Antonia Hover

From: Antonia Hover on behalf of Records Clerk
Sent: Monday, January 24, 2022 4:01 PM
To: 'dadams@bja-law.com'
Cc: Consumer Contact
Subject: FW: Docket #20200226-SU
Attachments: EU PSC Sewer system application.docx; Ackerman Study.pdf

Good Afternoon, David Adams.

We will be placing the comments below in consumer correspondence in Docket No. 20200226, and forwarding them to the Office of Consumer Assistance and Outreach.

Thank you!

Toni Hover
Commission Deputy Clerk I
Florida Public Service Commission
2540 Shumard Oak Boulevard
Tallahassee, FL 32399
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From: David W Adams <dadams@bja-law.com>
Sent: Monday, January 24, 2022 2:25 PM
To: Office of Commissioner La Rosa <Commissioner.LaRosa@psc.state.fl.us>; Office of Commissioner Clark <Commissioner.Clark@psc.state.fl.us>; Office of Commissioner Passidomo <Commissioner.Passidomo@psc.state.fl.us>
Cc: Records Clerk <CLERK@PSC.STATE.FL.US>
Subject: Docket #20200226-SU

Dear Commissioners:

My name is David Adams, and with my partners, I own property at 8356 Little Gasparilla Island (LGI) in Placida, Florida. We have owned our property for approximately 11 years and have purchased water through Little Gasparilla Water Utility which I understand is related to Environmental Utilities (EU).

Lack of Proven Need for Service

I have reviewed the PSC docket and spent some time reviewing the documentation associated with the EU application. I am unable to locate sufficient background facts and documentation to show there is a proven need for the service. The vast majority of LGI houses are vacation properties for which the residents occupy occasionally on the weekends. It is not like there is a heavy nitrogen load coming from the south end of the island. While Charlotte County made reference to nitrogen load studies in their correspondence to the PSC, none of those were conducted at or around the proposed service area. Additionally, the Ackerman study is not comparable for LGI because the Ackerman subdivision contained a plethora of canals near the studied septic systems, which canals increased the plume of nitrogen entering the bay, prior to the StoS conversion. Therefore, additional study and facts demonstrating a proven need for service should be in the record before the commission approves the application.

Sewer Service

I am not aware of anyone requesting sewer service on LGI. However, if there was a proven need, then I would expect Charlotte County to provide the utility. Providing water and sewer is a core governmental function. It is not fair for Charlotte County to shirk its obligation to provide core government services to the ratepayers. It is also unfair to the ratepayers to force them to use a private utility which has an unproven track record for a project of this magnitude. If construction or operation of the sewer system is compromised (such as a hurricane or flooding), then the ratepayers will be left without any means to dispose of raw sewage because the plan requires all homeowners to remove properly functioning septic tank systems. EU does not have the same resources as Charlotte County to mitigate climate change and flooding. Additionally, if Charlotte County undertook the project, then it would be done with governmental bonding and financing which results in a significantly lower cost of capital. For example, EU requires a large lump sum payment for construction of the system, as compared to Charlotte County which allows ratepayers to spread the hookup fee over a long period of time (I believe 10 years). The operating costs would also be spread among the entire Charlotte County population as opposed to the LGI residents. This would result in lower rates and operating costs. Some of the homeowners are on fixed incomes and the abnormal hookup cost and operating fees will force them to sell their properties on the island. As proposed, EU will receive a guaranteed profit for constructing and operating the Sewer System. As a governmental entity, Charlotte County does not need to make money operating the sewer system, which is better for the ratepayers. Moreover, Charlotte County has the expertise and experience to install and operate complex sewer system such as the one proposed by EU. It seems insincere for Charlotte County to claim that this project is a priority in its long term septic to sewer plan, but is unwilling to schedule and complete the project consistent with its claims that LGI is a priority project to reduce nitrogen load in Charlotte Harbor.

Technical Expertise/Customer Service

The application does not demonstrate any experience or expertise in constructing or operating a sewer system. The ratepayers are at risk if EU is unable to properly construct or operate the system. Charlotte County is in a much better position to design construct and operate the sewer system proposed by the applicant. While I have not had much interaction with the affiliated party to the applicant, Little Gasparilla Water Utility, when we did have billing problems, there was no one who answered the telephone and our billing correspondence was not answered on a timely basis. If ratepayers are required to use EU, they deserve prompt and professional customer service.

Costs and Rates

The documentation attached to Charlotte County's letter to the PSC includes plans and estimates that were based on 2017 dollars. Accordingly, the estimates for construction and operation of the system are grossly understated (considering inflation, labor and cost of materials). Additional information and estimates are necessary in order to make a thoughtful decision of this magnitude. There is a lack of information available for analysis at this time.

Conclusion

For the above reasons, I ask that the Commission deny EU's application to provide Sewer Service at Little Gasparilla Island at this time.

Thank you,

David Adams
813 452 2882

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PAPER

Pathways and timescales associated with nitrogen transport from septic systems in coastal aquifers intersected by canals

Tanten T. Buszka[1] · **Donald M. Reeves**[1]

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Abstract

Septic systems located near coastal waterways can contribute to nutrients that lead to eutrophication, harmful algal blooms, and high levels of fecal coliforms such as *E. coli*. This study defines pathways and timescales of nitrogen transport released from septic systems using a groundwater-flow and nitrogen transport model of a coastal subdivision connected to 2,000 septic systems and dissected by a dense network of canals. Lift station effluent data are used as a proxy to quantify average household septic nitrogen and fluid contributions of 11 kg/year and 160 m^3/year, respectively. These fluxes are upscaled and applied to five sewer conversion zones, each having a known number of septic systems. Model results provide a basis for assessing nitrogen transport timescales associated with (1) coastal groundwaters for regions with high septic density near the coastline and (2) groundwater–canal interaction. Timescales associated with nitrogen removal by natural groundwater flow in a sandy surficial aquifer, following septic to sewer conversion, are predicted by the model to be on the order of 2–3 years for 50% reduction and 8–10 years for 90% reduction. Both numerical and collected field data indicate that canals significantly influence groundwater flow and have the potential to convey nitrogen to coastal waters at rates several orders of magnitude higher than introduced by submarine discharge along the coast. Pre and post sewer conversion data on nitrate and total nitrogen in shallow groundwater from a nearby field site, obtained post-model development, support the nitrogen concentrations and timescales predicted by the numerical model.

Keywords Coastal aquifers · Eutrophication · Estuary · Nitrate · Sewer conversion

Introduction

Eutrophication occurs when surface water is overly enriched in nutrients and is typically caused by the overabundance of phosphorus and/or nitrogen from agricultural runoff or livestock and human waste products (Schindler 1974; Nixon 1995; McIsaac et al. 2001; Conley et al. 2009). Excess nutrients create favorable conditions for plant, algae, and bacterial growth beyond the natural balance. *Karenia brevis*, a naturally occurring dinoflagellate in coastal waters, has the potential to rapidly concentrate and form red tides, a subset of harmful algal blooms (HAB) where the combination of hypoxic conditions and the release of brevetoxins can lead to significant fish kills (Poli et al. 1986; Anderson et al. 2002; Landsburg 2002; Pierce and Henry 2008; Landsberg et al. 2009). Human health may be adversely impacted by red tides as near shore wave and wind action can facilitate the transfer of the neurotoxins to the airborne phase (Pierce 1986).

Eutrophication is typically associated with an abundance of phosphorous and nitrogen; however, nitrogen is generally the limiting nutrient for phytoplankton growth in estuaries (Howarth and Marino 2006), and particularly in southwest Florida (USA) coastal waters due to natural phosphoric enrichment in the soil (Mansfield 1942; Zhang et al. 2002). HAB frequency in southwest Florida has increased approximately 15-fold from a baseline period of 1954–1963 to 1994–2002 (Brand and Compton 2007). Many of these occurrences are located in the northern section of Charlotte Harbor (Fig. 1). Given the abundance of naturally occurring phosphorus, limiting nitrogen fluxes into coastal waters is a viable management tool to control HABs (Froelich et al. 1985; Vargo et al. 2004).

