwater modeling indicates even with a high level of projected sea level rise our wellfields will not be impacted by salt water intrusion. Further modeling is currently underway to extend the planning scenarios fifty years out, and will include climate change such as increases and decreases in annual precipitation, and extreme weather events.

6.1 Introduction

Southeast Florida is one of the most vulnerable regions to the impacts of climate change and sea level rise as a result of our flat topography, porous limestone geology, and dense coastal development. Climate change and sea level rise are expected to present significant challenges relating to water resource planning, management and infrastructure for the counties located in south Florida, including Broward, Miami-Dade, Monroe, and Palm Beach Counties. These counties have agreed to partner in regionally-coordinated climate mitigation and adaptation strategies as part of the Southeast Florida Regional Climate Change Compact and have adopted a Regional Climate Action Plan which highlights "Water Supply, Management, and Infrastructure" as a primary focal area. (http://southeastfloridaclimatecompact.org/). Investigations and evaluations conducted at the national, regional, and local levels have reinforced the need to plan for the predicted impacts of more frequent and severe drought, increases in tidal and storm-related flooding, and the loss of coastal wellfield capacity due to saltwater intrusion. In the absence of proactive planning, these impacts will present liabilities for coastal and inland communities with implications for urban water supplies, water and wastewater infrastructure, and both regional and local drainage/flood control systems. Investments in water supply planning and infrastructure that account for these predicted trends will improve the resilience of our communities, provide public health benefits, and reduce the potential for economic losses.

Miami-Dade County along with Broward, Monroe, Palm Beach Counties, local governments and water utilities in the southeast Florida region have begun to formalize the integration water supply and climate change considerations as part of coordinated planning efforts, including updates to local government and water utility 10 year Water Supply Facility Work Plan and enhancements to local government's Comprehensive Plans. Key considerations for communities within the four County Compact planning area areas include: 1) sea level rise, 2) saltwater intrusion, 3) extreme weather, and 4) infrastructure investments to support diversification and sustainability of water supply sources, and adaptive stormwater and wastewater systems. Sea level rise produces varied challenges with the respect to water resources sustainability, water management, and water/wastewater facilities and infrastructure. Impacts include salt water intrusion into coastal wellfields, infiltration of groundwater with chloride levels into wastewater collection systems, impairing normal operations and maintenance as well as challenges for beneficial use of reclaimed water as an alternative water supply. Water management systems are also at risk with systems constrained by rising groundwater and canal gate tailwater elevations, which reduce soil storage and discharge capacity, with increased potential for both inland and coastal flooding.

6.2 Miami-Dade County Sea Level Rise and Climate Change Recent Government Action

As part of the Miami-Dade County Evaluation and Appraisal Report adopted in 2011, climate change was identified as one of the priorities to address in the County's Comprehensive Development Master Plan (CDMP). Miami-Dade has incorporated climate change considerations and language in several of the Elements of the CDMP update which was approved by the Board of County Commissioners in October, 2013.

The Miami-Dade Sea Level Rise Task Force was created by Resolution R-599-13 on July 2, 2013 to review the relevant data and prior studies, assessments, reports, and evaluations of the potential impact of sea level rise on vital public services and facilities, real estate, water and other ecological resources, water front property, and infrastructure (http://www.miamidade.gov/planning/boards-sea-level-rise.asp). Their recommendations included in the June 2014 Final Report Recommendation 4:

