A water quality assessment of the Maryland Coastal Bays including nitrogen source identification using stable isotopes

Data Report

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Executive Summary

The Maryland Coastal Bays receive nutrient inputs from point sources, including wastewater treatment plants and septic systems, in addition to non-point source (diffuse) nutrient inputs including agricultural and stormwater run-off. When compared with Chesapeake Bay, the Maryland Coastal Bays are much smaller, in bay and watershed area, as well as shallower (less vertical stratification which means vertical profiles are generally not as critical). Therefore, although the Maryland Coastal Bays receive fewer terrestrial inputs and have less potential for vertical stratification, the limited water exchange and small size make them highly sensitive to nutrient inputs.

An assessment of the Maryland Coastal Bays was conducted during June of 2004. A relatively new technique using stable isotope ratios of macroalgae incubated *in situ* was used to determine the impacts of point sources such as sewage and septic derived nitrogen. A suite of more traditional parameters was also measured to produce spatially explicit maps of water quality.

Reporting regions in the bays were defined and a Water Quality Index (WQI) calculated based on six parameters. The regions, ranked from best to worst are Isle of Wight Bay (0.69 / Good), Sinepuxent Bay (0.68 / Good), Chincoteague Inlet (0.62 / Good), Assawoman Bay (0.56 / Fair), Chincoteague Bay (0.42 / Fair), Newport River (0.36 / Poor), Newport Bay (0.33 / Poor) and St. Martin River (0.29 / Poor). Results demonstrated that the St. Martin River, Isle of Wight and the southern portion of Chincoteague Bay (near the town of Chincoteague and Wallops Island) were compromised with sewage/septic derived nutrients, with elevated δ15N isotopic ratios. Follow up investigations will be required to identify the sources of elevated δ15N values . Isle of Wight Bay received a 'Good' WQI rating, probably due to the relatively high flushing with the ocean at the southern end of the bay. The areas with the lowest WQI were St. Martin River, Newport River and the western side of Chincoteague Bay. Low Secchi, high total phosphorus and high chlorophyll *a* were the main factors resulting in the poor overall WQI for Chincoteague Bay.

This study provided a proof of concept. With a more comprehensive temporal sampling using the demonstrated spatial intensity over a range of parameters, a robust water quality index could be

established. This would provide effective feedback to managers and researchers, assisting in directing both management priorities and research directions.

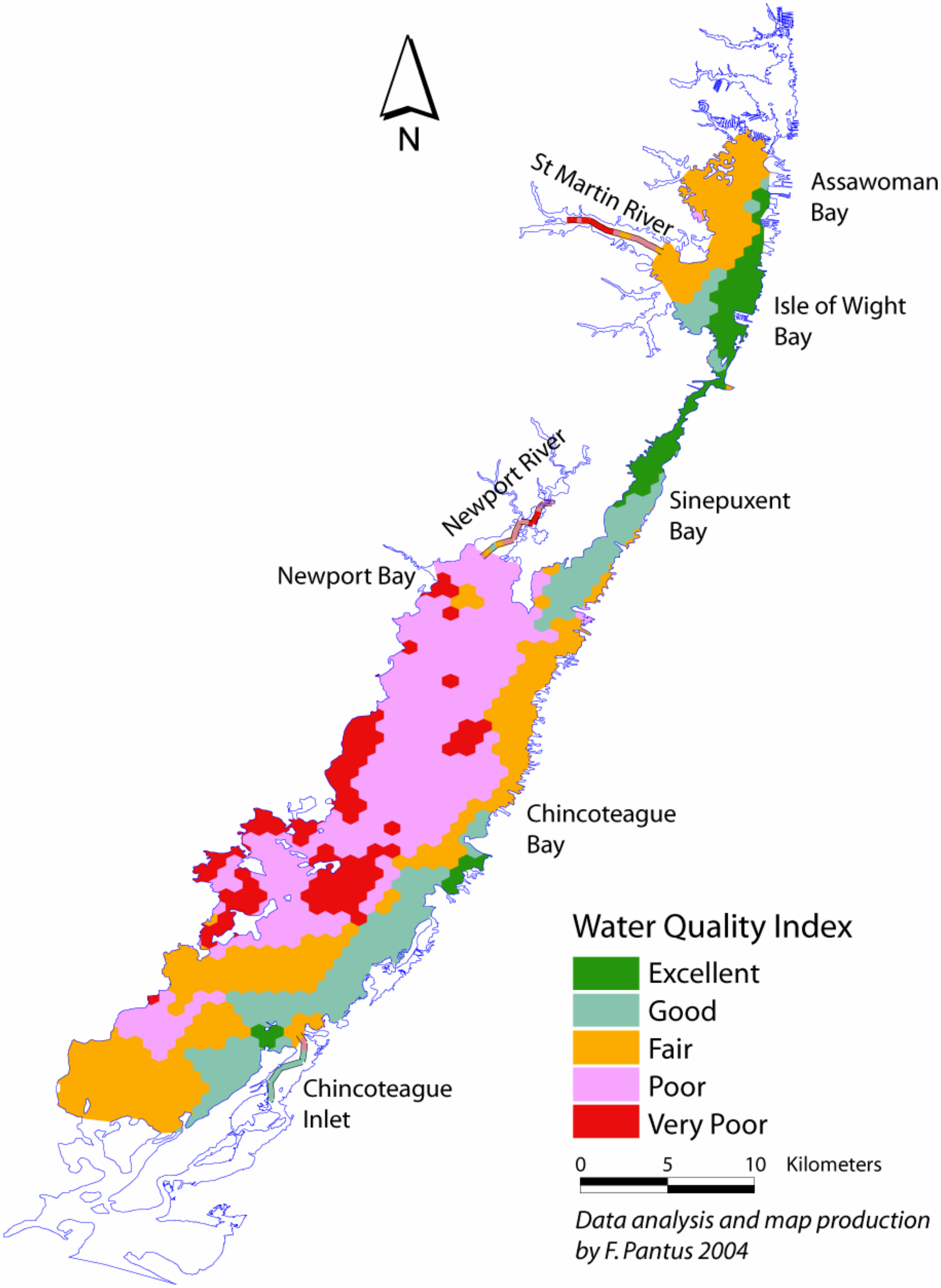

Figure 1. Water Quality Index for the Maryland Coastal Bays.

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Introduction

Maryland's Coastal Bays are shallow water bodies (less than 10 feet deep) that are uniform in depth, occurring between a small coastal watershed (175 sq. miles) and sandy barrier islands. Tidal exchange is limited, and restricted to the Ocean City and Chincoteague inlets. River input is low and groundwater is an important source of freshwater inflow. Wind blowing across these shallow waters results in very strong mixing, meaning oxygen levels usually remain high in open areas (Fig. 2). They receive inputs from a range of nutrient sources, including wastewater treatment plants, septic systems, agricultural inputs, stormwater runoff and several golf courses. Comparatively, Maryland's Coastal Bays have fewer human impacts than Chesapeake Bay, but the limited water exchange makes them more sensitive to inputs.

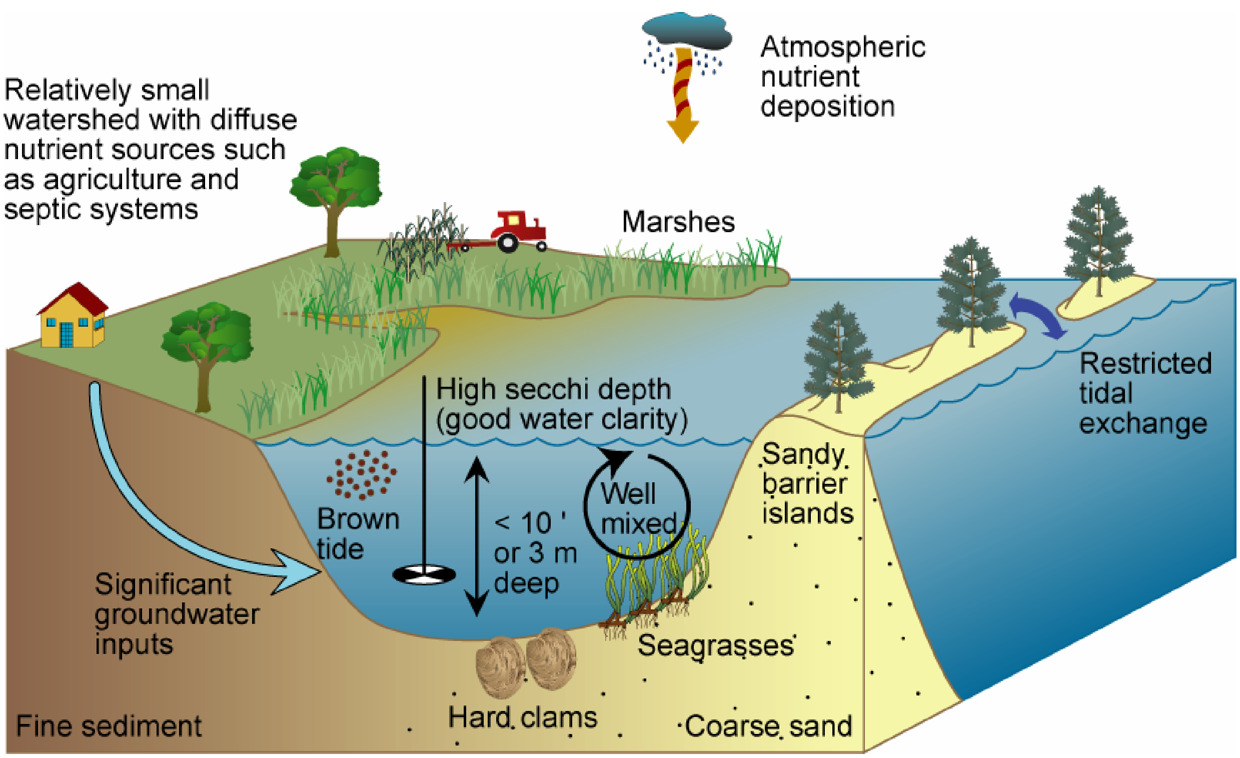

Figure 2. Conceptual diagram showing the key physical and biological properties of the Maryland Coastal Bays.

The slow flushing times (months) in the Coastal Bays result in a system where the water quality is strongly impacted by land use. The northern sections of the Coastal Bays are more heavily developed, particularly in the region of Ocean City, whereas the southern sections are predominantly agriculture and forest (Fig. 3).

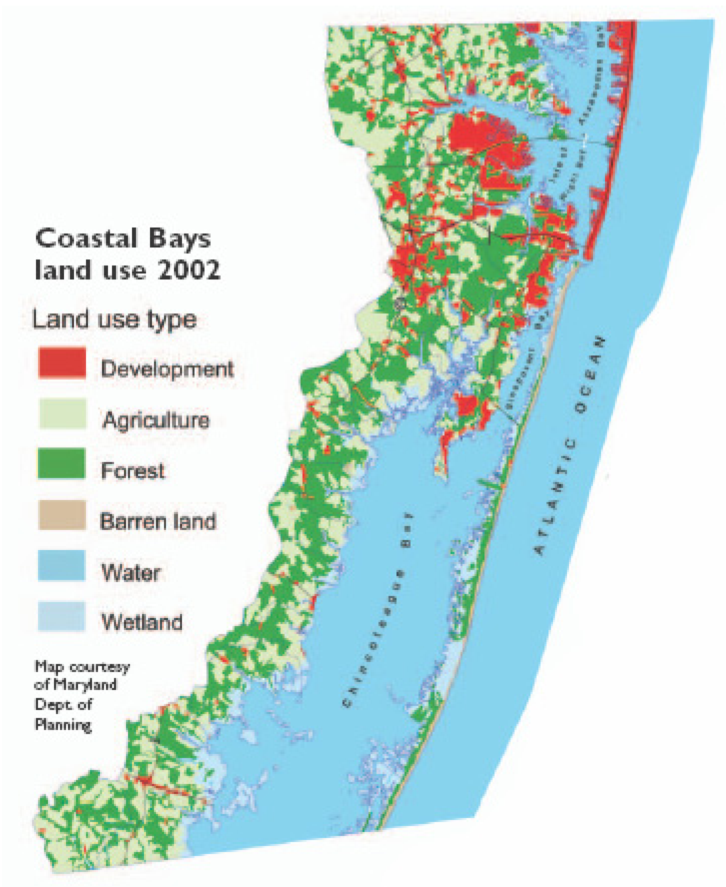

Figure 3. Land use map of the Maryland Coastal Bays (Map courtesy Maryland Department of Planning).

Wastewater treatment plants in the Maryland Coastal Bays are all within the northern sections; St. Martin River, Isle of Wight Bay, Newport Bay and its tributaries, and in the ocean offshore from Ocean City (Fig. 4). In Chincoteague Bay septic systems are used, resulting in a more distributed input of nutrients.