Anthropogenic sources of nitrogen such as agricultural return flows, fertilizers, atmospheric deposition and effluent water disposal, are likely responsible for the increases in HABs

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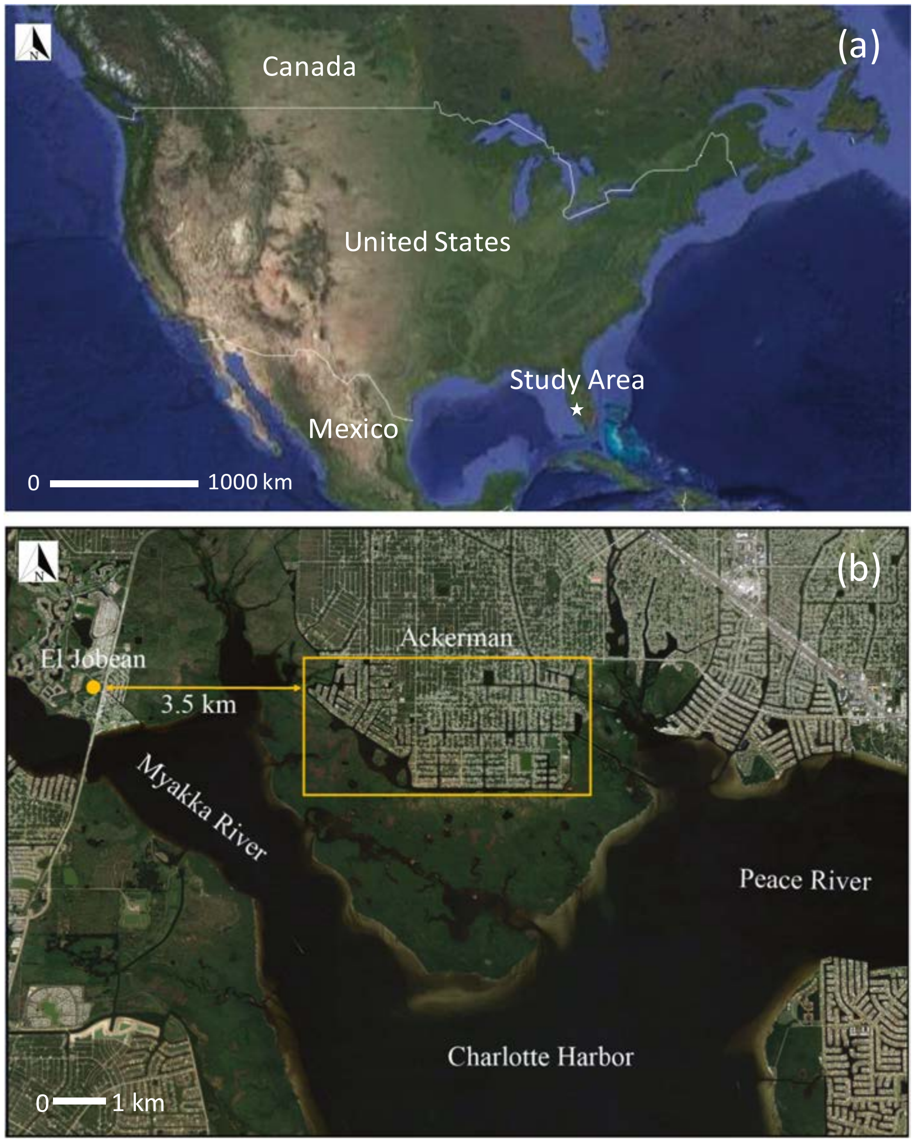

Fig. 1 Maps showing the location of **a** the study area relative to the United States, and **b** Ackerman subdivision relative to El Jobean, Charlotte Harbor, and the Myakka and Peace rivers (Map data: Google, TerraMetrics 2021). The orange box has approximate dimensions of 5 km × 2.5 km

and red tides (LaPointe and Clark 1992; Paul et al. 2000; Shaddox and Unruh 2018). Septic effluent is a poorly characterized, nonpoint source of nitrogen to the Charlotte Harbor (MML 1997; Lapointe et al. 2015). Over 45,000 homes in Charlotte County are connected to septic systems, creating the potential for excess nitrogen loading into Charlotte Harbor. The vast majority (~95%) of these are conventional septic systems that capture outflowing waste in a tank where a baffle is used to separate solids (which settle to the bottom of the tank) from liquids (Tilley et al. 2014). Anaerobic conditions within the tank reduce solid volumes through biodegradation; liquid effluent flows out of the tank into a drainfield with laterals comprised of perforated PVC pipes. Drainfield laterals are installed in trenches filled with highly permeable media such as gravel or pebbles, to facilitate infiltration (AGT 1998).

Treatment of waste by septic systems relies on naturally occurring geochemical reactions within the soil that are often facilitated by microbes (Cogger and Carlile 1984; Tilley et al. 2014). In a properly functioning system, nitrifying bacteria in the shallow drainfield convert ammonium (NH_4^+) in the presence of oxygen to nitrite (NO_2^-) and nitrate (NO_3^-). Nitrate may then be converted to N_2 gas under anaerobic conditions through denitrification; this results in a transfer of nitrogen to the atmosphere that reduces nitrogen loading to groundwater (Seiler 1996; Harden et al. 2010; Tilley et al. 2014). The conversion of nitrate to N_2 gas is often limited by field conditions, with most conventional septic systems achieving only 20–25% nitrogen removal through denitrification (Costa et al. 2002).

Proper functioning of septic systems relies on establishing and maintaining an unsaturated zone of separation between the drainfield and water table. In Florida, the minimum separation distance is 61 cm (Florida Administrate Code 64E-6.001). Large water-table fluctuations between seasonal dry and wet periods on the scale of approximately 1 m, and close proximity to the land–water interface along coastlines and/or canal systems, often violate the minimum separation distance criterion. Shallow water-table conditions render many of the older septic systems ineffective (Lambert and Burnett 2003; Meeroff et al. 2008; Harden et al. 2010) as nitrogen-rich septic effluent is injected directly into surficial aquifers (Mallin 2013). Submarine groundwater discharge along coastal areas or to adjacent canals from these shallow aquifers is the primary transport mechanism responsible for the loading of septic-derived nitrogen to Charlotte Harbor.

Several studies have investigated the role of nitrogen as the leading cause of the degradation of Charlotte Harbor water quality and have noted correlations between residential areas along the coast with high densities of septic systems and elevated nitrogen levels in nearby surface water bodies (LaPointe 1987; LaPointe and Clark 1992; LaPointe et al. 2004). These studies primarily rely on data obtained from surface-water sampling and do not investigate specific subsurface transport mechanisms responsible for nitrogen loading to coastal waters. LaPointe (2016) detected sucralose, an artificial sweetener, in canal waters as a proxy for septic discharge from shallow aquifers into surface-water canals. The detection of sucralose throughout the canal samples indicated relatively widespread discharge of septic effluent into the canal systems. Extensive usage of canals to lower water tables for home construction, coupled with a high density of septic systems, suggest that canal systems likely serve as a dominant transport pathway for nitrogen loading to Florida coastal waters. More importantly, canal systems are tidally influenced which may facilitate rapid nitrogen transport to Charlotte Harbor. The influence of tidal cycling on nitrogen flux to coastal waters has not been comprehensively investigated and remains relatively unknown.

Five dominant mechanisms are responsible for nitrogen loading to Charlotte Harbor: (1) streamflow from Caloosahatche, Myakka, and Peace rivers, (2) atmospheric deposition (3) saturation excess overland flow, (4) coastal groundwater discharge, and (5) groundwater discharge into canal systems. Together, these mechanisms account for 99% of estimated nitrogen fluxes to Charlotte Harbor (MML 1997; Badruzzaman et al. 2012). Agricultural applications of fertilizers and return flows have been identified as the dominant nitrogen sources to the Peace and Myakka rivers (McPherson et al. 1996; MML 1997). Occasional overflows from Lake Okeechobee into the Chaloosahatch River lead to concentrated pulses of agriculturally applied nitrogen into Charlotte Harbor. Mote Marine Laboratories (MML 1997) estimates atmospheric deposition to contribute approximately 20% of total nitrogen into the harbor. The relative contributions of other nonpoint sources of nitrogen are more challenging to quantify. The third mechanism, where the water table seasonally intersects the land surface, is limited to small drainages that convey only minor nitrogen contributions to the harbor but are responsible for numerous beach closures due to high total coliform levels (Lipp et al. 2001; LaPointe et al. 2016; CHNEP 2019). This study serves as one of the few groundwater-specific investigations into the fourth and fifth mechanisms, as very little is known about the surficial aquifer in the Charlotte Harbor region.