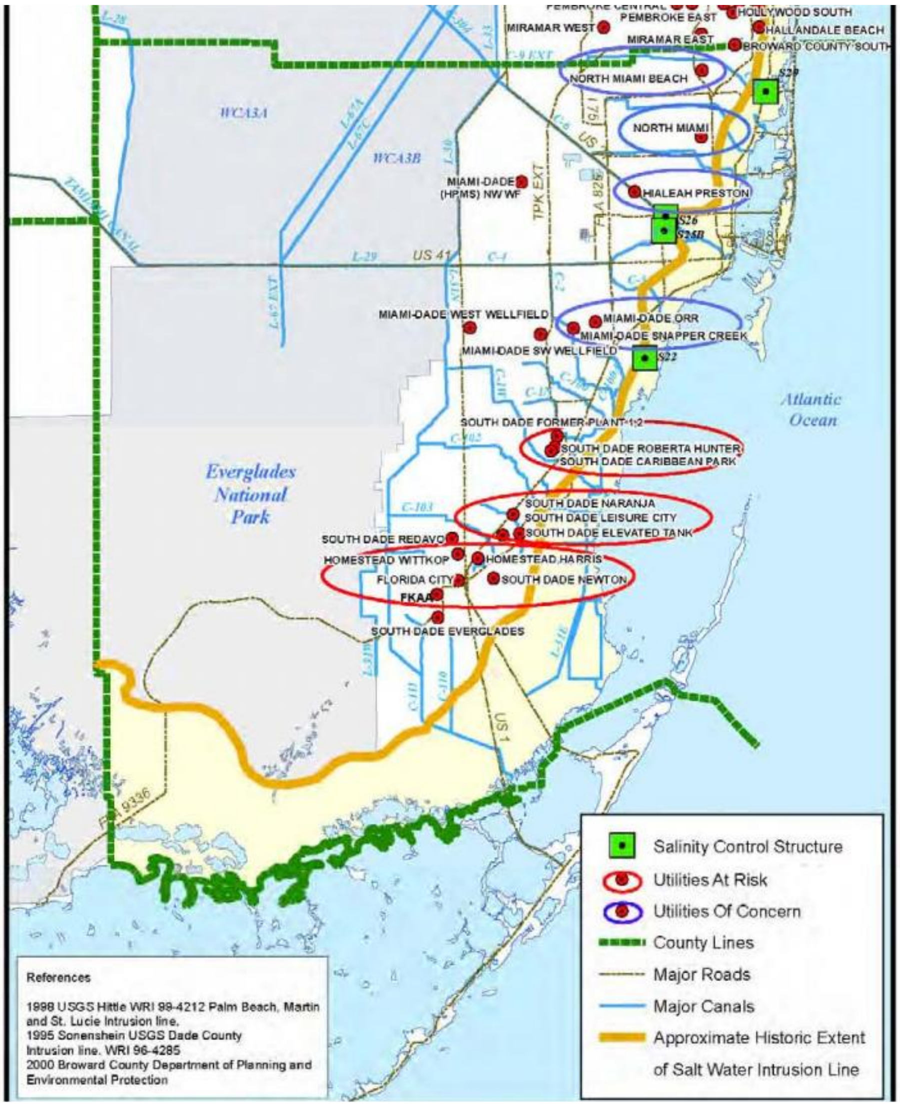
> *While recognizing the recent efforts to address flood protection and saltwater intrusion by the South Florida Water Management District and the Miami-Dade County, the Sea Level Rise Task Force recommends that Miami Dade County work jointly with the District and the SE Climate Compact partners to conduct a comprehensive study and develop adaptation strategies to address potential flood damage reduction and saltwater intrusion associated with sea level rise. This strategy should expeditiously address rising sea levels, a time frame for implementation, and a potential funding mechanism.*

Miami-Dade Board of County Commissioners adopted in September an ordinance relating to the rules of procedures of the Board of County Commissioners amending Section 2-1 of the Code of Miami-Dade County, Florida, to require that in all agenda items related to planning, design, and construction of county infrastructure a statement be included that the impact of sea level rise has been considered (File 141211 http://www.miamidade.gov/govaction/matter.asp?matter=141211&file=true&yearFolder=Y2014).

6.3 Saltwater Intrusion

Along the coast of southeast Florida, and several miles inland, groundwater supplies and potable wells are vulnerable to saltwater contamination. The Biscayne Aquifer, which serves as the region's primary water supply, is a shallow, surficial aquifer characterized by limestone karst geology which is highly porous and transmissive. Salt water intrusion is defined by the South Florida Water Management District (SFWMD) as chloride concentrations exceed drinking water standards of 250 mg/l. The SFWMD has identified "Utilities at Risk" for salt water intrusion, which include utilities with wellfields near the saltwater/freshwater interface that do not have an inland wellfield, have not developed adequate alternative sources of water, and have limited ability to meet user needs through interconnects with other utilities; and "Utilities of Concern", which include utilities having wellfields near the saltwater/freshwater interface, the ability to shift pumpages to an inland wellfield, or an alternative source that is not impacted by the drought (SFWMD, 2007). Miami-Dade WASD wellfields included as "Utility at Risk" are South Miami-Dade Wellfields (Newton, Elevated Tank, Naranja, Leisure City, Roberta Hunter- Caribbean Park). MDWASD Utilities of Concern include the North and Central Miami-Dade Wellfields (Hialeah-Preston and Alexander Orr) (Figure 1).