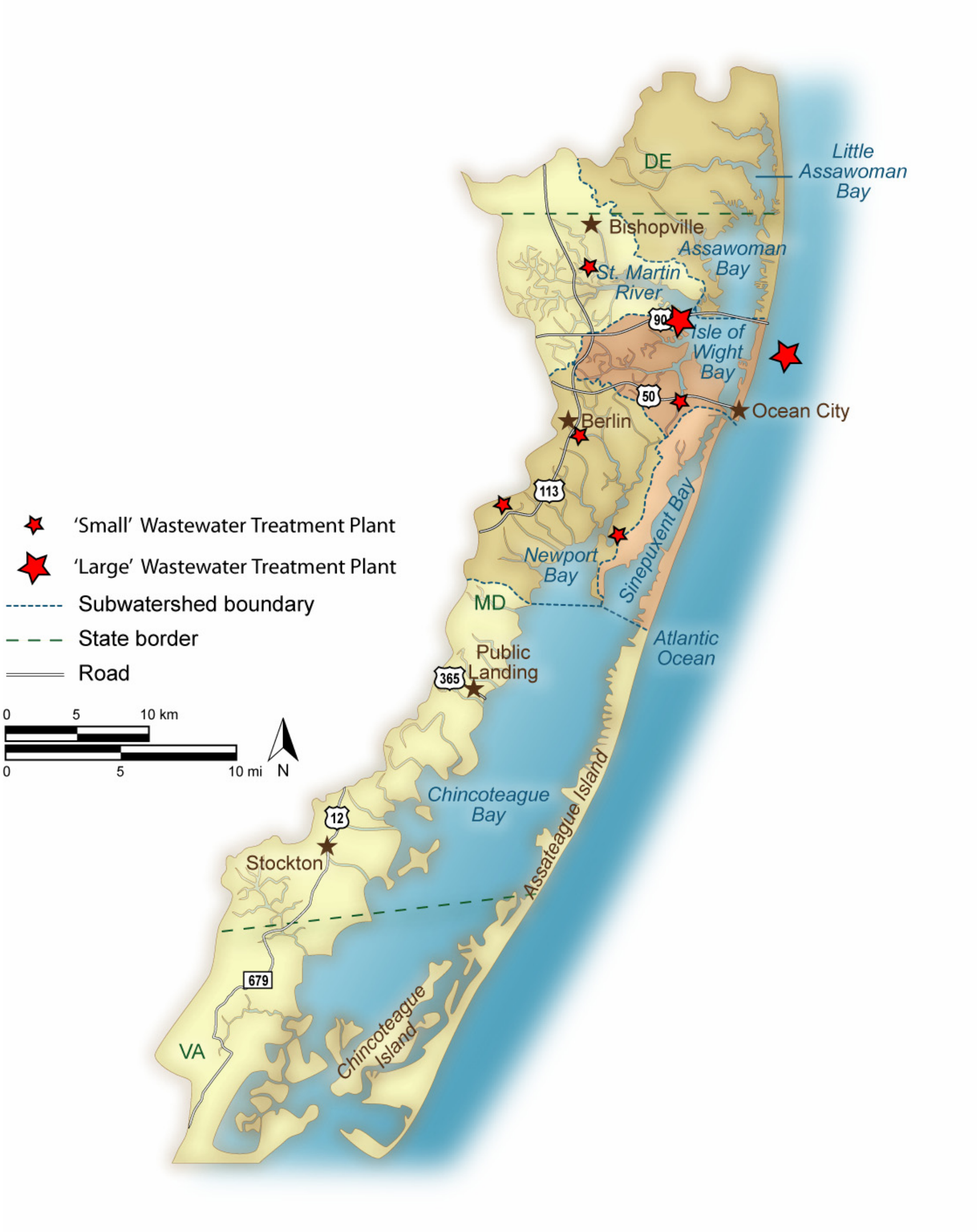

Figure 4. Location of sewage treatment plants in the Maryland Coastal Bays.

Determining the impacts and extent of sewage and septic derived nitrogen in marine systems with multiple inputs (both point and non-point source) is typically problematic, and it has been shown that physical and chemical water quality monitoring techniques are unable to determine the ecological impact of wastewater discharges. Biological indicators have long been used to determine ecological impacts of point source discharges (Worf, 1980; Kramer, 1994). The key feature of biological indicators is their ability to provide temporally and spatially integrated insights into the biological impacts of changes in anthropogenic activity. Unlike traditional chemical analyses of water column nutrients, these biological indicators reflect the availability of biologically available nutrients which provides more ecologically meaningful information. This is in contrast to ‘traditional’ water quality parameters such as dissolved nutrient concentrations, which simply provide an instantaneous chemical measurement.

Nitrogen (N) occurs in two naturally stable forms, ^{15}N and ^{14}N, with the predominant form being ^{14}N (99.6%). The various sources of nitrogen often have distinguishable ^{15}N to ^{14}N ratios, thereby making it possible to identify the source of the nutrients (Heaton, 1986). Stable isotope ratios of nitrogen ($\delta^{15}N$) have been used widely in marine systems as tracers of discharged nitrogen from point and diffuse sources, including sewage effluent (Rau *et al.*, 1981; Heaton, 1986; Wada., 1980; Van Dover *et al.*, 1992; Macko & Ostrom, 1994; Cifuentes *et al.*, 1996; McClelland & Valiela, 1998). Plant $\delta^{15}N$ signatures have been used to identify nitrogen sources available for plant uptake (Heaton, 1986). Elevated $\delta^{15}N$ signatures in seagrass, mangroves and macroalgae have been attributed to plant assimilation of N from treated sewage effluent (Wada, 1980; Grice *et al.*, 1996; Udy & Dennison, 1997; Abal *et al.*, 1998). The elevated $\delta^{15}N$ signature subsequent to treatment of the sewage effluent is a result of isotopic fractionation during ammonia volatilization, nitrification and denitrification (McClelland & Valiela, 1998).

The main limitation with all bio-indicator sampling techniques has been spatial resolution due to natural occurrence of appropriate indicator organisms, especially in estuaries with strong gradients of light and salinity. A technique has been developed to detect and integrate the effects of nitrogen inputs by analyzing the isotopic signature of nitrogen ($\delta^{15}N$) in biological indicator organisms actively deployed and incubated *in situ* (Dennison and Abal 1999; Costanzo, *et al.* 2001). The stable isotope analysis ($\delta^{15}N$) of aquatic plants has proven successful in identifying the location and extent of plumes from sewage treatment plants, aquaculture farms, septic outfalls and agriculture (Costanzo *et al.* 2001; Jones *et al.* 2001).

The primary aim of this project was to conduct a comprehensive, spatially intensive survey of the Maryland Coastal Bays, analyzing stable nitrogen isotope ratios ($\delta^{15}N$), together with traditional water quality parameters (pH, dissolved oxygen, temperature, salinity, total nitrogen and phosphorus, and chlorophyll *a* concentration) to assess the sources and distribution of nutrients. These parameters were spatially correlated to produce a water quality index (WQI).

Materials and Methods

Study Region

The Maryland Coastal Bays comprise a series of shallow lagoons behind Fenwick and Assateague Islands. In June 2004, an intensive field sampling program (248 sites) was conducted to measure a suite of water quality parameters and to determine the $\delta^{15}N$ isotopic signature of deployed macroalgae (*Gracilaria*). Site locations were generated randomly using GIS software. This spatial grid allowed the production of statistically valid interpolated maps. The area was divided into eight reporting regions (Fig. 5).

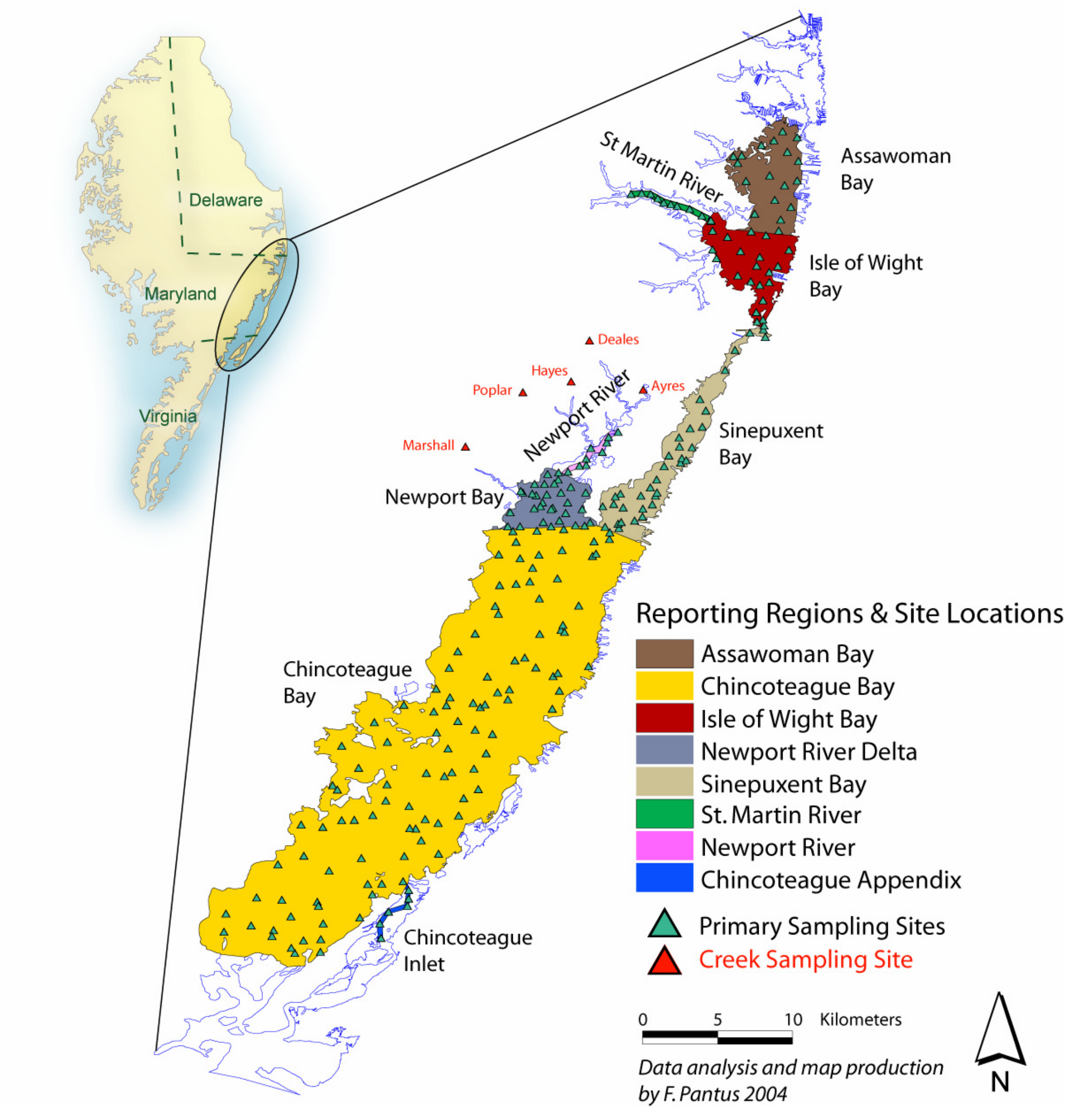

Figure 5. Map of the Maryland Coastal Bays showing the 248 sites sampled intensively during June 2004.

Table 1. Reporting region statistics detailing five regions with spatial predictions and three regions with linear predictions.

Reporting region	Extent	Unit	# sample sites	sample density	unit
Assawoman Bay	26.27	km^2	18	0.69	samples/km^2
Chincoteague Bay	325.49	km^2	106	0.33	samples/km^2
Isle of Wight Bay	23.19	km^2	20	0.86	samples/km^2
Newport Bay	17.45	km^2	31	1.78	samples/km^2
Sinepuxent Bay	30.24	km^2	36	1.19	samples/km^2
Chincoteague Inlet	5.08	km	7	1.38	samples/km
St Martin River	5.86	km	11	1.88	samples/km
Newport River	5.90	km	10	1.69	samples/km

Water quality sampling

Salinity, pH, temperature and dissolved oxygen (DO) were measured with WTW and Hydrolab water quality probes. Secchi depth was determined by lowering a 20 cm diameter Secchi disk through the water column until it was no longer possible to distinguish between the black and white sections.

Water column nutrients

Total nitrogen and total phosphorus were determined by collecting water samples in pre-rinsed containers, placed on ice and returned to the laboratory where they were frozen for subsequent analysis in accordance with the methods of Clesceri *et al.* (1989).

Chlorophyll a

Chlorophyll *a* concentrations were used as an indicator of phytoplankton biomass. At each site, chlorophyll *a* concentration was determined by filtering a known volume of water through a Whatman GF/F filter which was immediately frozen. In the laboratory, the filter was ground in acetone to extract chlorophyll *a*, spectral extinction coefficients were determined on a fluorometer.

Stable isotope technique

Gracilaria sp. (a red macroalgae) was collected from Greenbackville on the Maryland/Virginia border. Sub-samples were analyzed for their initial $\delta^{15}N$ isotopic signature. At each site, the macroalgae were incubated for four days in transparent, perforated chambers (at half Secchi depth to ensure uniform light availability) using a combination of buoy, rope and weights (Plate 1 & Fig. 6). Samples were oven dried to constant weight at 60 °C, ground and oxidized in a CN Biological Sample Converter. The resultant N_2 was analyzed by a continuous flow isotope ratio mass spectrometer (Fig. 9). Total %N was determined, and the ratio of ^{15}N to ^{14}N was expressed as the relative difference between the sample and a standard (N_2 in air) using the following equation (Peterson & Fry, 1987): $\delta^{15}N = (^{15}N/^{14}N\text{ (sample)} / {}^{15}N/^{14}N\text{ (standard)} - 1) \times 1000$ (‰).

Plate 1. Preparation of the macroalgal $\delta^{15}N$ incubation rig: a) securing rope to bricks for anchor; b) tying on the buoy; c) zip tying a sinker part way down the rope to keep the chamber under water; d) measuring the Secchi depth; e) finding the point on the rope that is half the Secchi to standardize the light regime between sites; f) zip tying the chamber lid to the rope at 'half Secchi depth'; g) placing approximately 5 g (wet wt) of macroalgae into the perforated chamber; h) screwing the chamber into its lid; i & j) deploying chamber at GIS located site.