This study is motivated by the need to better understand impacts of septic-to-sewer conversion in canal dominated coastal areas and provides estimates of timescales associated with the flushing of nitrogen from the shallow surficial aquifer after sewer conversion. A numerical model supported by field data is used to simulate groundwater flow, groundwater-canal interaction, and decadal-scale nitrogen transport released from a subdivision with high septic and canal density. Study findings are then placed in the context of broader implications for nitrogen transport from septic systems situated in coastal regions with and without canals.

Numerical simulation of aquifer-canal septic transport

The Ackerman subdivision is located along the coast of Charlotte Harbor (Fig. 1) and contains 2,000 homes connected to septic systems. Due to its proximity to the coastline and high canal density, the Charlotte County Utilities Department (CCUD) is planning on converting all homes in the Ackerman subdivision to sewer to reduce the loading of septic-derived nitrogen to Charlotte Harbor. Charlotte County requested a study of this area to provide likely trends and timescales associated with the flushing of nitrogen by natural groundwater flow processes through the shallow surficial aquifer and into Charlotte Harbor after septic to sewer conversion, and to enhance the current knowledge of impacts of: (1) coastal groundwater discharge in regions with high septic density near the coastline, and (2) groundwater–canal interaction and the potential for rapid nitrogen transport into Charlotte Harbor. The numerical model was developed using Visual MODFLOW Flex 6.1 (VMF) which integrates MODFLOW 2005 (Harbaugh 2005), MODPATH Version 7 (Pollock 2016), and MT3DMS (Zheng and Wang 1998; Bedekar et al. 2016). The flow and transport models are supported by hand auger observations of subsurface sediment at the Ackerman site, estimates of monthly precipitation and evapotranspiration, annual runoff, and contributions of effluent and nitrogen fluxes from septic systems. The flow and transport model development, calibration, and nitrogen source term are provided in detail in the following.

Model development and calibration

Ackerman is located between the freshwater outlets of the Myakka and Peace rivers. The MODFLOW model domain is 4.84 km east–west and 2.48 km north–south and honors these natural hydrologic boundaries as the entire peninsula landform is encompassed and bounded by canals on the east, west, and south; the northern extent of the model is constrained at Edgewater Drive (Fig. 1). The canals are hydraulically connected to Charlotte Harbor and facilitate drainage of the shallow groundwater system. Both the shallow groundwater salinity measured at El Jobean (Fig. 1) (average 3 parts per thousand) and salinity, measured in the Ackerman canals (average 7.6 parts per thousand) by LaPointe et al. (2016), indicate brackish waters with relatively minor salinity differences that are approximately 10% of the contrast between freshwater and salt water. Given these minor differences, density-driven effects on fluid flow were not simulated in the model. Canals bounding the model domain are represented as constant head boundaries set to an elevation of mean sea level.

A finite-difference model grid with horizontal cell dimensions of 40 m on a side was found to best discretize canal geometry (Fig. 2). Variable cell thickness was used to capture the distribution of land surface elevations from a 10-m resolution digital elevation map (Fig. 3). These elevations were converted to gridded points, kriged using VMF, and then assigned to individual model cells. All homes in the Ackerman area are connected to the city water supply and the subsurface geology at the site is unknown beyond the sparse hand augering performed in this study to map water-table elevations in support of flow model calibration and regional geologic interpretations. Subsurface textures encountered during augering mostly included sandy sediment with a significant content of limestone in gravel and cobble size fractions. The occurrence of rock fragments increased with depth and made hand augering significantly more challenging. Discussions with local utility operators with experience in this area and visual inspection of canal dredged sediment further confirmed the ubiquitous limestone cobbles. Based on regional interpretations by Wolansky (1983), the surficial aquifer system at Ackerman consists of undifferentiated fine-to-medium light-grey quartz sands with some interbedded clay lenses and is underlain by a continuous confining unit of regional extent. Torres et al. (2001) reports the same regional lithologic sequence and notes the Upper Hawthorn Formation (shallow near Ackerman) consisting of sand, with shell beds and limestone clasts and a thick clay unit near the top, approximately 7.6 m below land surface. Consistent with regional interpretations and visual interpretations indicating a lack of a clay confining unit in the canals and canal excavated sediment, the lower model domain is set to 5 m below sea level to correspond to the presence of a confining unit located several meters below the bottom of the canals.

Texturally distinct sediment layers were not observed during either the augering or inspection of the canals and canal excavated sediment. Groundwater flow through the sandy surficial aquifer is simulated in the model using a single layer that extends from land surface to the clay confining unit. Hydraulic properties are assigned to the model according to two distinct zones representing the sandy surficial aquifer and canal system. Using a georeferenced Google Earth image of the Ackerman area, a shapefile was created in ArcMap to map the canal boundaries. This shapefile was then imported into VMF and superimposed on the model grid for delineation of grid cells representing the canals. The sandy surficial aquifer was assigned a best-fit K value of 6.5×10^{-4} m/s determined during calibration, and a K value of 10 m/s was assigned to the canals to establish an approximate five-order-of-magnitude contrast between the canals and surrounding aquifer. This level of contrast ensures that the canals serve as highly preferential flow features within the groundwater flow system while maintaining numerical stability (Reeves et al. 2014).

Aquifer recharge is defined as the net difference between annual precipitation, ET, and runoff. The Ackerman area has an overland drainage system comprised of unlined swales that gently slope towards outflow pipes to the canal system. Annual runoff coefficients for Ackerman are estimated at 0.051 using tables supplied by ERD (2007) for a curve number of 40, distribution of binned precipitation events for a representative region, and a 5% estimate of directly connected impervious area. Given the use of unlined swales that promote

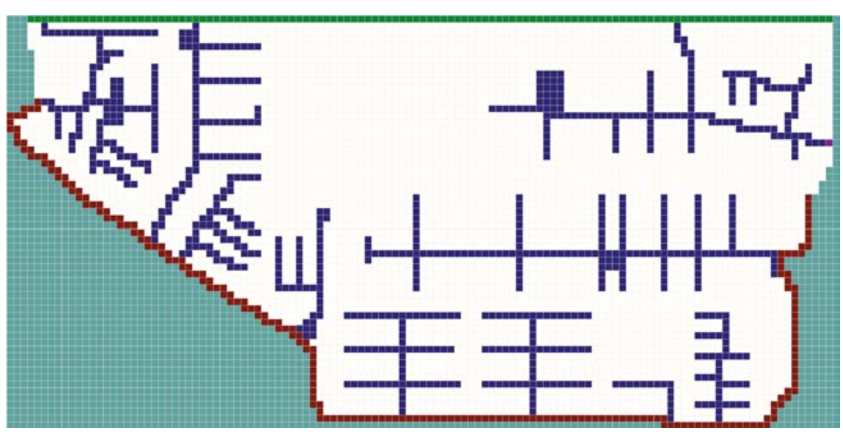

Fig. 2 Model grid showing canal systems and boundary conditions. Green cells denote the northern constant head boundary set to water level measurements. Red cells follow the canal perimeter and are set to set level. A single purple cell set to sea level represents the outlet of the canal system located in the northeast section of the domain. White cells denote surficial aquifer cells with canal cells shown in blue; inactive cells are aquamarine. Grid cells are 40 m on a side

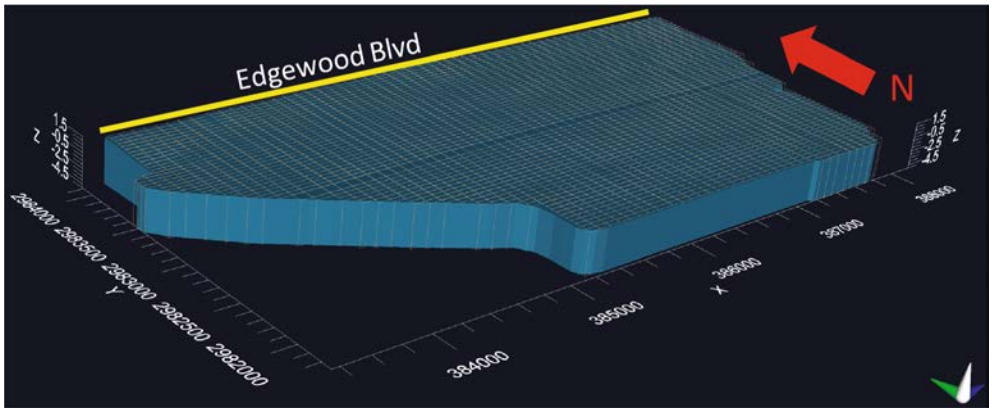

Fig. 3 Model grid domain of 4.84 km × 2.48 km showing surface topography and variable cell thickness as a function of easting (x-axis), northing (y-axis), and elevation (z-axis). All values are in meters

vertical infiltration in highly permeable soils, low percentage of directly connected impervious area to swales, low topographic gradient, and errors associated with the curve number approach, runoff for the Ackerman area is challenging to quantify and likely significantly less than the ERD (2007) estimates. Recharge estimates neglected runoff and were defined as the net difference between annual precipitation data retrieved from the Punta Gorda County Airport NOAA weather station and annual evapotranspiration computed by the Southwest Florida Water Management District (SWFWMD). The SWFWMD data are limited to a time period of 1997–2005. The average of net differences in annual precipitation and ET for these data is 178 mm/year, which equates to approximately 13% of mean annual precipitation. To account for uncertainty in net recharge, this base case value is perturbed ±25% to generate dry and wet scenarios of 134 and 223 mm/year, respectively. For all three scenarios, recharge is uniformly applied to the top of all active cells within the model domain as a constant recharge flux boundary.