Figure 1. Utilities and Risk and Utilities of Concern, Miami-Dade County (SFWMD, 2007).



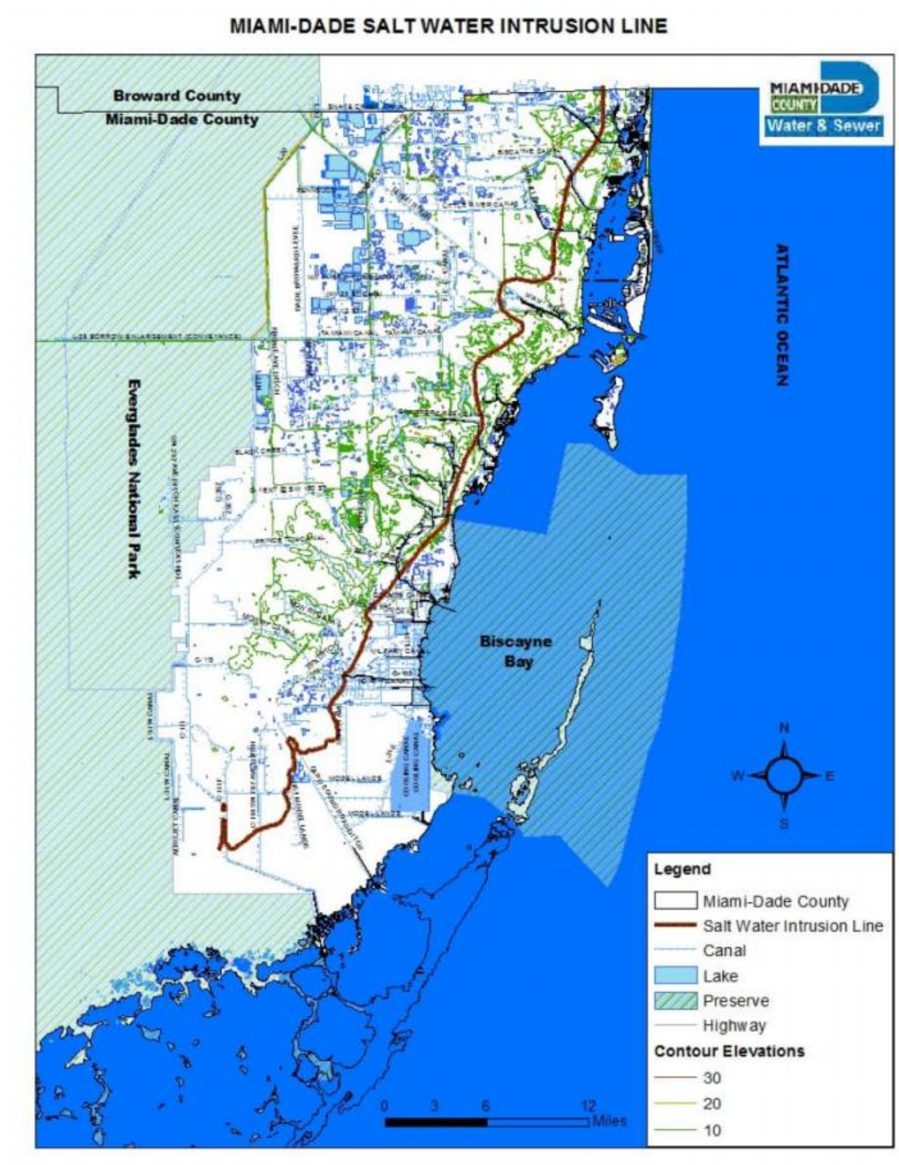
6.3.1 Salt Intrusion Monitoring Network

Saltwater intrusion in Miami-Dade County is monitored through a joint effort of the Miami-Dade Water and Sewer Department (MDWASD), Miami-Dade Department of Regulatory and Economic Resources (RER), and the U.S. Geological Survey (USGS). A network of small diameter wells have been drilled to the base of the aquifer to serve as monitor wells to identify the location of the saltwater intrusion front. The salt front is identified as the location, at the base of the aquifer, of the 1,000 milligrams/per liter (mg/L) isochlor, or line of equal chloride concentration of 1,000 mg/L). Sampling of the monitor wells is done by the USGS, under a co-operative Joint Funding Agreement (JFA) contract with Miami-Dade County for wells currently included in the salt front monitoring program (JFA #14GGESMC0000109). Additional wells are sampled quarterly or yearly basis depending on well location, but every year the sampling schedule includes a county-wide sampling event conducted at the height of the dry season to coincide with the time when inland movement of the saltwater front would be at its peak. The data derived from that sampling is used by the USGS to identify any significant movement of the salt front, and to map the location of the salt front if a significant movement is evident. MDWASD reports the data to the South Florida Water Management District (SFWMD) quarterly, as part of the WUP #13-00017-W requirements, and is required as part of Limiting Condition 37 of the 20-Year WUP (SFWMD, 2007; Appendix H) to submit an annual report summarizing the data collected and recommendations for adjustments to the salt front monitoring network as a result of data analysis.

6.3.2 Salt Intrusion Front Delineation