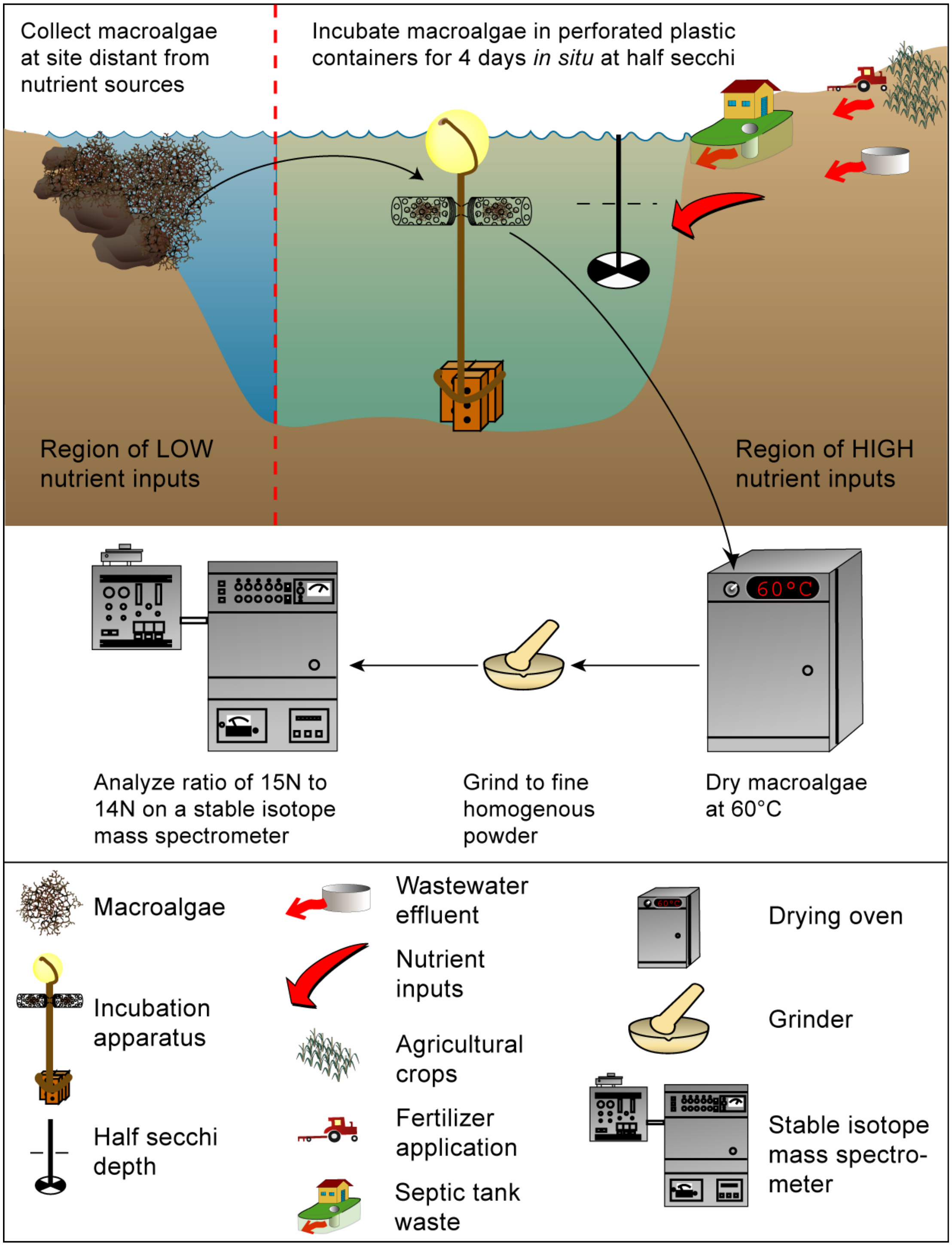

Figure 6. Plume mapping technique showing deployment of macroalgae at half Secchi in perforated plastic jar using a system of weight, rope and buoy and subsequent grinding and analysis on a stable isotope mass spectrometer.

Developing the Water Quality Index (WQI)

Management objectives such as clear water and reduced nutrient inputs can be linked to water quality indicators which can then be quantified, mapped and integrated. A reference value for each of these indicators provides information on whether the management objectives are being met. These indicators should ideally provide information on various aspects of the ecosystem.

Two important steps in the development of a Water Quality Index (WQI) for an area are the choice of indicators to be included in the assessment, and the method of integrating them into an informative measure that is conceptually simple to understand and easy to communicate. It is important that water quality indicators be tied to management objectives to ensure their ability to provide effective feedback on resource management actions. In this pilot study on the Maryland Coastal Bays, we utilized six indicators derived from the management objectives set out by the Maryland Coastal Bays Program.

The WQI is based on the concept of compliant zones with respect to a performance measure and is that portion of a reporting region where the performance measure does not exceed the reference value, as specified in the management objectives (see Table 2 for the indicator reference values used in the present study). The reference values for this pilot study were based primarily on guidelines set by the Maryland Coastal Bays Program Scientific and Technical Advisory Committee. The $\delta^{15}N$ value is currently the most ambiguous due to the lack of research with this parameter in the Chesapeake region. A value of 14‰ was chosen based on the highest and mean values obtained, and on research done in 2003 on the Choptank and Patuxent Rivers (Jones *et al.*, 2003). Continued research in the region will likely alter this value in the future. The threshold function assigns a value of 1 to each performance measure complying with the reference value and 0 otherwise. The mean value for all parameters is the Water Quality Index for that site.

Various reporting regions (Fig. 5) were established to enable the creation of a WQI for spatially defined regions. The power of a WQI is improved with the number of parameters used in its calculation. This technique can be greatly enhanced by incorporating various living resources, land use and habitat indicators to develop an Ecosystem Health Index (EHI).

Table 2. Table of management objectives for the Maryland Coastal Bays together with water quality indicators and reference values (as set by the Scientific and Technical Advisory Committee of the Maryland Coastal Bays Program) to determine the status of the objectives.

Management Objective	**Water Quality Indicator**	**Reference Value**
Maintain suitable fisheries habitat	Dissolved oxygen	DO > 5 mg L^{-1}
Clear water	Secchi depth	Secchi > 1.0 m
Reduce phytoplankton	Chlorophyll *a*	Chl *a* < 15 µg L^{-1}
Reduce phosphorus	Total phosphorus	TP < 1.2 µM
Reduce nitrogen	Total nitrogen	TN < 46 µM
Reduce sewage/septic inputs	Delta ^{15}N ($\delta^{15}N$)	$\delta^{15}N$ < 14 ‰

Results

Salinity

Surface salinity ranged from 0 psu in the upper creek sites to 32.7 psu in Chincoteague Bay with a mean of 27.3 psu. Salinities were highest near the two openings with the ocean, Ocean City and Chincoteague (Fig. 7).

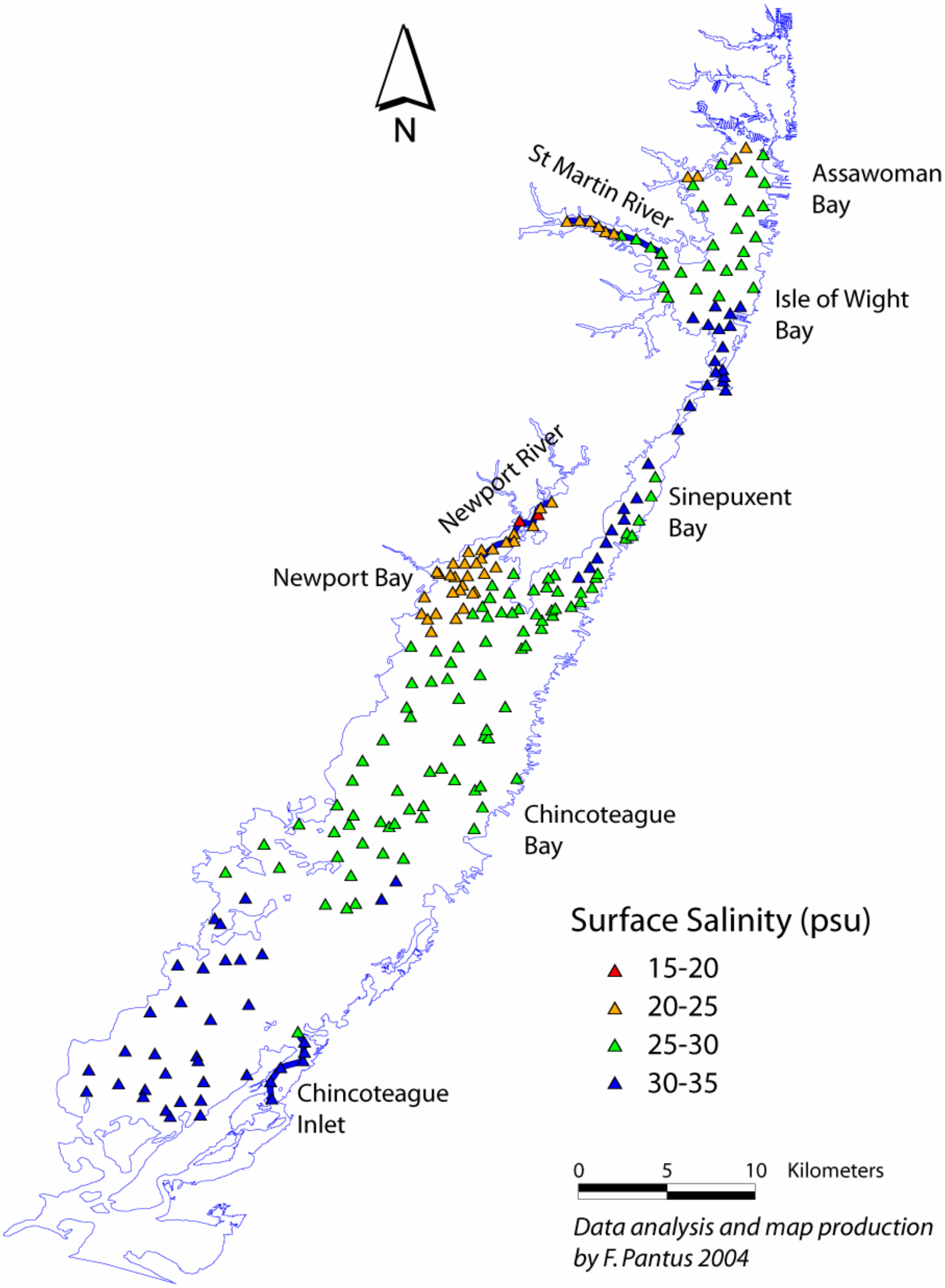

Figure 7. Surface salinity (psu) in the Maryland Coastal Bays. Please note that the colors used to portray the different value ranges in this map are NOT related to the WQI scale from 'excellent' to 'very poor'.

pH

The upper creek sites exhibited the biggest range in surface pH, from the lowest recorded, 6.45 (in Poplar Creek) to the highest, 8.75 (in Hayes Creek). The overall mean for all sampling sites was 7.93 (Fig. 8).

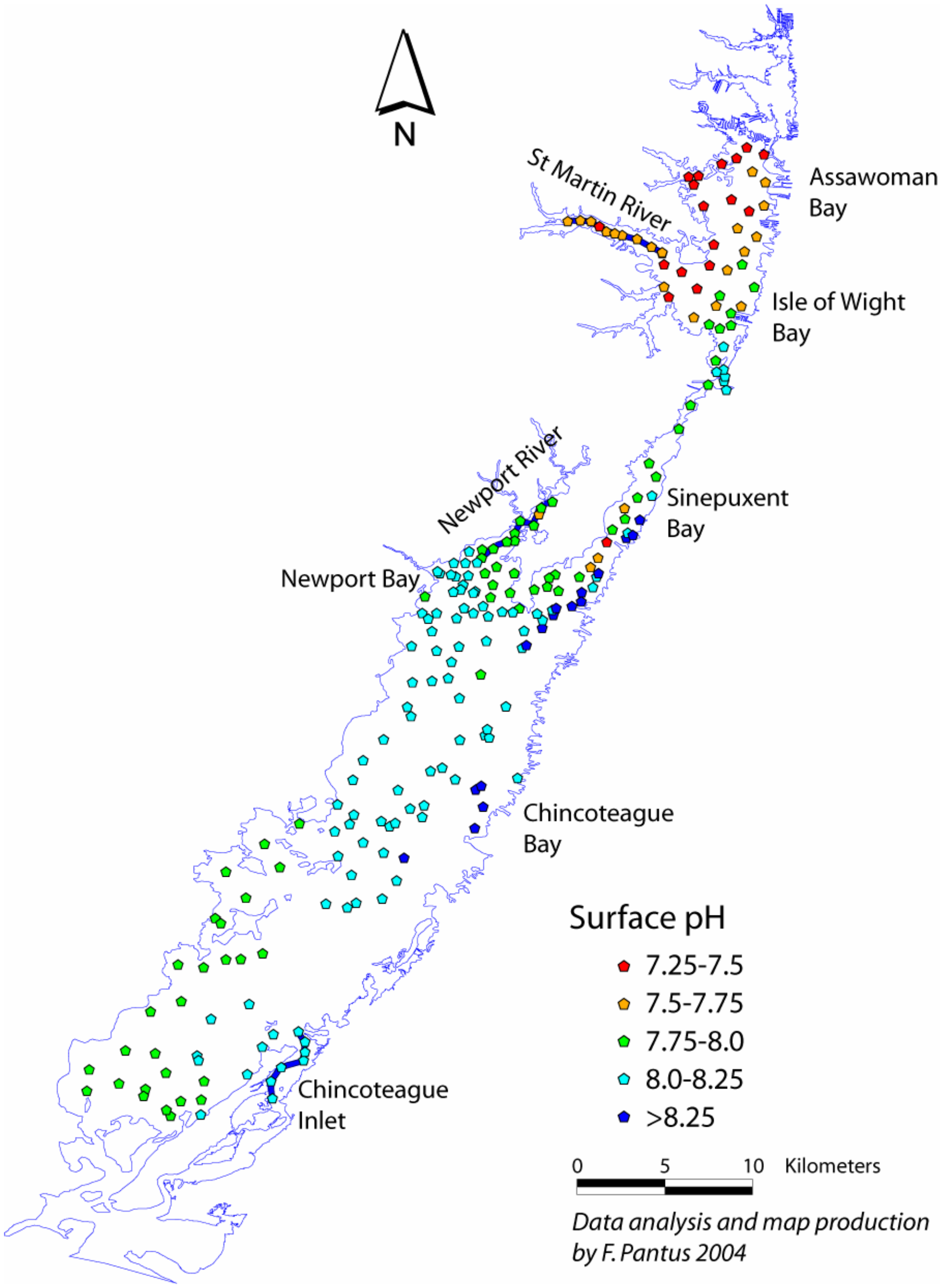

Figure 8. Surface pH in the Maryland Coastal Bays. Please note that the colors used to portray the different value ranges in this map are NOT related to the WQI scale from 'excellent' to 'very poor'.