Proper assignment of the northern head boundary and calibration of the model necessitated the collection of water levels. In November of 2019, a water-table survey was performed by hand augering until the water table was encountered and recording depths to water using an e-tape. Surface elevation for each of the auger holes was surveyed by the CCUD using a Trimble R10 rover with a reported elevational accuracy of ±5 mm. The water level measurements were concentrated along four transects: E–W on Edgewood Dr., N–S on Collingswood and Midway Blvd, and along the southern canals, and six measurements were taken in the interior. The water levels along the northern transect yielded head values in the range of 0.5–0.7 m above mean sea level. The contour patterns show groundwater flow directions consistent with landform geometry and topography, and a water-table high in the area near the north central portion of the domain lacking canals (Fig. 4). Head values assigned to the northern boundary are spatially variable to capture this pattern and held constant over time. Of the 17 observation points, 12 were used in the model calibration. The five discarded points had erroneously low water-table elevations likely caused by the presence of fine-grained sediment near the top of the saturated zone and insufficient time for water levels to equilibrate in the borehole prior to measurement. The parameter estimator PEST (Doherty 2015) was used to calibrate the model to the measured head data by determining best fit K of the sandy aquifer. The calibrated model has a root mean squared error (RMSE) equal to 0.035 m (3.5 cm), and when normalized by a 0.75-m head drop across the model domain, produces a model error of 6%.

Steady-state head contours of the calibrated model along with path lines are shown in Fig. 5. Consistent with the water-table map (Fig. 4), general groundwater flow follows the geometry and topography of the landform with flow directions from north to south, southeast and southwest. Observed mounding in the north central area where canals are lacking is reproduced in the model. MODPATH particles (white dots) placed along two locations of the sewer conversion zones show the concentration and preferred migration pathways of particles (white lines) through the canal systems.

Septic nitrogen source term

Nitrogen and effluent volumes at the 23 O'Hara lift station were monitored by CCUD over an approximate 12-month period: 10/06/2016 to 09/25/2017. The lift station receives effluent from 733 households via low-pressure sewer tanks that function analogous to septic tanks: the solids settle and only the liquid effluent leaves the tank. Thus, the lift station effluent serves as an ideal proxy for septic fluid and nitrogen contributions. The primary difference between the two systems is that effluent in the low-pressure sewer is conveyed to a collection station for treatment, whereas septic tank effluent is gravity fed to the drainfield for treatment in the shallow subsurface. Fluid samples were collected weekly to quantify the mass loading of total nitrogen to the lift station. Records of water usage were then used by CCUD to account for variability in home occupancy throughout the year, resulting in an

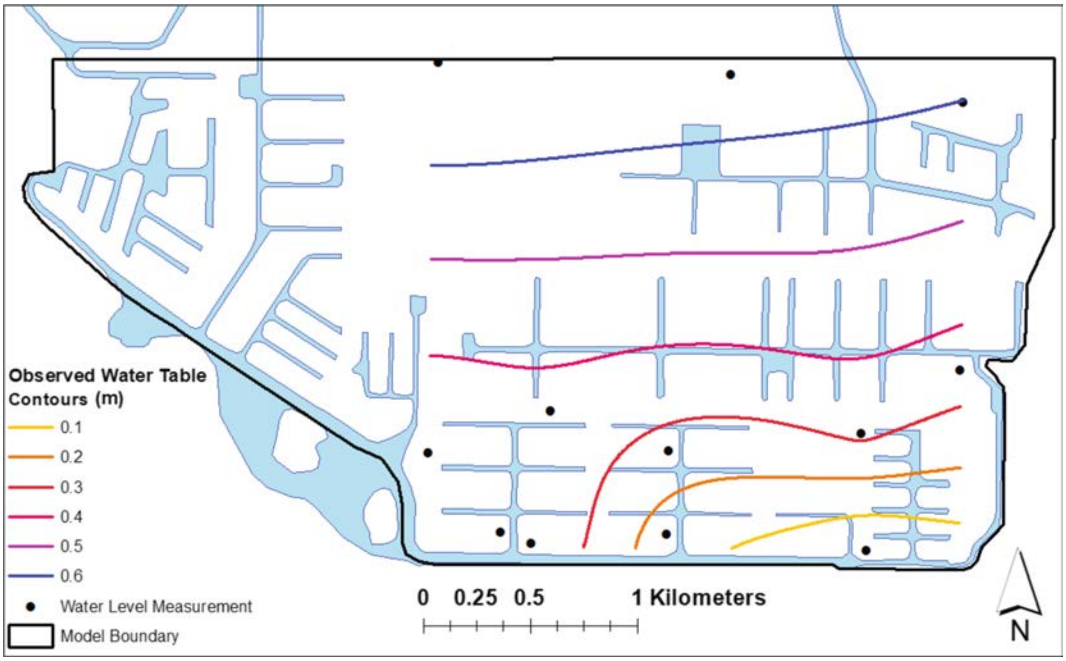

Fig. 4 Map of water-table contours generated from field measurements (black dots). Contour values are in meters

average household contribution of 11 kg/year of total nitrogen and 160 m^3/year of effluent.

Fluid and nitrogen loading within the Ackerman model is assigned according to five conversion zones outlined in the CCUD sewer conversion plan (Fig. 6). The fluid and nitrogen mass fluxes from the 23 O'Hare lift stations are scaled to the number of homes within each zone, and MT3DMS is used to model contaminant input as a constant flux (m/day) of water into the aquifer with a constant nitrogen concentration (mg/L) (Table 1). All nitrogen applied to the subsurface is assumed to be nitrate and nonsorptive (Almasri and Kaluarachchi 2007; Bhatnagar et al. 2010). Nitrogen transformations by various processes were not simulated. Longitudinal and transverse dispersivities were set to 0.4 m (10% of the cell size) and