Miami-Dade WASD entered into a JFA with the USGS in 2007 (JFA #08E0FL208004) to delineate the current extent of saltwater intrusion in the Biscayne aquifer, to characterize how the extent has changed since the last mapping effort, to improve salinity monitoring in the Biscayne aquifer and to identify the sources of the saltwater to better understand the actions required to prevent or mitigate saltwater intrusion. As part of this effort eleven new monitoring wells have been installed in areas where there was insufficient information to identify the location of the front, and data from geophysical tools and techniques were incorporated into the analysis. To improve accessibility of salinity monitoring information to the public, the USGS cooperative water conditions website was improved and a new website created. "Saline Intrusion Monitoring, Miami-Dade County, Florida," serves data collected during this study, as well as data from the active salinity monitoring network, and provides the interpreted maps of the inland extent of saltwater intrusion (*http://www.envirobase.usgs.gov/FLIMS/SaltFront/viewer.htm*, U.S. Geological Survey, 2011g). This website allows the USGS to deliver timely hydrologic data, analyses, and decision-support tools concerning saltwater intrusion. As a result of the JFA, an updated salt front map was published in 2011 (Figure 2) and the final report summarizing the study and recommendations and conclusions published in 2014 (Prinos, et. al. 2014).

Figure 2. Salt Water Intrusion extent, Miami-Dade County, FL. (USGS 2011)



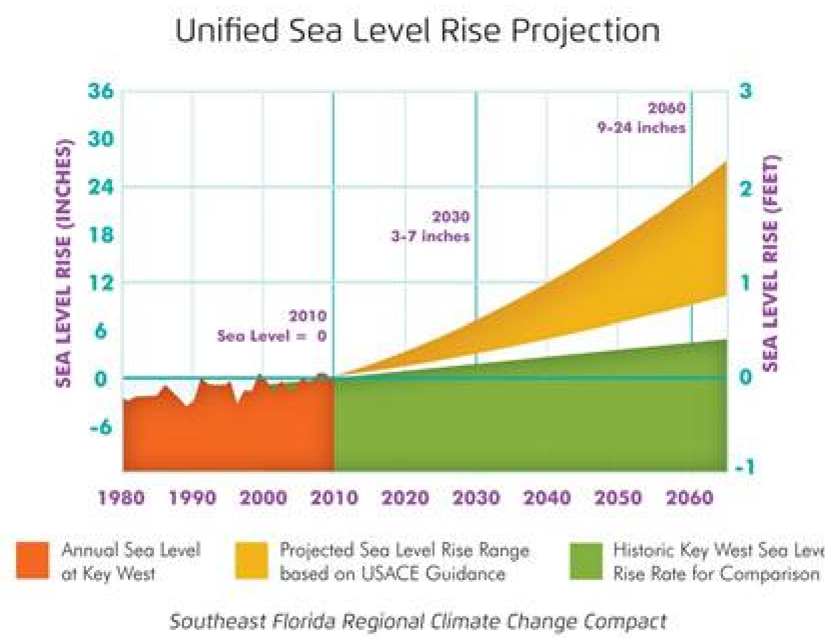
6.4 Urban Miami-Dade County Surface Water/Groundwater Model

Miami-Dade County entered into a Joint Funding Agreement (JFA 08E0FL20817) with the USGS in February 2008 to develop an integrated surface/groundwater numerical flow model, with one of the objectives of the project to evaluate if sea level rise will cause salt water intrusion into coastal wellfields. The numerical model is designed among other uses to evaluate if the current surface-water structure control operational criteria effectively control saltwater intrusion with projected population increase and sea level rise. MDWASD and the USGS use this integrated surface-water/groundwater model to evaluate how the position of the freshwater/saltwater interface will change with increased well field pumpage, increased sea level, and a combination of increased well field pumpage and increase sea level.