Temperature

The upper creek sites also exhibited the greatest range in surface temperatures, ranging from 16.7°C (at Marshall Creek) to 27.5°C (in Hayes Creek) with an overall mean of 23.4°C (Fig. 9).

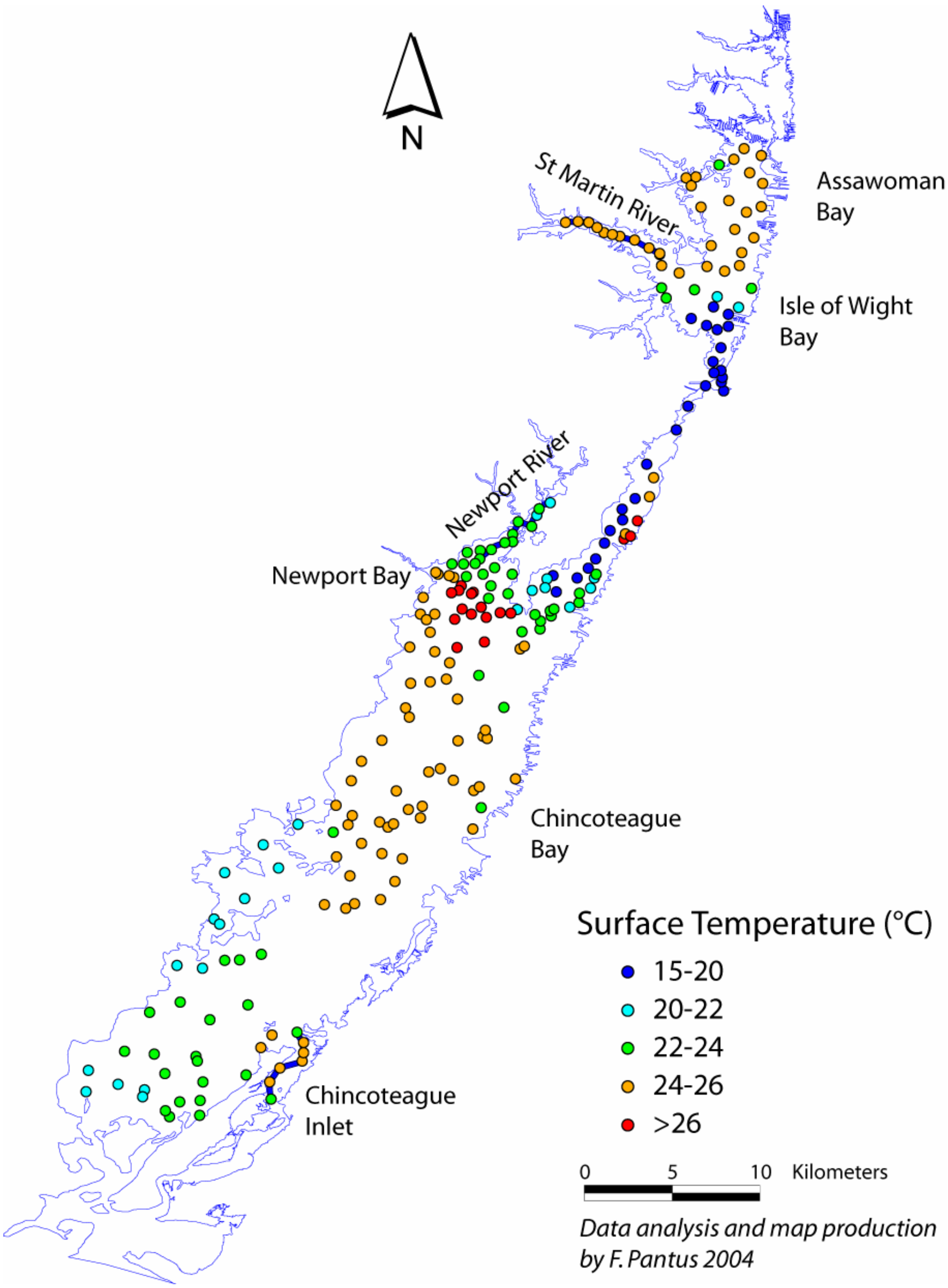

Figure 9. Surface water temperature (°C) in the Maryland Coastal Bays. Please note that the colors used to portray the different value ranges in this map are NOT related to the WQI scale from 'excellent' to 'very poor'.

Dissolved oxygen

The concentration of surface dissolved oxygen (DO) ranged from 1.16 mg L^{-1} in Poplar Creek to 13.3 mg L^{-1} at the southern end of Sinepuxent Bay, with a mean of 6.49 mg L^{-1} (Fig. 10).

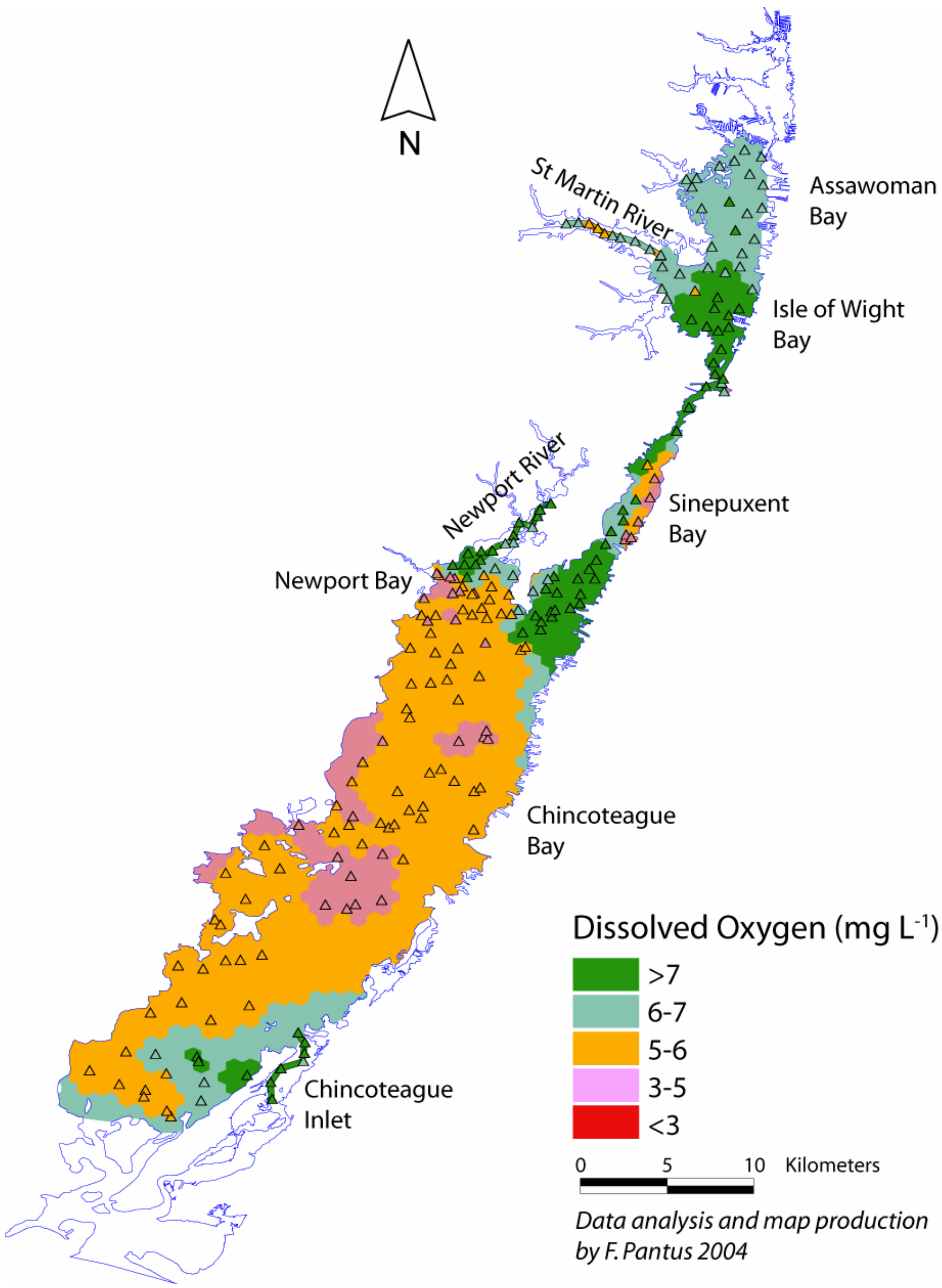

Figure 10. Surface dissolved oxygen concentrations (mg L^{-1}) in the Maryland Coastal Bays.

Secchi depth

Secchi depths were shallower in the upper creek sites, with the lowest recorded value of 0.03 m at Ayres Creek. The deepest Secchi of 2.0 m was in Isle of Wight Bay, with an overall mean of 0.72 m (Fig. 11).

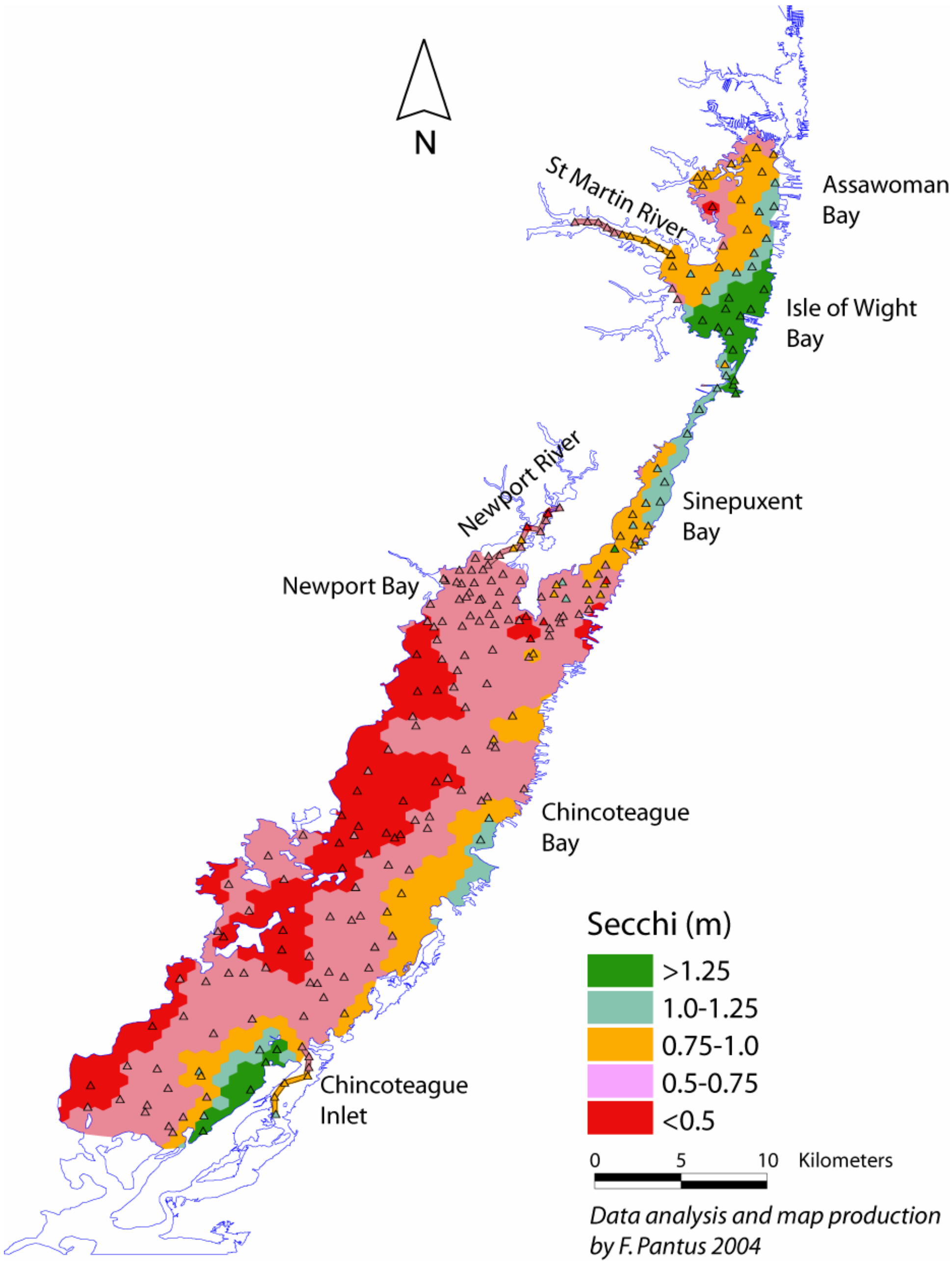

Figure 11. Secchi depth (m) in the Maryland Coastal Bays.