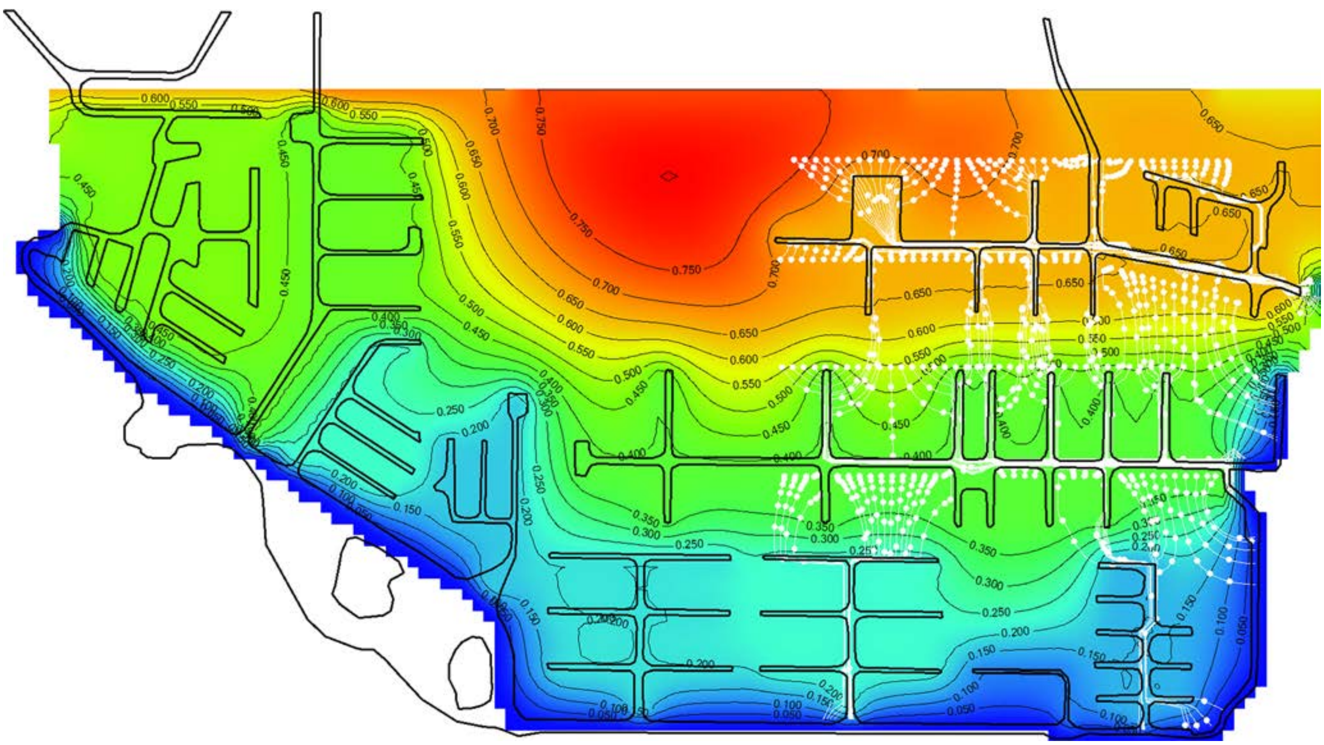

Fig. 5 Steady-state head profile of base case model along with canal shapefile and MODPATH generated path lines (white). Contour values are in meters

Table 1 Septic loading rates and concentrations for each of the conversion zones outlined in the CCUD master plan

Septic conversion zone	Number of septic systems	Flux applied (m/day)	Nitrogen concentration (mg/L)
1	396	2.1×10^{-4}	67
2	446	2.5×10^{-4}	67
3	456	2.3×10^{-4}	67
4	473	2.0×10^{-4}	67
5	229	2.4×10^{-4}	67

0.04 m (10% of longitudinal dispersivity), respectively. The base case model applies a constant recharge rate of 178 mm/year and represents canals as high *K* features.

Results

A 40-year model spin-up period is used to approximate long-term nitrogen loading and nitrate accumulation in the study area prior to septic conversion (Fig. 7). Simulated nitrogen loading begins on January 1, 1980. After 30 years of septic loading into the system, nitrogen mass reaches an approximate steady-state plateau facilitated by constant rates of net recharge and applied septic effluent. This leads to an initial condition where the nitrogen mass applied to the surficial aquifer is equal to the amount of nitrogen leaving the aquifer with a large continuous nitrate plume extending from the Ackerman subdivision to the downgradient model boundary (Fig. 8). An instantaneous and complete sewer conversion was initiated on January 1, 2020, ceasing all septic contributions of nitrogen and water to the aquifer (Fig. 7). Sharp declines in nitrogen concentrations occur over time in the surficial aquifer after sewer conversion. The timescales associated with the decline in nitrogen mass in the surficial aquifer is the focus of the model results.

A total of six scenarios were used to account for uncertainty in recharge (and subsequent volumetric flow through the surficial aquifer) and provide a range of timescales associated with nitrogen flushing in the surficial aquifer after sewer conversion. Fluxes of 75% (R75), 100% (R100), and 125% (R125) of the base case recharge rate of 178 mm/year were applied to the model. Each of these recharge scenarios were simulated with and without canal features to better understand the impact of canal features on nitrogen transport (Fig. 9). Transport times are quantified using t_{50} and t_{10} values which represent the time after sewer conversion for nitrogen concentrations to decline to 50 and 10% of the original nitrogen mass remaining in the aquifer, respectively (Table 2). The models containing canals generated t_{50} values ranging from 2.4 (R125) to 3.2 (R75) years, with a base case (R100) estimate of 2.8 years (Table 2). Timescales associated with t_{10} are closer to a decade and range from 7.6 to 9.9 years. As expected, models without canals resulted in slower t_{50} and t_{10} values with these timescales ranging from 3.6 (R125) to 5.4 (R75) years and 11.6 (R125) to 16.6 (R75) years, respectively.

Discussion

The numerical model of the Ackerman subdivision allowed for detailed study of the transport of septic derived nitrogen in a near coastal environment with high canal and septic density. The canals are surface-water features represented as high *K* zones in the model. Even though the canals would be better represented as open-channel flow, a 5-order-of-magnitude contrast sufficiently captures the hydraulic influence of the

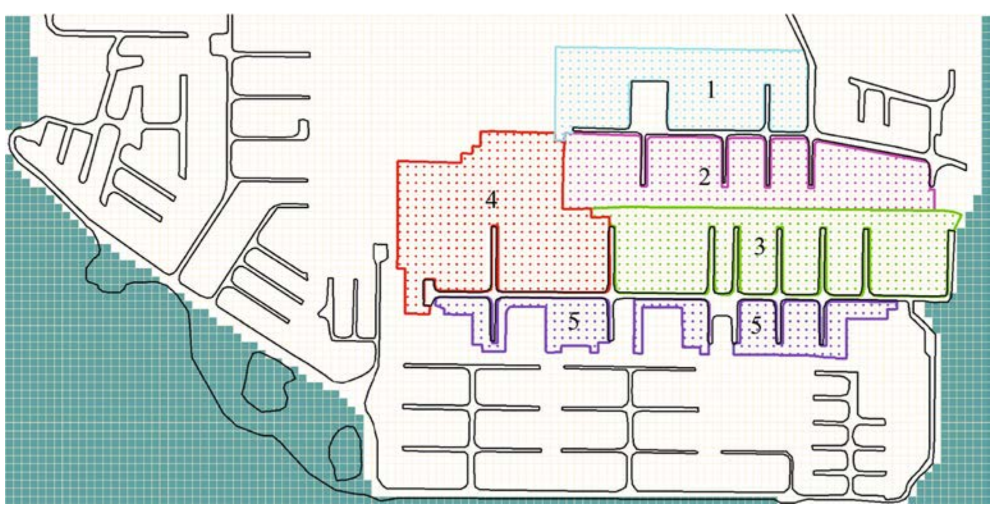

Fig. 6 The Charlotte County Utilities District septic to sewer conversion plan zones mapped onto the Ackerman model domain

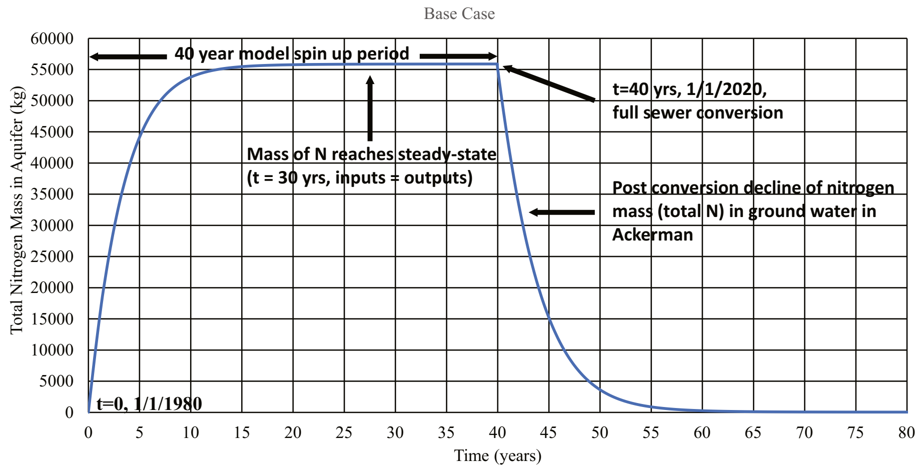

Fig. 7 Plot of total nitrogen mass (kg) in the surficial aquifer released from the five Ackerman conversion zones depicting a 40-year spin-up period with constant nitrogen inputs starting in 1/1/1980 followed by an instantaneous full sewer conversion on 1/1/2020

canals on the groundwater flow system. This can be observed in the steady-state head field where the canals flatten the hydraulic gradient by effectively draining the shallow aquifer (Fig. 5) and decrease the background natural hydraulic gradient of 1.5×10^{-3} measured at El Jobean to 3.1×10^{-4} at Ackerman (Fig. 1). A groundwater mound in the north central portion of the model forms in the only region not intersected by the canal system. This mound and modeled hydraulic gradients across the system are consistent with water level data from this project and past measurements by CCUD.