The model was developed and calibrated a coupled surface-water/groundwater model of the urban areas of Miami-Dade County, Florida. The model is designed to simulate surface-water stage and discharge in the managed canal system and dynamic canal leakage to the Biscayne aquifer as well as seepage to the canal from the aquifer. The model was developed using USGS MODFLOW-NWT with the SWR1 Process and the SWI2 Package to simulate the surface-water system and seawater intrusion, respectively (Hughes et. al., 2013). Automated parameter estimation software (PEST) and highly-parameterized inversion techniques were used to calibrate the model to observed surface-water stage, surface-water discharge, net surface-water sub-basin canal discharge, and groundwater level data from 1997 through 2004 by modifying hydraulic conductivity, specific storage coefficients, specific yield, evapotranspiration parameters, canal roughness coefficients (Manning's *n* values), and canal leakance coefficients (Walsh and Hughes, 2014).

MDWASD and the USGS used the modified guidance developed by the U.S. Army Corps of Engineers (USACE, 2011) and a planning scenario of 9 to 24 inches additional rise by 2060, consistent with projections presented in the 2014 NCA, and formally adopted by the partner counties in the Southeast Florida Regional Climate Change Compact (Figure 3) for the modeling effort.

Figure 3: Unified Southeast Florida Sea Level Rise Projection for Regional Planning Purposes



The USGS has completed the preliminary model and initial scenarios regarding sea level rise, and results are pending publication (USGS, verbal communication). The model simulation period is from 1/1/1996 to 12/31/2010, with daily surface-water and groundwater timesteps. The model was calibrated using highly-parameterized inversion methods, with an 8 year calibration period (1997-2004) and a 6 year verification period (2005-2010). To represent future conditions, 30-year scenario simulation periods representing conditions from 2011 through 2040 were run. The thirty year scenario period was chosen as being scientifically defensible at this point in time with available sea level rise and climate change data available.

Four scenarios have been completed to date, and will be included in the pending publication:

- ***Base scenario***
  - Daily 2010 well field withdraws repeated for 30 year daily
  - meteorological data set (recycled twice)
  - 2008 land use
  - Predicted Virginia Key tidal stage with current linear rate of SEA LEVEL RISE-0.5 ft over 30 years

- Everglades Depth Estimation Network (EDEN) data set (recycled twice)
- Historical structure operations - effective gate openings

- ***Scenario 1***
  - Base scenario
  - Increased WASD well field withdrawals - increased rates provided by WASD (WUP 2012 allocations)