Water column total nitrogen

The concentration of total nitrogen ranged from 0.69 µM (0.001 mg L^{-1}) in Isle of Wight Bay to 417 µM (5.8 mg L^{-1}) in Marshall Creek, with a mean of 48.5 µM (0.68 mg L^{-1}). The mean for the upper creek sites only was 176 µM (2.46 mg L^{-1}). Newport River was the next highest region with a mean of 63.5 µM (0.89 mg L^{-1}) (Fig. 12).

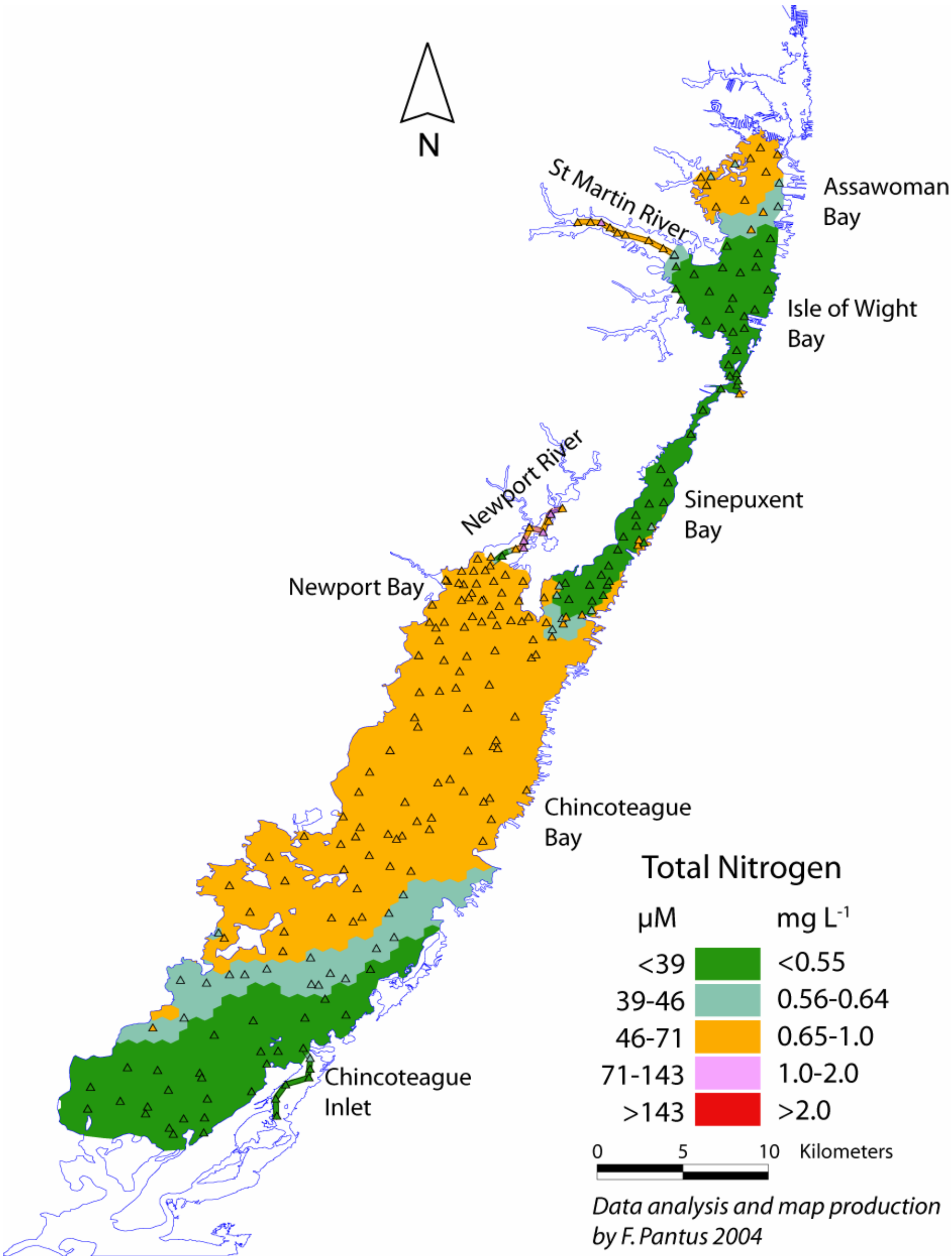

Figure 12. Water column total nitrogen concentration (µM) in the Maryland Coastal Bays.

Water column total phosphorus

The concentration of total phosphorus ranged from 0.69 µM (0.02 mg L^{-1}) in Isle of Wight Bay to 5.52 µM (0.17 mg L^{-1}) in Chincoteague Bay, with a mean of 2.6 µM (0.08 mg L^{-1}) (Fig. 13).

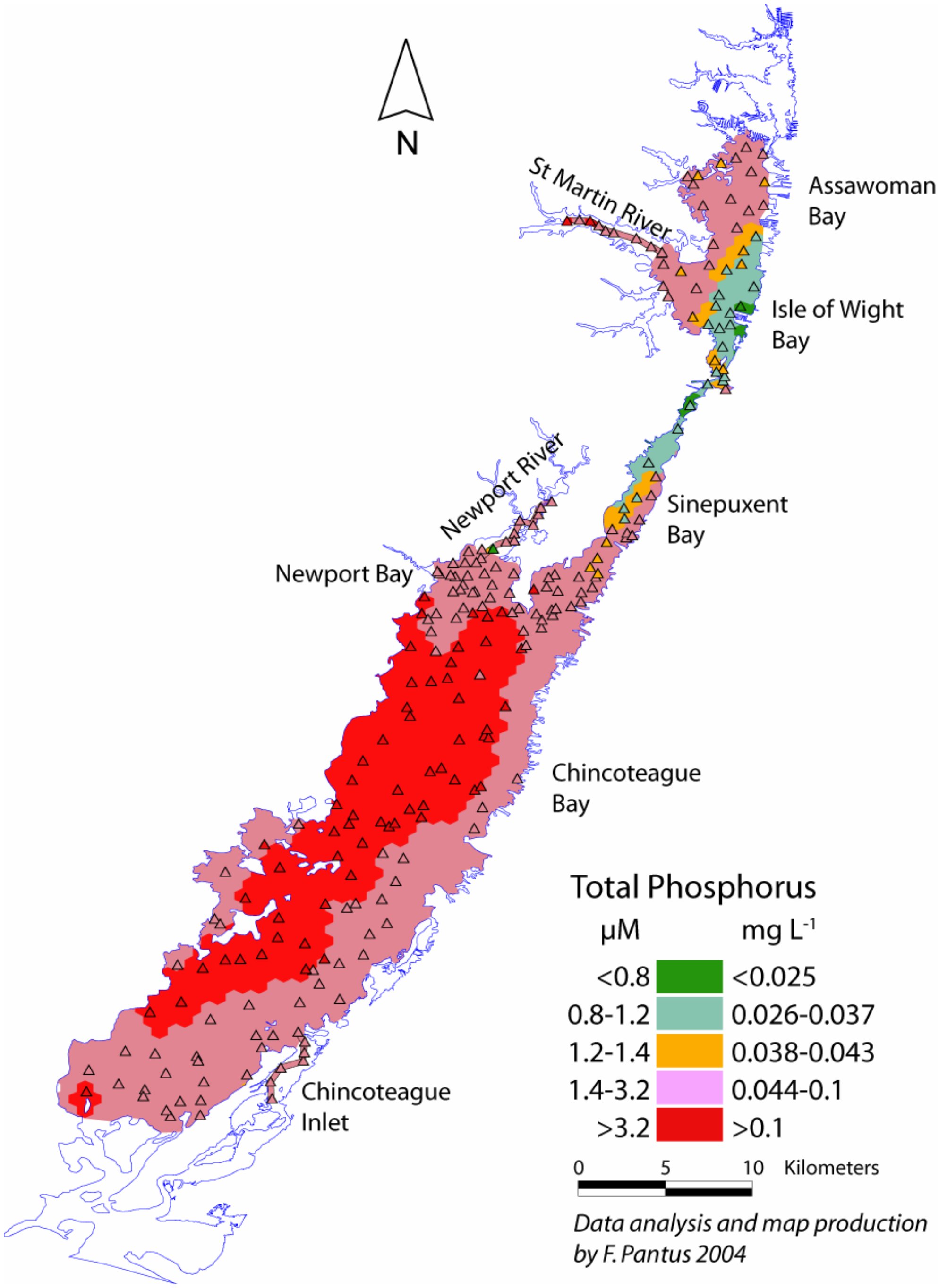

Figure 13. Water column total phosphorus concentration (µM) in the Maryland Coastal Bays

Chlorophyll a *concentration*

The concentration of chlorophyll *a* ranged from 0.25 μg L^{-1} in Marshall Creek to 49.8 μg L^{-1} in Hayes Creek, with a mean of 14.4 μg L^{-1} (Fig. 14).

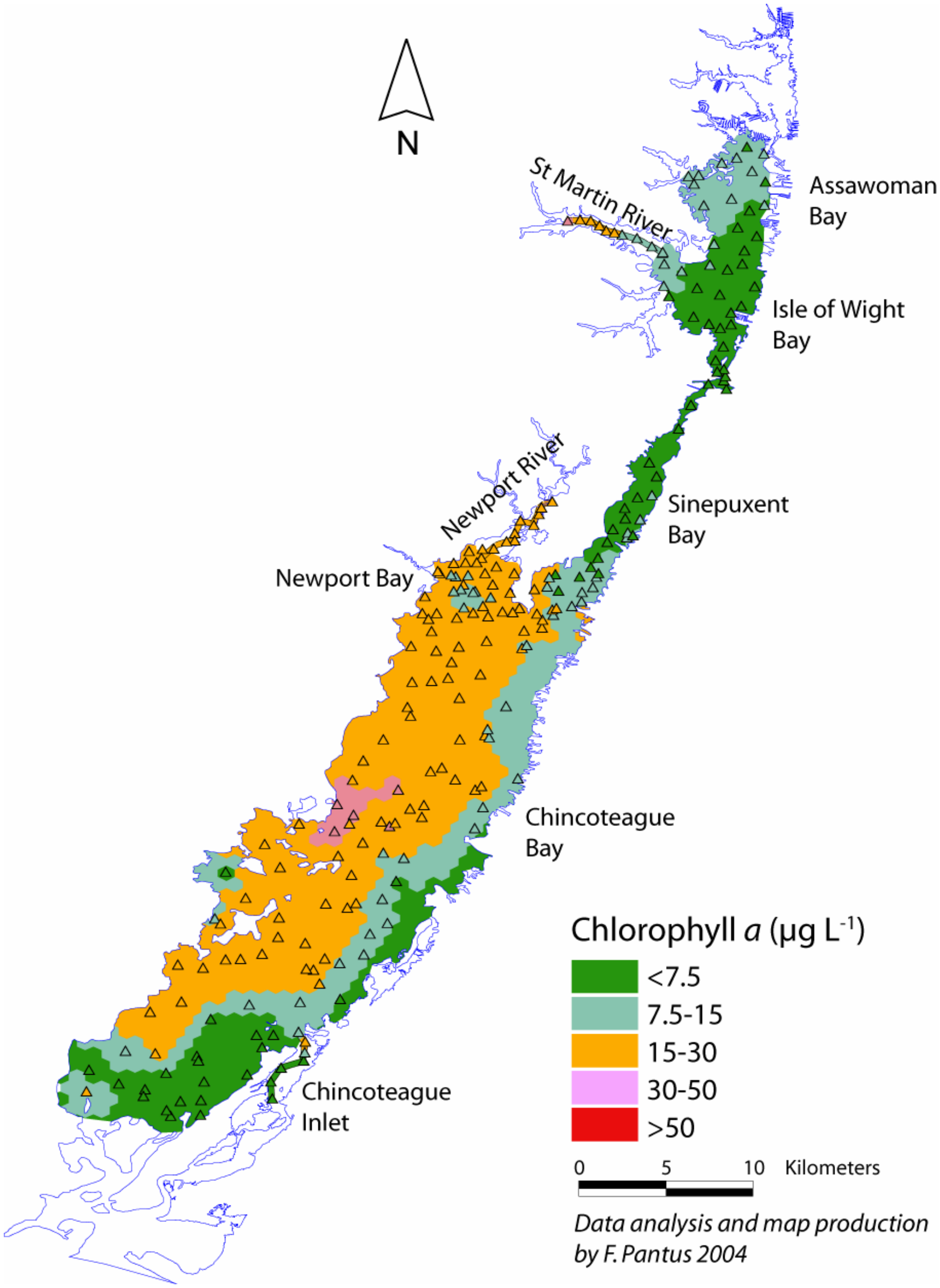

Figure 14. Chlorophyll *a* concentration (μg L^{-1}) in the Maryland Coastal Bays

δ^{15}N stable isotope ratio of nitrogen

The δ^{15}N isotopic signature of the deployed macroalgae ranged from 8.94‰ in northern end of Chincoteague Bay to 26.39‰ in the southern end of Chincoteague Bay, with a mean of 12.93‰ (Fig. 15).