Lift station data collected from low pressure sewer tanks serve as an ideal proxy for fluid and nitrogen loading from septic systems. Net values per household were upscaled to a total of five sewer conversion zones in Ackerman (Fig. 6). A model spin-up period with constant background recharge, septic effluent volumes, and nitrogen mass loading were used to approximate past background conditions (Fig. 7). A constant nitrogen mass in the surficial aquifer was reached after 30 years with a plume emanating from the septic systems to the harbor (Figs. 7 and 8). The septic to sewer conversion was initiated instantaneously and resulted in sharp declines in nitrogen mass in the shallow surficial aquifer. The plume sharply follows the canal system that effectively conveys nitrogen to the south and east of the model, as also indicated by the simulated pathlines shown in Fig. 5. Results of canal scenarios show 50% reduction of nitrogen mass over the coastal aquifer

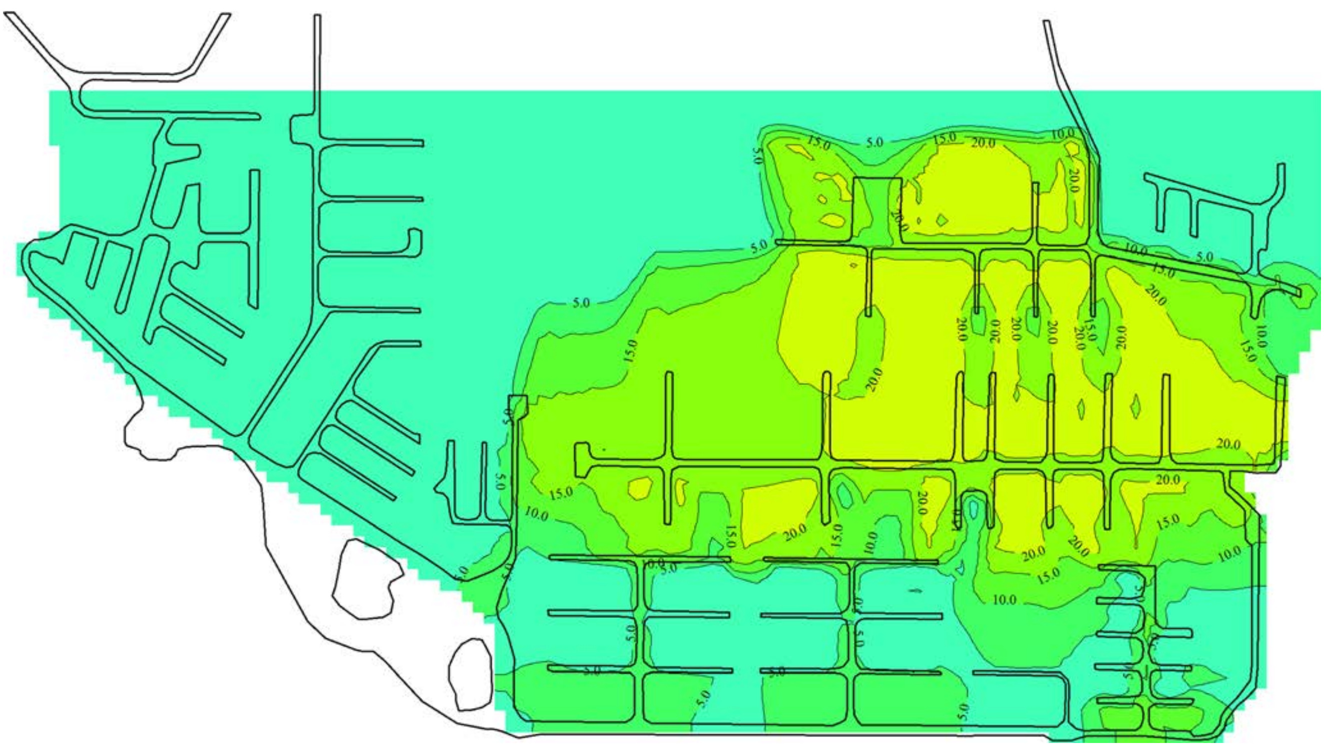

Fig. 8 Nitrate plume concentrations (mg/L) at nearly 40 years of elapsed simulation time prior to sewer conversion

Table 2 Values of t_{50} and t_{10} (in years) for the six modeled scenarios

Recharge scenario	Canal		Noncanal	
	t_{50}	t_{10}	t_{50}	t_{10}
R75	3.2	9.9	5.4	16.6
R100	2.8	8.5	4.3	13.2
R125	2.4	7.6	3.6	11.6

in 2.4–3.2 years and 90% reduction in 7.9–9.9 years given uncertainty in recharge (Fig. 9; Table 2). Exclusion of canals in the base model increased t_{50} and t_{10} timescales by 55%, further emphasizing the impact of canals on the hydrologic system.

The model incorporated many simplifying assumptions and boundary conditions for investigating nitrogen transport in the Ackerman area, including steady-state recharge, inclusion of canals as high K porous media, instantaneous septic to sewer conversion, and no tidal cycling or processes affecting nitrogen transformation. These abstractions and generalizations were useful for assessing nitrogen transport in areas with high septic and canal density and predicting timescales associated with declines in nitrogen after sewer conversion. The steady-state recharge conditions allowed for a smooth spin-up period with the surficial aquifer reaching a constant nitrogen mass after 30 years. In reality, climate is nonstationary and variability in net recharge and ET will lead to unsteady groundwater flow conditions and perturbations in the simulated trends of nitrogen mass transport. These perturbations will naturally lead to some variability and differences in nitrogen transport rates, but are not expected to dramatically change the overall study findings and outcomes that indicate relatively fast reduction in nitrogen concentrations after septic-to-sewer conversion and the role of canals in serving as fast transport pathways for nitrogen transport to Charlotte Harbor.

An independent field study was performed by Tetra Tech and Johnson Engineering (2020) on a small plot of coastal land at East Spring Lake, located approximately 9.1 km east of Ackerman. The area contained 42 septic systems within an area of 4.25 ha located along the Charlotte Harbor coast. Study results were shared by CCUD after the Ackerman model was completed and provided a rare opportunity to assess model performance and study findings. Total nitrogen, total phosphorus, and fecal coliforms were sampled in monitoring wells. After establishing a nitrogen and phosphorus baseline, septic systems in the area were converted to sewer and the monitoring well was sampled quarterly. Groundwater nitrogen concentrations preconstruction averaged 27 mg/L with concentrations ranging from 13 to 43 mg/L. These concentrations are consistent overall with the simulated plume concentrations in Fig. 8, with the exception that the model evenly mixes the applied nitrogen over the entire aquifer thickness leading to more dilute concentrations. The nitrogen concentrations are stratified in a natural system and accumulate in the upper portion of the surficial aquifer leading to higher