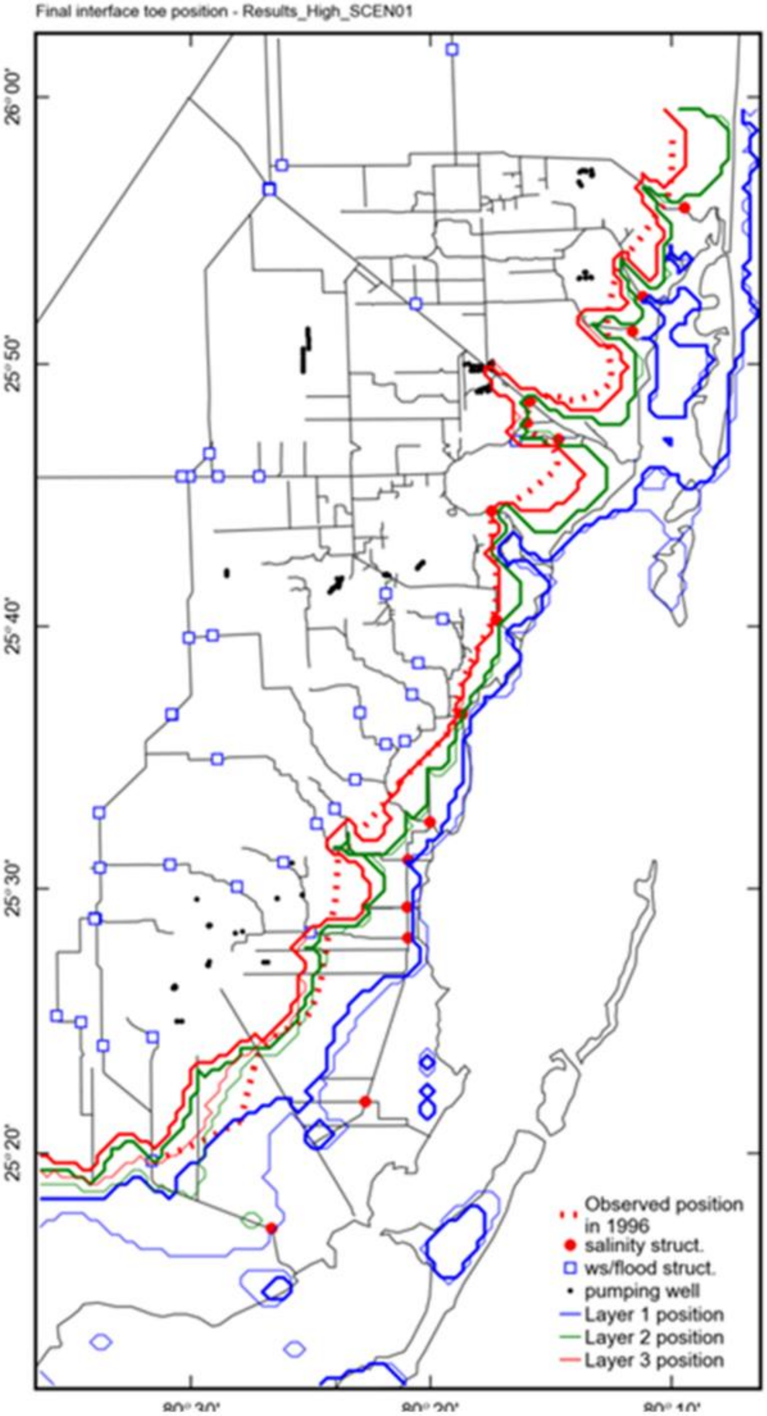
- ***Scenario 2***
  - Base scenario
  - High sea-level rise rate (NRC III rate - 1.23 ft increase over 30 years) added to predicted
  - Virginia Key tidal stage
  - Blend EDEN data and increased sea level where needed

- ***Scenario 3***
  - Scenario 2
  - Increased WASD well field withdrawals at permitted 2025 allocations

Therefore, Scenario 3 represents the high-level rate of sea level rise and the permitted wellfield withdrawals allocated in the SFWMD 20-Year WUP. Results of Scenario 3 indicate minimal change in the salt front (Figure 4).

As a result of the USGS Salt Front JFA, and the on-going salt front monitoring, and the groundwater flow modeling project, Miami-Dade WASD wellfields are not considered at risk for salt water intrusion within the next ten years.

Figure 4. Scenario 3 Salt Water Intrusion Results. (Walsh and Hughes, 2014).



6.5 Extreme Weather Events

As extreme events increase in frequency and severity, MDWASD will consider impacts and risks associated with drought, water shortages and reduced groundwater tables, all of which can hasten saltwater intrusion and exacerbate water supply impacts. Conversely, more intense and rapid rainfall will cause flooding, increased runoff, impacts to the natural systems and provide less recharge potential. Integrated water resources management strategies will help to mitigate for these impacts, particularly those projects that can serve to provide additional storage of stormwater runoff, long term storage, and redistribution of excess rainfall during dry periods and drought. Regional surface water reservoirs and belowground aquifer storage and recovery systems are potentially viable alternative water supply projects and climate adaptation strategies. Increases in groundwater elevations, in both direct and indirect response to sea level will challenge the function of drainage systems and is expected contribute to exacerbate flooding, for even mild storm events. Conditions will be more severe with extreme rainfall events can increase damage to lowlying utility infrastructure and contribute to prolonged surface water flooding. Planning for the combined influences of storm events, high tides and sea level rise on drainage system functions and other public infrastructure is a critical need as is the assessment of viable water supplies and impacts to the natural systems from prolonged droughts.

MDWASD has entered into a JFA in 2014 (JFA 14GGESMC0000110) with the USGS to continue the modeling effort, and will develop additional future scenarios with County Departments, local governments, regional agencies for further climate change and sea level rise assessment. These scenarios will include additional years simulation, changes in recharge as a result of climate change, land use changes, and revised sea level rise projections. Future model scenarios to be developed with the USGS include simulating extreme weather events superimposed on future conditions as simulated in model runs.