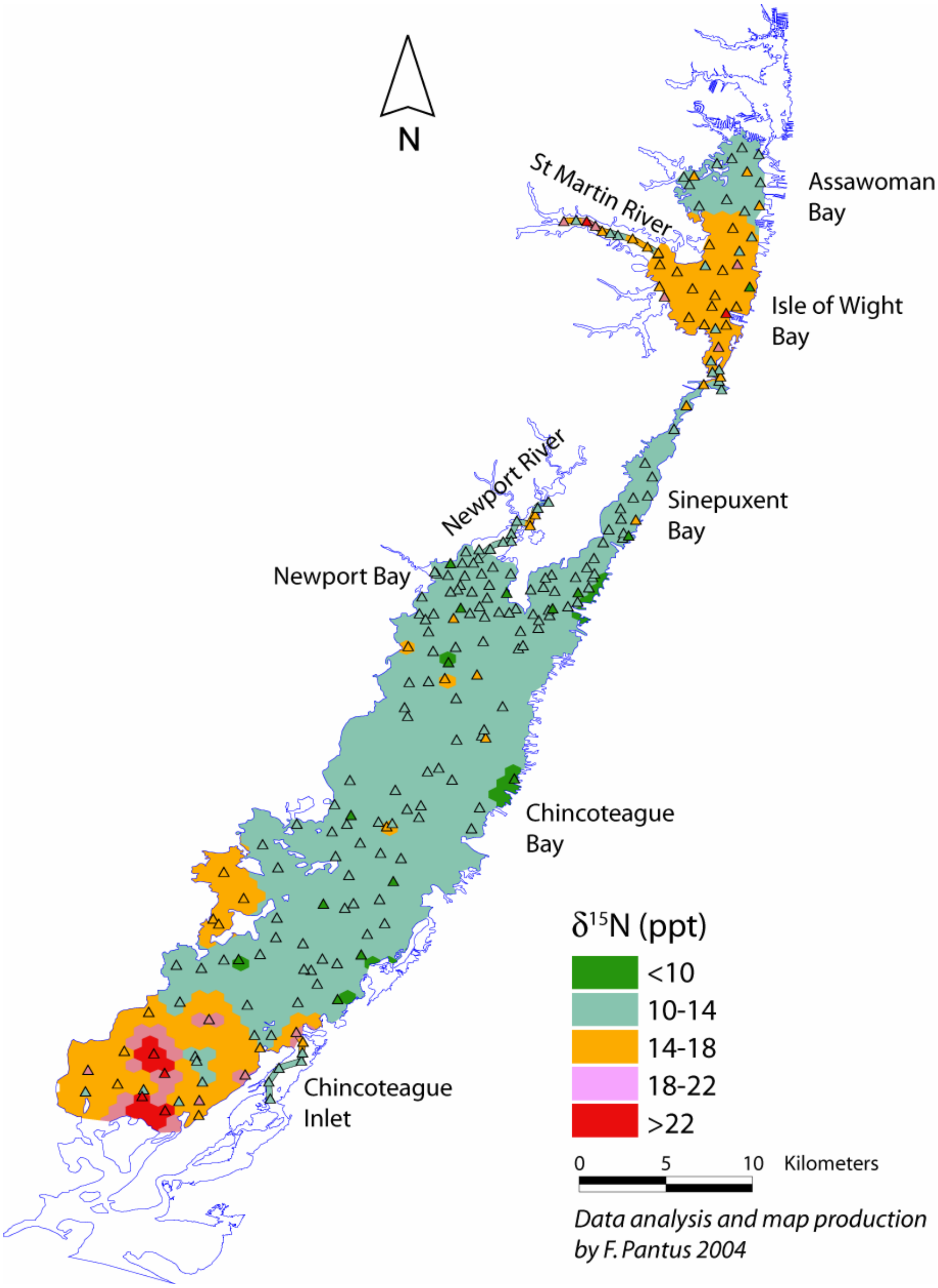

Figure 15. δ^{15}N isotopic signature of deployed macroalgae in the Maryland Coastal Bays

Upstream creek sites - water quality

These upper creek sites are in the freshwater reaches of several tributaries of the Newport River. These results have not been included in the spatial analysis and so data is presented in Table 3. Typically, the upper creek sites had very poor Secchi depths and very high total nitrogen and phosphorus concentrations. Secchi depths indicate high turbidity, and a comparison of chlorophyll *a* concentrations indicated that in some creeks (Deales, Marshall, Poplar) this is due to phytoplankton while some others (Ayres, Hayes) are turbid due to high suspended sediments.

Table 3. Table of water quality results for five upstream creek sites that were sampled. Given the location of these sites it was not possible to include them for statistical analysis, but they were sampled to provide data on potential upstream influences to the Maryland Coastal Bays. Colors represent water quality index ratings based on the reference values listed in Table 2 (Very Poor, Poor, Fair, Good, Excellent).

Site	DO ($mg\ L^{-1}$)	Secchi (m)	Chlorophyll *a* ($\mu g\ L^{-1}$)	Total N (μM)	Total P (μM)	$\delta^{15}N$ (ppt)
Ayers	6.47	0.032	25.757	76.7	2.73	13.33
Deales	6.54	0.1	2.908	113	3.04	13.45
Hayes	11.53	0.25	49.760	98.5	4.15	11.66
Marshall	6.92	0.3	0.247	417	3.20	13.88
Poplar	1.16	0.05	1.025	174	2.69	18.41

Water Quality Index (WQI)

The Water Quality Index was determined for each of the reporting regions in the Maryland Coastal Bays (Figure 16 & Table 4). The rankings are similar to those in the recent State of the Maryland Coastal Bays (SoMCB) report (Wazniak *et al.*, 2004). The SoMCB report also included living resource and habitat indicators into its ranking from 'excellent' (although no region received this ranking) to 'very poor'. In the present study, we used water quality parameters including the $\delta^{15}N$ technique and have generated a WQI using the same rankings from 'excellent' to 'very poor'. Table 5 is a comparison of the WQI generated in the SoMCB report (i.e. the ranking without the living resources and habitat parameters) and the one generated in the present study. The SoMCB report WQI did not include Secchi depth or $\delta^{15}N$ values. The most noticeable difference is the poorer rating of Chincoteague Bay (WQI: 0.74 to 0.42) in the present study. This appears to be primarily due to the increase in total phosphorus mean from 0.04 mg L^{-1} to 0.1 mg L^{-1}. The other major change is the improvement for Assawoman Bay (WQI: 0.33 to 0.56).

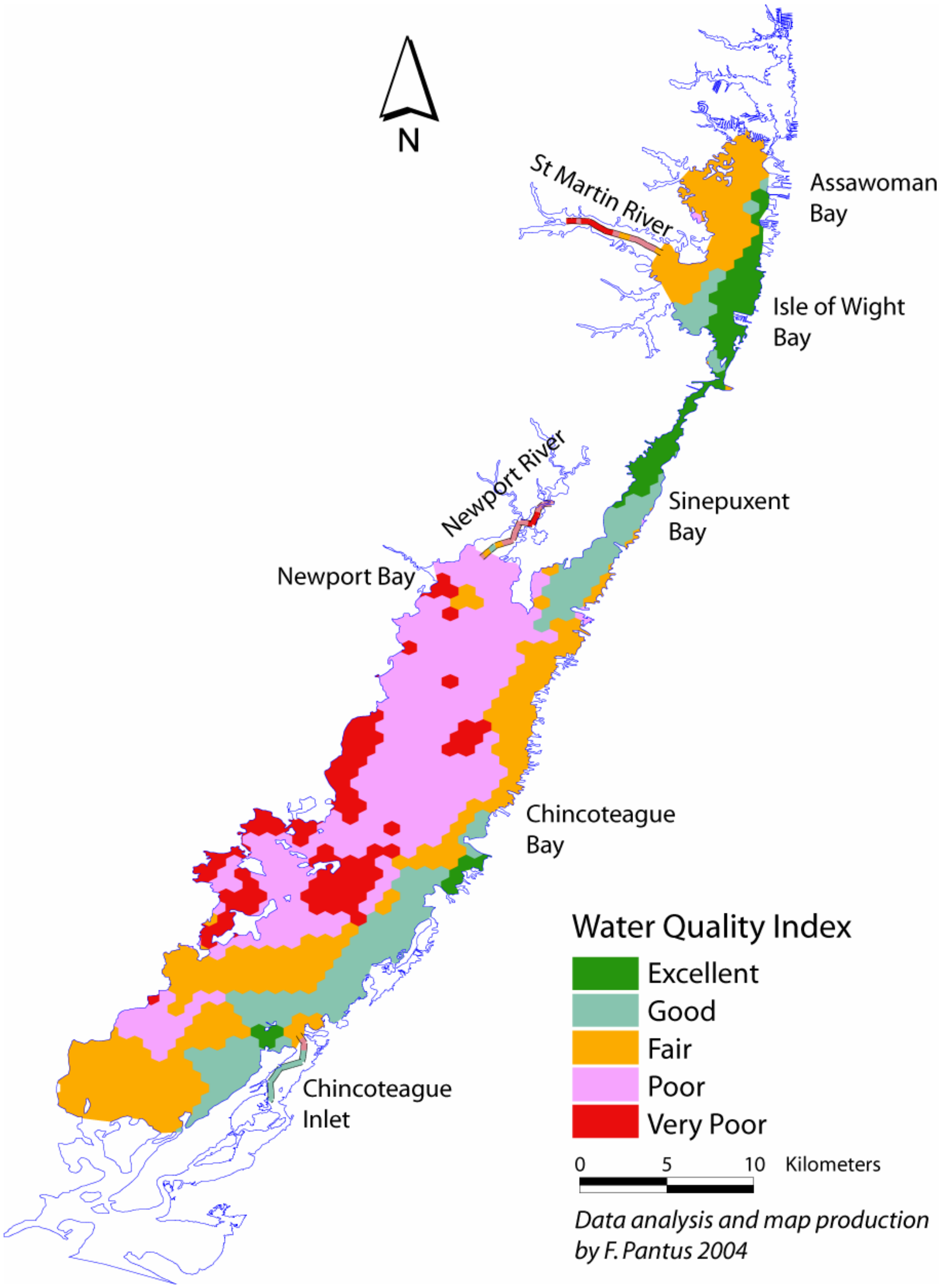

Figure 16. Water Quality Index (WQI) for the Maryland Coastal Bays

Table 4. Water Quality Indices (0-1) and compliance values for the various reporting regions. WQI is for the entire region with individual indices for all the parameters. The values for the indicators used are the mean compliance value for that indicator for that region. NB: The colors used in this table for WQI are consistent with the Very poor, Poor, Fair, Good, Excellent ratings. However, for the individual parameters they represent the mean compliance value for the reporting region (e.g. the mean value of 1 and dark color for DO in Assawoman Bay means that all sites met the compliance value, which in the case of DO is > 5 mg L^{-1}, rather than reflecting values of > 7 mg L^{-1} as indicated by dark green on that scale).

Reporting region	**WQI**	**Chl *a***	**$\delta^{15}N$**	**DO**	**Total N**	**Total P**	**Secchi**
Assawoman Bay	**0.56**	1	0.63	1	0.45	0.06	0.15
Chincoteague Bay	**0.42**	0.40	0.76	0.87	0.40	0	0.05
Chincoteague Appx	**0.62**	0.86	0.80	1	1	0	0.02
Isle of Wight Bay	**0.69**	1	0	1	1	0.44	0.70
Newport River	**0.36**	0	0.83	1	0.21	0.07	0
Newport Bay	**0.33**	0.11	1	0.89	0	0	0
Sinepuxent Bay	**0.68**	0.88	1	0.96	0.86	0.21	0.22
St Martin River	**0.29**	0.45	0.25	1	0.03	0	0

Table 5. Table of water quality index results comparing the present study to the recent State of the Maryland Coastal Bays (SoMCB) report (Wazniak *et al.* 2004). Colors for the WQI are those used in the present study applied to both studies: Very poor, Poor, Fair, Good, Excellent are the same as used in the WQI map (Fig. 13).

Reporting region	**WQI** (Present study)	**WQI** (SoMCB 2004)
Assawoman Bay	0.56	0.33
Chincoteague Bay	0.42	0.74
Isle of Wight Bay	0.69	0.53
Newport River & Bay combined	0.34	0.35
Sinepuxent Bay	0.68	0.85
St Martin River	0.29	0.33

Discussion

The overall Water Quality Index (WQI) map shows a distinct trend of improved water quality on the eastern side of the Maryland Coastal Bays where flushing with the ocean occurs. All of the individual water quality parameters have higher rankings near the two openings to the ocean at Ocean City and the town of Chincoteague to the south. The exception is the $\delta^{15}N$ isotopic signature of the macroalgae, which was elevated in Isle of Wight Bay, in the plume from St. Martin River (and the Ocean Pines Wastewater Treatment Plant) and in the southern end of Chincoteague Bay, which may be a result of septic inputs from the town of Chincoteague, which has seasonally high summer population, during the time of sampling.

The $\delta^{15}N$ technique, unlike all the other water quality parameters sampled, integrates the nutrient regime of a region over the four days that the macroalgae are deployed. This makes the technique sensitive to nutrient inputs, even in regions that are well flushed, and consequently have relatively low nutrient concentrations, due to the instantaneous nature of nutrient sampling techniques. In a study by Costanzo *et al.* (2000), *Gracilaria* sp. was used to detect small pulses of nutrients in low nutrient oceanic waters.

The high $\delta^{15}N$ of the macroalgae incubated in Johnson Bay appears difficult to explain, the region is shallow, the sediments are muddy, and there were some blooms of *Ulva* in the area (which often indicates elevated nutrients). However, there appears to be little development or source of human/animal nutrients in the region, other than some oyster banks behind Mills Island.

A few very high $\delta^{15}N$ values were also recorded in the upper St Martin River, maybe as a result of discharge from the wastewater treatment plant for the Recreational Vehicle (RV) park (at the top of the St. Martin River) in combination with various septic inputs and tidal flow upstream from the Ocean Pines Wastewater Treatment Plant.