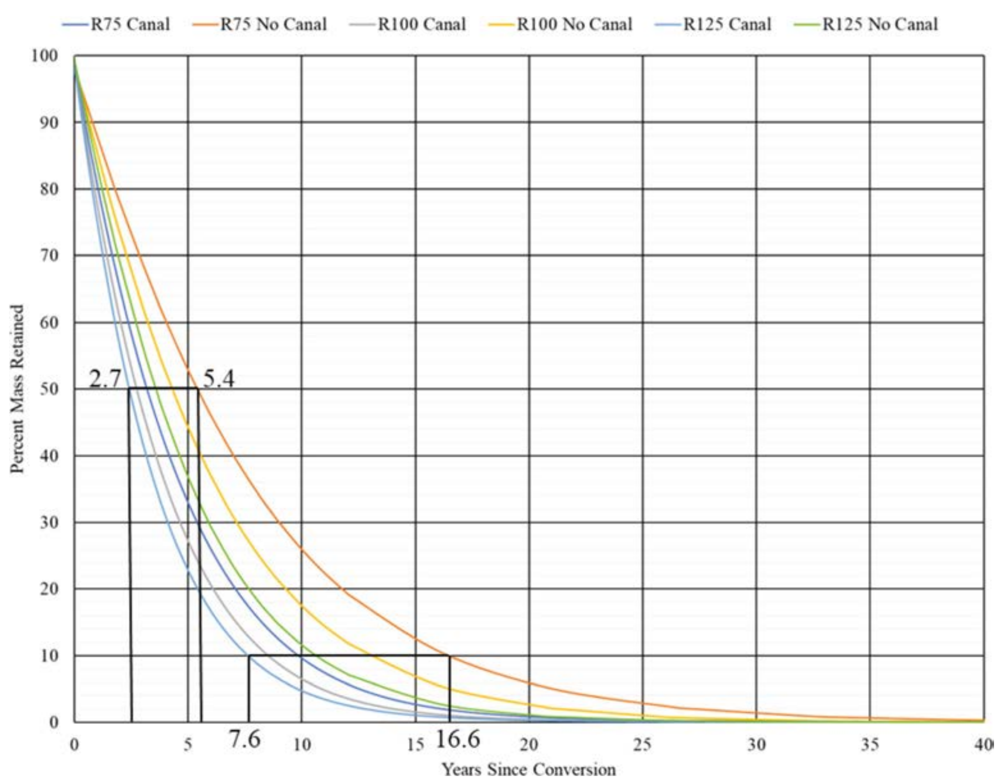

Fig. 9 Percent of total nitrogen mass retained in the surficial aquifer after instantaneous sewer conversion for all six model scenarios along with simulated ranges for t_{50} and t_{10}

concentrations. Timescales of t_{50} were achieved in the monitoring wells after approximately 1.25 years. This observed timescale is consistent with reductions observed in subregions (on a similar scale and lacking canals) of the septic conversion areas within the Ackerman model.

The simulation of tidal fluctuations requires a complex set of boundary conditions that was not possible in the model. Tidal fluctuations (max tide is 0.6 m in Charlotte Harbor region) are likely an important rapid transport mechanism for septic-derived nitrogen, particularly for septic systems located in close proximity to canals. At high tide, water levels in the canals exceed groundwater elevations and suppress groundwater discharge due to differences in hydrostatic head. This likely creates a mixing zone in the surficial aquifer surrounding the canals where harbor water mixes with shallow groundwater. This region is expected to have geochemical differences in salinity, pH, and redox conditions that may influence nitrogen transformation. As the tide subsides, water levels in the canals will become lower than shallow groundwater creating an enhanced hydraulic gradient between the shallow groundwater and canals. As discharge occurs across the groundwater–canal interface, any dissolved nitrogen, some of which may be in the ammonium from if contributed by septic systems located in very close proximity to the canals, will migrate to the canal. Once in the canal, nitrogen will naturally be transported to the harbor in the outgoing tidal water. A series of two high and low tidal cycles occur approximately every 25 h, and thus the residence time of nitrogen in canal waters may be on the scale of several hours to a day. A future study using field and geochemical methods to better understand canal-shallow groundwater interaction and tidal cycling on nitrogen transport is in the planning stages.

Many coastal communities in Florida and elsewhere are experiencing similar issues with aging septic systems (Lapointe and Clark 1992; Bowen and Valiela 2004; LaPointe et al. 2004). Results of this study including relative timescales of water quality improvement upon septic to sewer conversion can be extrapolated to other coastal communities with and without canals to aid homeowners and legislators with policy decisions concerning septic systems. Both Tomasko et al. (2001) and LaPointe et al. (2004) conclude that septic systems contribute a significant quantity of nitrogen into coastal waters causing eutrophication. For many areas, the primary management strategy for constraining nitrogen fluxes to coastal waters is converting septic systems to municipal sewers. This process is both costly and time consuming. In the case of Charlotte County, approximately 800 homes can be converted to sewer per year, resulting in over three decades for full conversion of all septic. This study's results indicate that sewer conversion plans should prioritize areas concentrated along the coast with high septic and canal density.

Conclusion

A numerical model simulating groundwater flow and groundwater-canal interaction was developed to investigate nitrogen transport from shallow groundwater into Charlotte Harbor, Florida. The numerical model has high septic and canal density, and provides timescales of kilometer-scale flushing of nitrogen through shallow coastal aquifers in response to septic-to-sewer conversion. Steady-state head profiles, flow path lines, and timescales of nitrogen flushing for models incorporating recharge variability and canal/noncanal scenarios were used to comprehensively investigate the influence of canals and recharge on nitrogen loading from the Ackerman subdivision to Charlotte Harbor. The base case model generated t_{50} and t_{10} values of 2.8 and 8.5 years, indicating the time for 50 and 10% of the original mass, respectively, to exit the aquifer and enter the harbor. Recharge variability was used to provide uncertainty bounds in t_{50} of 2.4–3.2 years, and t_{10} of 7.6–9.9 years. Excluding canals in the base model increased timescales of t_{50} and t_{10} by 55%. Plume concentrations and estimated times of nitrogen reduction in the base case model are in good agreement with data produced by an independent field study performed by Tetra Tech and Johnson Engineering at a nearby coastal area. These data were provided after model development and provided a rare opportunity to evaluate the model results. Future work is needed to further investigate fast transport mechanisms associated with canal–groundwater interaction and tidal cycling. Planning for a study to address these features is underway and will incorporate geochemical, isotopic, and physical measurements.

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Declarations

Conflicts of interest The authors declare no conflicts of interest.

References

Almasri MN, Kaluarachchi JJ (2007) Modeling nitrate contamination of groundwater in agricultural watersheds. J Hydrol 343:211–229. https://doi.org/10.1016/j.jhydrol.2007.06.016

American Ground Water Trust (AGT) (1998) Septic systems for wastewater disposal. https://agwt.org/content/septic-systems. Accessed 20 April 2020

Anderson DM, Glibert PM, Burkholder JM (2002) Harmful algal blooms and eutrophication: nutrient sources, composition, and consequences. Estuaries 25:704–726. https://doi.org/10.1007/BF02804901

Badruzzaman M, Pinzon J, Oppenheimer J, Jacangelo JG (2012) Sources of nutrients impacting surface waters in Florida: a review. J Environ Manag 109:80–92. https://doi.org/10.1016/j.jenvman.2012.04.040

Bedekar V, Morway ED, Langevin CD, Tonkin M (2016) MT3D-USGS version 1: a US Geological Survey release of MT3DMS updated with new and expanded transport capabilities for use with MODFLOW. US Geol Survey Tech Methods 6-A:53–69

Bhatnagar A, Kumar E, Sillanpää M (2010) Nitrate removal from water by nano-alumina: characterization and sorption studies. Chem Eng J 163:317–323. https://doi.org/10.1016/j.cej.2010.08.008

Brand LE, Compton A (2007) Long-term increase in *Karenia brevis* abundance along the Southwest Florida coast. Harmful Algae 6:232–252. https://doi.org/10.1016/j.hal.2006.08.005

Bowen JL, Valiela I (2004) Nitrogen loads to estuaries: using loading models to assess the effectiveness of management options to restore estuarine water quality. Estuaries 27:482–500. https://doi.org/10.1007/BF02803540

Coastal and Heartland National Estuary Partnership (CHNEP) (2019) Water atlas. http://chnep.wateratlas.usf.edu/bay/waterquality.asp?wbodyid=330000&wbodyatlas=bay. Accessed 20 December 2019

Cogger CG, Carlile BL (1984) Field performance of conventional and alternative septic systems in wet soils. J Environ Qual 13:137–142. https://doi.org/10.2134/jeq1984.00472425001300010025x

Conley DJ, Howarth HW, Boesch DF, Seitzinger SP, Havens KE, Lancelot C, Likens GE (2009) Controlling eutrophication: nitrogen and phosphorus. Science 323A:1014–1015. https://doi.org/10.1126/science.1167755

Costa JE, Heufelder G, Foss S, Milham NP, Howes B (2002) Nitrogen removal efficiencies of three alternative septic system technologies and a conventional septic system. Environ Cape Cod 5:15–23

Doherty J (2015) Calibration and uncertainty analysis for complex environmental models. Watermark, Brisabane, Australia

Froelich PN, Kaul LW, Byrd JT, Andreae MO, Roe KK (1985) Arsenic, barium, germanium, tin, dimethylsulfide and nutrient biogeochemistry in Charlotte Harbor, Florida, a phosphorus-enriched estuary. Estuar Coast Shelf Sci 20:239–264. https://doi.org/10.1016/0272-7714(85)90041-1