6.6 Infrastructure Assessment

Effective water treatment plant operations require proper control of flooding from both stormwater (riverine) and tidal sources. Comprehensive engineering analysis considers both short-term and long-term effects of climate change. Short-term effects, such as current increased sea levels and higher estimates of tidal boundary conditions, will be incorporated into the system design and operations as necessary. Potential longer-term climatic changes are typically addressed incrementally as needed through systems master planning, to provide the appropriate level of protection for the given time period, including:

- Greater levels and rates of sea level rise,
- Higher spring tides (exceptionally high astronomical tides that occur around the new and full moon when the planets align to exert maximum effect on the tides),
- Higher tidal boundary effects and backflow,
- Increased levels of tidal surge and wind and wave effects from tropical storms and hurricanes, and
- Potential changes in design rainfall depths and intensities.

MDWASD requires capital improvement projects to include an assessment of climate change and sea level rise. Background information on the site stormwater and tidal conditions is required for site specific projects, and assessment includes projections of potential increases in sea levels, potential ranges of effects on the WTP stormwater management system, and site grading considerations and access for proper operations. The Miami-Dade County hydrologic and hydraulic model XP-SWMM is used to develop peak stage and flood inundation maps. XPSWMM uses a node-link architecture to dynamically route rainfall-runoff through pipe networks and open channels. A variety of data can be analyzed (example FDEP and NOAA tidal data, canal stage data, tidal stillwater data) to adequately assess MDWASD operational sites' vulnerability to continued sea level rise and to provide for potential adaptation options (CDM Smith, 2013).

References

CDM Smith, 2013. Technical Memorandum *Miami-Dade Water and Sewer Department PSA No. 01CDAM003 – Task Authorization No. 12 South Miami Heights (SMH) Water Treatment Plant (WTP) Program Climate Change Adaptation Review*

http://www.envirobase.usgs.gov/FLIMS/SaltFront/viewer.htm

http://www.miamidade.gov/govaction/matter.asp?matter=141211&file=true&yearFolder=Y2014

Hughes, J.D., Langevin, C.D., Chartier, K.L., and White, J.T., 2012, *Documentation of the Surface-Water Routing (SWR1) Process for modeling surface-water flow with the U.S. Geological Survey Modular Ground-Water Model (MODFLOW–2005)*: U.S. Geological Survey Techniques and Methods, book 6, chap. A40 (Version 1.0), 113 p.

Miami-Dade County, July 1, 2014. *Miami-Dade Sea Level Rise Task Force Report and Recommendations (http://www.miamidade.gov/planning/boards-sea-level-rise.asp)*

Prinos, S.T., Wacker, M.A., Cunningham, K.J., and Fitterman, D.V., 2014, *Origins and delineation of saltwater intrusion in the Biscayne aquifer and changes in the distribution of saltwater in Miami-Dade County, Florida*: U.S. Geological Survey Scientific Investigations Report 2014–5025, 101 p., *http://dx.doi.org/10.3133/sir20145025*.

South Florida Water Management District, 2007. *Utilities of Concern in the Lower East Coast Region and Lake Okeechobee Service Area*.

Southeast Florida Regional Climate Change Compact, *http://southeastfloridaclimatecompact.org/*

U.S. Geological Survey, 2007 Joint Funding Agreement 08E0FL208004 *Assessment of seawater encroachment and seawater encroachment monitoring network improvements in Miami-Dade County, Florida.*

U.S. Geological Survey, 2008. Joint Funding Agreement 08E0FL208017 *An integrated model of surface and groundwater flow for evaluating the effects of competing water demands in Miami-Dade County.*

U.S. Geological Survey, 2013. Joint Funding Agreement 14GGESMC0000109 *Investigations of Water Resources.*

U.S. Geological Survey, 2014. Joint Funding Agreement 14GGESMC0000110 *Aquifer hydrogeologic framework, modeling tools and evaluating sea-level rise, Miami-Dade County.*

USACE Engineering Circular 1165-2-212: *Sea-Level Change Consideration for Civil Works Programs* USACE, 2011.

Walsh, V, and J. Hughes. 2014. *Urban Miami-Dade County Surface-Water/Groundwater Model – Application for Sea-Level Rise Evaluation.* 23rd Annual Southwest Florida Water Resources Conference, Fort Myers, FL. January 31, 2014