The majority of the Maryland Coastal Bays failed to meet the reference Secchi depth value of 1 m, with most areas having a Secchi depth of less than 0.75 m. This level of light penetration is considered inadequate for the survival and growth of aquatic plants like seagrasses. Most of the areas with compliant Secchi depths did sustain seagrass beds and were close to the two openings with the ocean. This east–west gradient in Secchi depth may also be related to resuspension and fetch. The western side of the bays have a higher percentage of mud in the sediment (Fig. 17) and are also subject to greater wind fetch from the prevailing easterly winds.

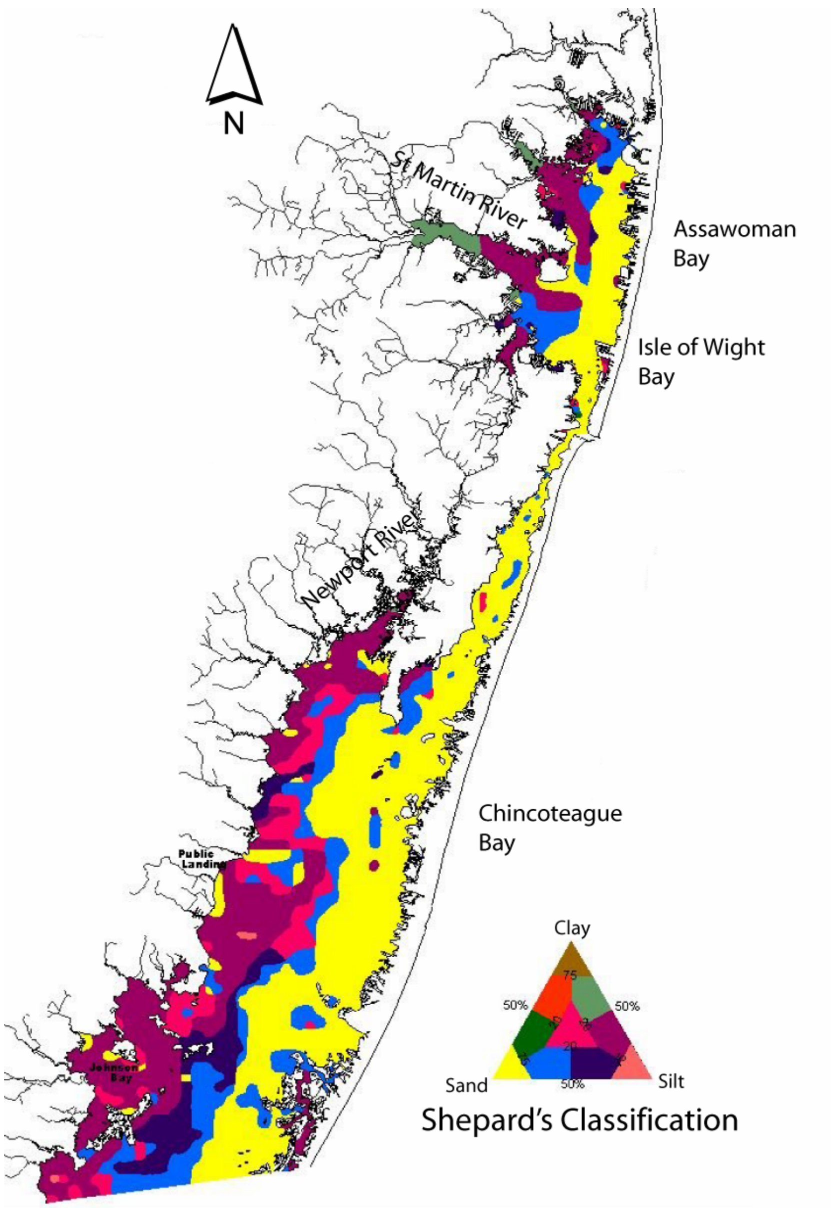

Figure 17. Map showing sediment composition (map courtesy Darlene Wells, Maryland Geological Survey). From west to east, the Coastal Bays have a gradient of high-mud to high-sand sediments.

The pattern of chlorophyll *a* concentration mirrored Secchi depth, with the highest chlorophyll *a* concentrations being in the areas with the lowest Secchi depths. This suggests that a major portion of the suspended particulates in this system are phytoplankton. Concentrations were also quite high in Newport and St Martin rivers. Chlorophyll *a* appeared positively correlated with total nitrogen concentration, and to a lesser extent, total phosphorus concentration. In the Sinepuxent region, chlorophyll *a* and total N concentrations were reduced, presumably due to increased flushing with the ocean, however total P remained relatively elevated. It appears that the bays may be becoming saturated with phosphorus due to an abundance in the groundwater (from agricultural runoff, septic tanks, atmospheric input, and wastewater treatment plants) that is now slowly building up in the bays. Phosphorus is not required by organisms in the same concentrations as nitrogen, and therefore may not be removed by biological uptake. In a region with minimal flushing like the Coastal Bays, this can lead to increases in phosphorus concentrations. The mean N to P ratio was 18, which is close to the expected Redfield ratio. However, the mean for the upper creek sites was considerably higher at 57, reflecting likely phosphorus limitation in these freshwater regions. The distribution of higher than Redfield N: P values followed the plumes of the Newport River, Grey's Creek, Roy's Creek, the area north of the Maryland border, and to some extent, the St Martin River (Fig. 18).

The mean surface dissolved oxygen (DO) concentrations were greater than 5 mg L^{-1} (compliance value) in all reporting regions, although some sites in Chincoteague Bay, Sinepuxent Bay, and St Martin River did not meet the compliance criteria. Bottom DO was also sampled and showed on average a 0 to 10% decrease from the surface values (Fig. 19). This is not a large decrease, but the shallow nature of the coastal bays promotes water column mixing, preventing typical stratification. In the Chincoteague Inlet, DO values were high, probably attributable to the high macroalgal biomass further evidenced by the two sites with higher bottom DO compared with the surface measurement. The high macroalgal biomass is likely to result in low DO problems during the night as respiration takes over. The region mid way along Sinepuxent Bay on the eastern side had relatively low DO, which may be a result of the sampling time and weather. These shallow sites were sampled at approximately 6 am on a very foggy morning, so night time respiration may be responsible for the low surface DO. It is hypothesized that photosynthesis on the benthos may have started, resulting in the concentrations of bottom DO being elevated relative to the surface. However, due to the very calm conditions it is likely that water column mixing was minimal.

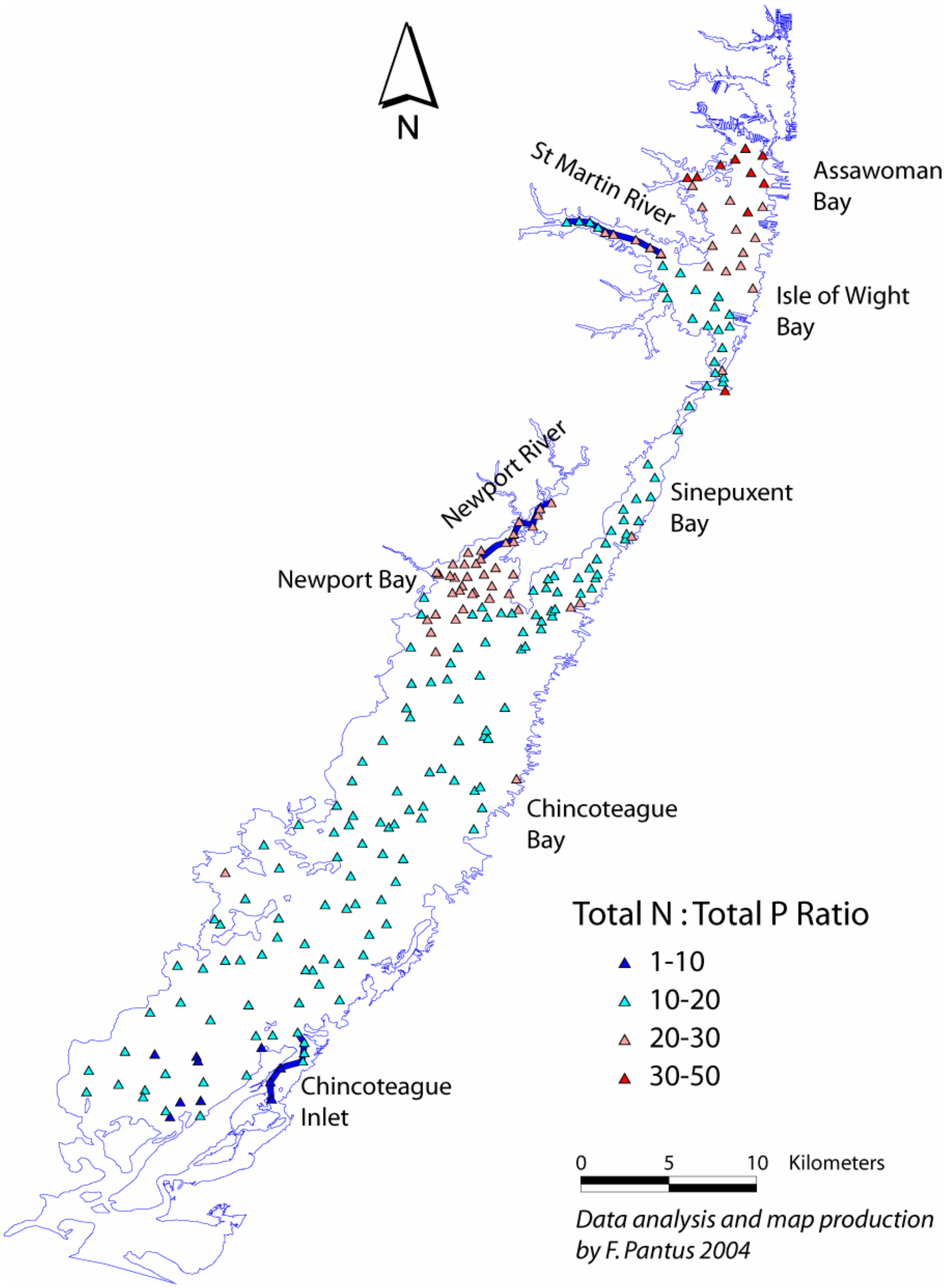

Figure 18. Total N :P ratio for the Maryland Coastal Bays (Redfield ratio 16:1)

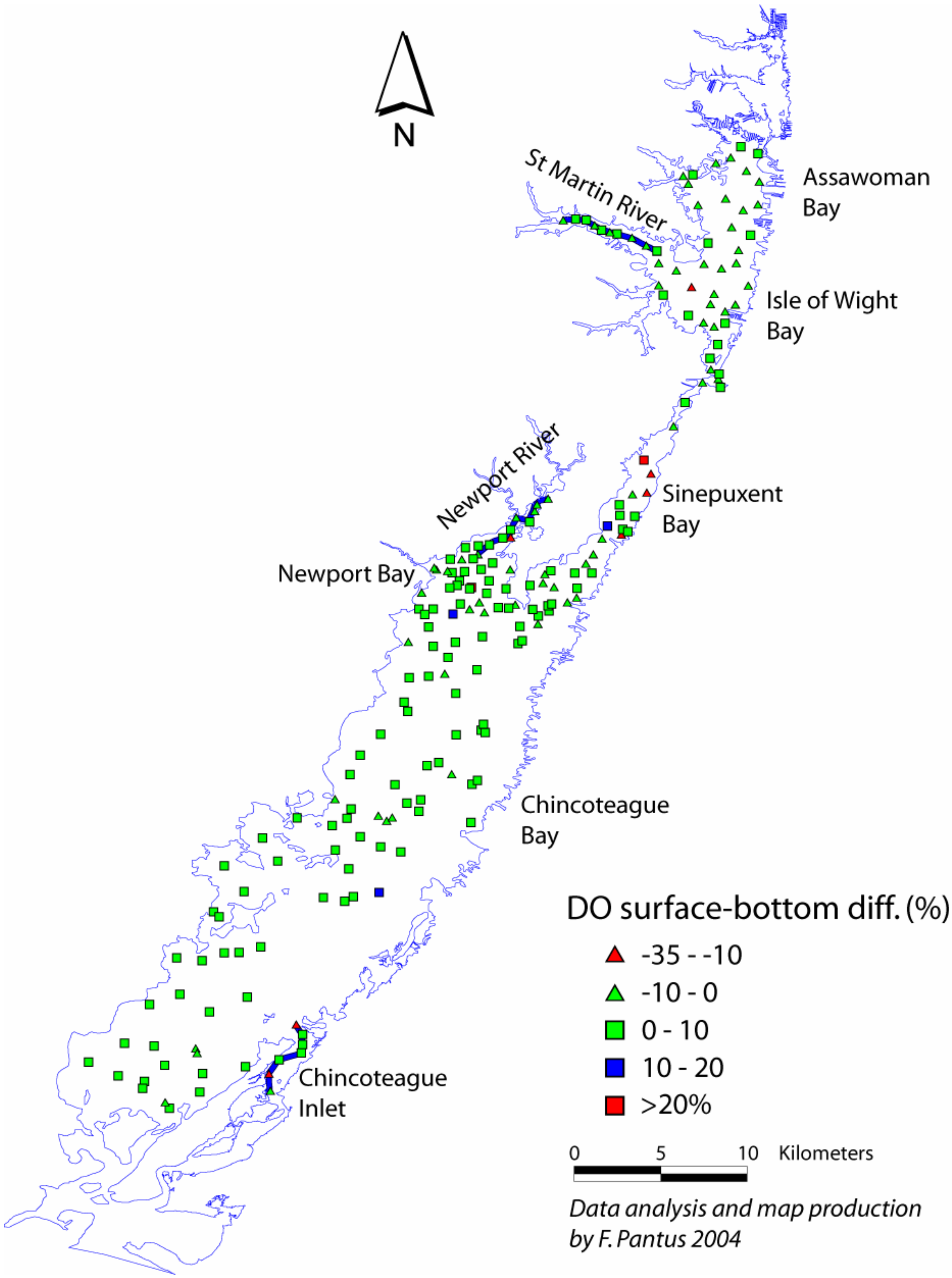

Figure 19. Percent reduction in DO concentration from surface to bottom for the Maryland Coastal Bays.