Harbaugh AW (2005) MODFLOW-2005, the US Geological Survey modular ground-water model: the Ground-Water Flow Process. US Geol Surv Techniques Methods 6-A16

Harden H, Chanton J, Hicks R, Wade E (2010) Wakulla County Septic Tank Study Phase II report on performance based treatment systems. Florida State University Department of Earth, Ocean and Atmospheric Science, Tallahassee, FL

Howarth RW, Marino R (2006) Nitrogen as the limiting nutrient for eutrophication in coastal marine ecosystems: evolving views over three decades. Limnol Oceanogr 51(a, part 2):364–376. https://doi.org/10.4319/lo.2003.51.1_part_2.0364

Lambert MJ, Burnett WC (2003) Submarine groundwater discharge estimates at a Florida coastal site based on continuous radon measurements. Biogeochemistry 66:55–73. https://doi.org/10.1023/b:biog.0000006057.63478.fa

Landsburg JH (2002) The effects of harmful algal blooms on aquatic organisms. Rev Fish Sci 10:113–390. https://doi.org/10.1080/20026491051695

Landsberg J, Flewelling L, Naar J (2009) Karenia brevis red tides, brevetoxins in the food web, and impacts on natural resources: decadal advancements. Harmful Algae 8:598–607. https://doi.org/10.1016/j.hal.2008.11.010

Lapointe BE (1987) Phosphorus- and nitrogen-limited photosynthesis and growth of *Gracilaria tikvahiae* (Rhodophyceae) in the Florida Keys: an experimental field study. Mar Biol 93:561–568. https://doi.org/10.1007/bf00392794

Lapointe BE, Clark MW (1992) Nutrient inputs from the watershed and coastal eutrophication in the Florida Keys. Estuaries 15:465–476. https://doi.org/10.2307/1352391

LaPointe BE, Barile PJ, Matzie WR (2004) Anthropogenic nutrient enrichment of seagrass and coral reef communities in the lower Florida Keys: discrimination of local versus regional nitrogen sources. J Exp Mar Biol Ecol 308:23–58

Lapointe BE, Herren LW, Debortoli DD, Vogel MA (2015) Evidence of sewage-driven eutrophication and harmful algal blooms in Florida's Indian River lagoon. Harmful Algae 43:82–102. https://doi.org/10.1016/j.hal.2015.01.004

LaPointe BE, Herren L, Paule A, Sleeman A, Brewton R (2016) Charlotte County water quality assessment. Florida Atlantic University, Boca Raton, FL, pp 3–40

Lipp EK, Farrah SA, Rose JB (2001) Assessment and impact of microbial fecal pollution and human enteric pathogens in a coastal community. Mar Pollut Bull 42:286–293. https://doi.org/10.1016/s0025-326x(00)00152-1

Mallin MA (2013) Septic systems in the coastal environment: multiple water quality problems in many areas. In: Ahuja S (ed) Monitoring water quality, quality: pollution assessment, analysis and remediation. Elsevier, Amsterdam, pp 81–102

Mansfield G (1942) Phosphorous resources of Florida. US Geol Surv Bull 934:3–10 https://pubs.usgs.gov/bul/0934/report.pdf

McIsaac GF, David MB, Gertner GZ, Goolsby DA (2001) Eutrophication: nitrate flux in the Mississippi River. Nature 414:166–167

McPherson BF, Miller RL, Stoker YE (1996) Physical, chemical, and biological characteristics of the Charlotte Harbor basin and estuarine system in southwestern Florida: a summary of the 1982–89 US Geological Survey Charlotte Harbor assessment and other studies. US Geol Surv Water Suppl Pap 2486. https://doi.org/10.3133/wsp248

Meeroff DE, Bloetscher F, Bocca T et al (2008) Evaluation of water quality impacts of on-site treatment and disposal systems on urban coastal waters. Water Air Soil Pollut 192:11–24. https://doi.org/10.1007/s11270-008-9630-2

Mote Marine Laboratory (MML) (1997) The state of Charlotte Harbor, Florida, its adjacent inland waters and watershed: a characterization report for the Charlotte Harbor National Estuary Program. Technical Report 505, Mote Marine Laboratory, Sarasota, FL

Nixon SW (1995) Coastal marine eutrophication: a definition, social causes, and future concerns. Ophelia 41:199–219. https://doi.org/10.1080/00785236.1995.10422044

Paul JH, McLaughlin MR, Griffin DW et al (2000) Rapid movement of wastewater from on-site disposal systems into surface waters in the lower Florida Keys. Estuaries 23:662–668. https://doi.org/10.2307/1352892

Pierce RH (1986) Red tide (*Ptychodiscus brevis*) toxin aerosols: a review. Toxicon 24:955–965. https://doi.org/10.1016/0041-0101(86)90001-2

Pierce RH, Henry MS (2008) Harmful algal toxins of the Florida red tide (*Karenia brevis*): natural chemical stressors in South Florida coastal ecosystems. Ecotoxicology 17:623–631. https://doi.org/10.1007/s10646-008-0241-x

Poli M, Mende TJ, Baden D (1986) Brevetoxins, unique activators of voltage-sensitive sodium channels bind to specific sites in rat synaptosomes. Mol Pharmacol 30:129–135

Pollock DW (2016) User guide for MODPATH Version 7: a particle-tracking model for MODFLOW. US Geol Surv Open-File Rep 2016–1086. https://doi.org/10.3133/ofr20161086

Reeves DM, Parashar R, Pohlman K, Russell C, Chapman J (2014) Development and calibration of dual-permeability flow models with discontinuous fault networks. Vadose Zone J 13(8):vzj2013 10.0183

Shaddox TW, Unruh JB (2018) The fate of nitrogen applied to Florida Turfgrass. University of Florida IFAS, Gainesville, FL

Schindler DW (1974) Eutrophication and recovery in experimental lakes: implications for lake management. Science 184:897–899. https://doi.org/10.1126/science.184.4139.897

Seiler RL (1996) Methods for identifying sources of nitrogen contamination of ground water in valleys in Washoe County, Nevada. US Geol Surv Open-File Rep 96–461

Tetra Tech Inc., Johnson Engineering Inc. (2020) Updated water quality review within East and West Spring Lakes. Charlotte County Utilities, Port Charlotte, FL

Tilley E, Ulrich L, Luthi C, Reymond P, Zurburgg C (2014) Compendium of sanitation systems and technologies. Dübendorf Swiss Federal Institute of Aquatic Science and Technology (Eawag), Dübendorf, Switzerland

Tomasko DA, Bristol DL, Ott JA (2001) Assessment of present and future nitrogen loads, water quality, and seagrass (*Thalassia testudinum*) depth distribution in Lemon Bay, Florida. Estuaries 24:926–938. https://doi.org/10.2307/1353183

Torres AE, Sacks LA, Yobbi DK, Knochenus LA, Katz BG (2001) Hydrogeologic framework and geochemistry of the Intermediate aquifer system in parts of Charlotte, De Soto, and Sarasota Counties, Florida. US Geol Surv Water Resour Invest Rep 2001–4015

Vargo GA, Heil CA, Ault DN, Neely MB, Murasko S, Havens J, Lester KM, Dixon LK, Merkt R, Walsh J, Weisberg R, Steidinger KA (2004) Harmful Algae 2002. Florida Fish and Wildlife Conservation Commission, Florida Institute of Oceanography and Intergovernmental Oceanographic Commission of UNESCO. Four Karenia brevis blooms: A comparative analysis pp 14–16. https://myfwc.com/media/13103/xhab_introductory_material.pdf; https://myfwc.com/media/13111/xhab_plenary_ecology.pdf

Wolansky RM (1983) Hydrogeology of the Sarasota-Port Charlotte area, Florida. US Geol Surv Water Resour Invest Rep 82-4089

Zhang MK, He ZL, Calvert DV, Stoffella PJ, Li YC, Lamb EM (2002) Release potential of phosphorus in Florida sandy soils in relation to phosphorus fractions and adsorption capacity. J Environ Sci Health 37:793–809. https://doi.org/10.1081/ese-120003589

Zheng C, Wang PP (1998) MT3DMS: a modular three-dimensional multispecies transport model for simulation of advection, dispersion, and chemical reactions of contaminants in groundwater systems documentation and users guide. US Army Corps of Engineers, Washington, DC

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