Conclusions

This study represents an intensive snapshot of the water quality of the Maryland Coastal Bays and includes the $\delta^{15}N$ stable isotope plume mapping technique to help identify regions compromised by sewage/septic derived nitrogen. Results revealed a general east–west gradient in water quality, with the highest rankings in the region of the Ocean City inlet. The southern end of Chincoteague Bay, near the town of Chincoteague, St Martin River and Isle of Wight Bay were identified as having the greatest proportion of processed nitrogen, which correlates to the presence of a high concentration of septic inputs (Chincoteague town) and wastewater treatment plant discharges (St Martin River).

This study also demonstrated that:

- Water quality indicators, based on management objectives, can be modeled, measured and mapped
- Maps of water quality indicators can be combined into overall water quality maps
- Water quality index values can be assigned for various reporting regions

Effective communication of water quality index values and integration into management programs can help produce water quality improvements by helping to focus management and research efforts by providing rapid and effective feedback on the health of a region.

Recommendations

- Incorporate water quality parameters, including $\delta^{15}N$ plume mapping, habitat, living resources, presence of harmful algae, sediment quality, stream health and watershed indicators into a bay–wide monitoring program to produce annual, spatially explicit ecosystem health assessments.
- Consider incorporating remote sensing, autonomous sampling and underway sampling programs to increase spatial and temporal sampling intensity.

This spatially explicit approach to reporting ecosystem health translates the scientifically rigorous data for broader communication and understanding of the results. An ecosystem health index serves as a device for succinctly reporting upon, and tracing the results of, management actions in terms of the stated objectives, based on targeted monitoring. In the context of an adaptive management approach, an ecosystem health index is an effective means to close the loop between monitoring and management actions. Tracking ecosystem health indices over time provides a means for measuring the effectiveness of management interventions relative to the stated operational objectives. By being explicit about the reporting requirements, development of an ecosystem health index also guides and constrains the process of design and implementation of monitoring programs, and helps to specify a clear goal for, often, costly field programs.

Science Communication

A science communication newsletter summarizing this report will be produced in the near future. It will be available for download from the Integration and Application Network (IAN) website's Maryland Coastal Bays project page at http://ian.umces.edu/mcb, together with detailed information on the techniques used, and a copy of this report.

This project was conducted after the production of the 'State of the Maryland Coastal Bays' report (Wazniak *et al.*, 2004). That report contains more information on the ecosystem health status of the Maryland Coastal Bays. It relies heavily on the science communication techniques detailed on the IAN website.

Acknowledgments

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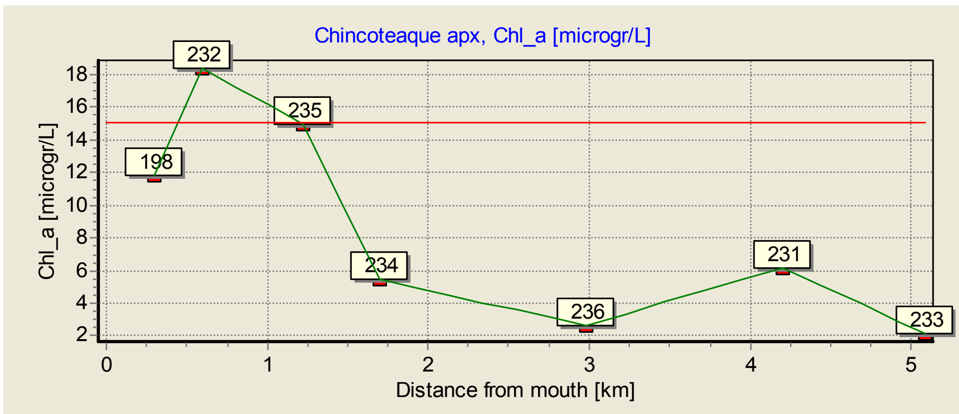
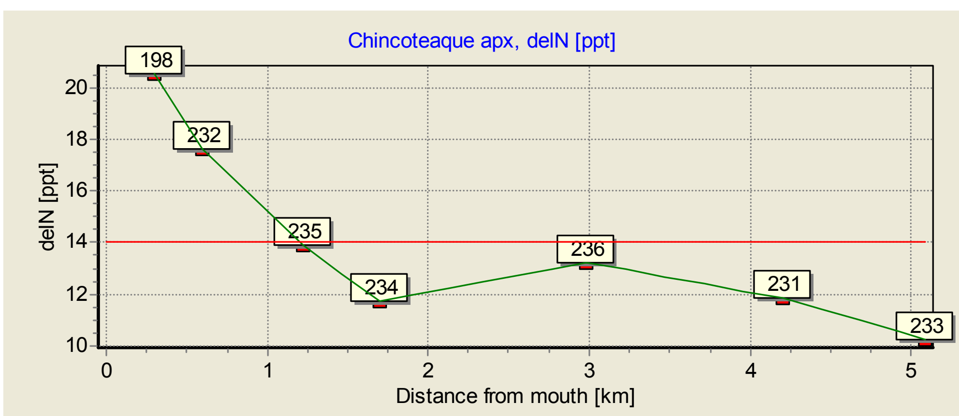
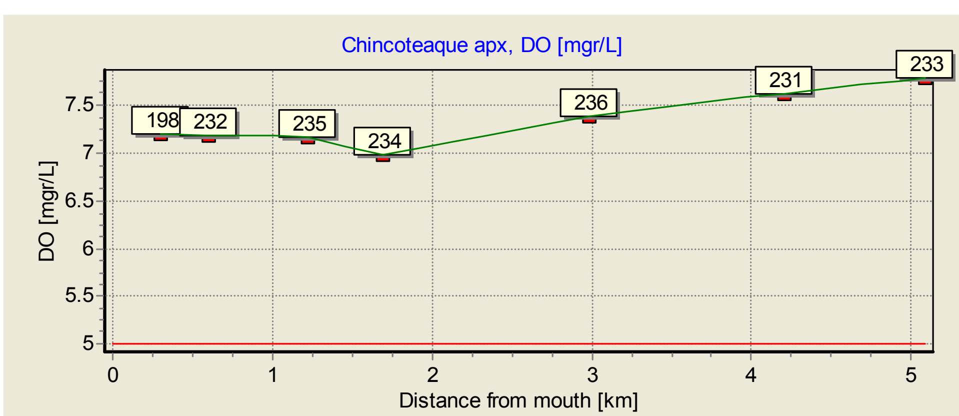
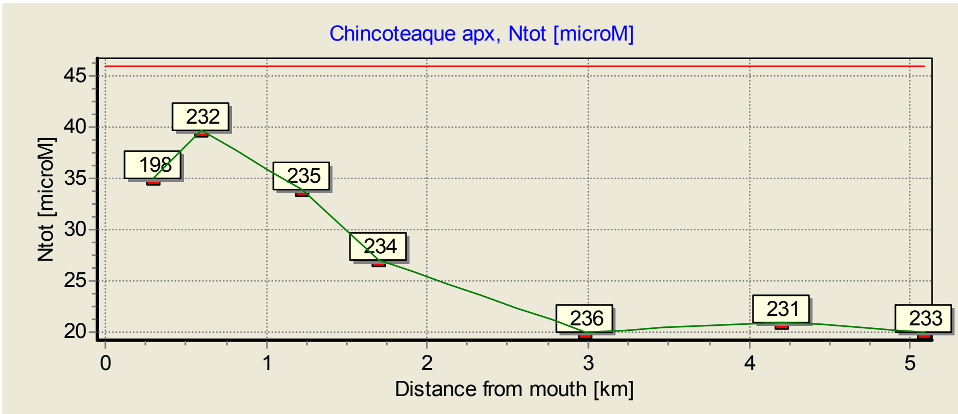
Appendix 1 – Linear prediction graphs

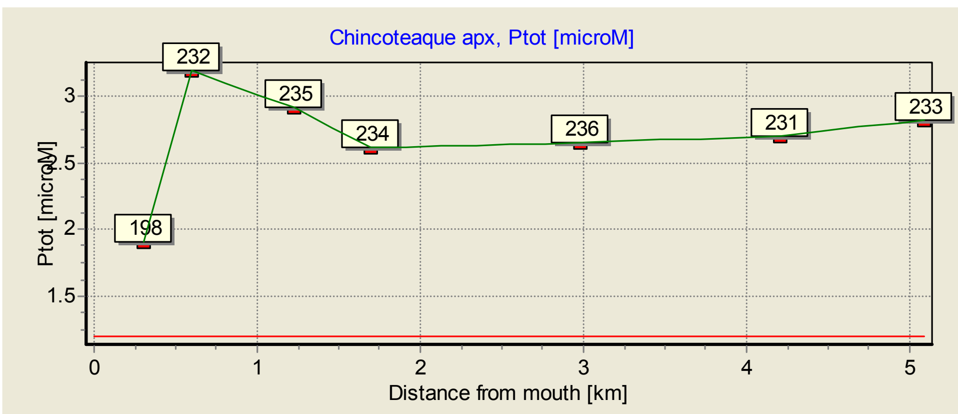
Region: Chincoteague Inlet

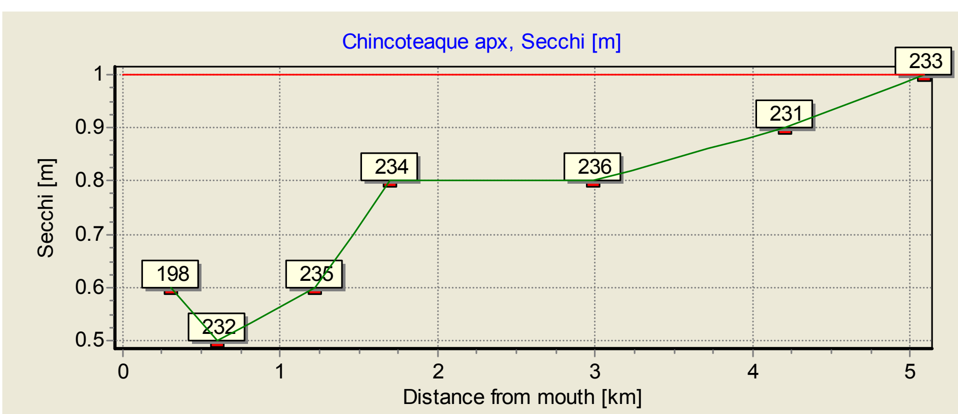




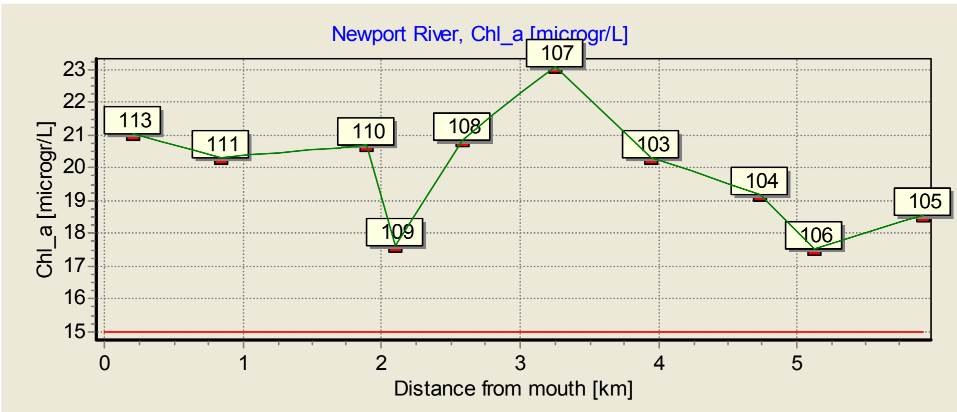


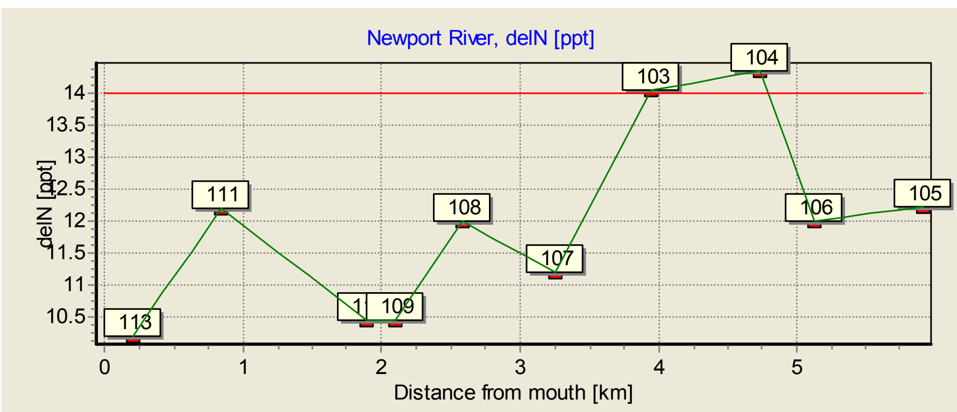

Chincoteaque apx, Ntot [microM]
Ntot [microM]
45
40
35
30
25
20
0
1
2
3
4
5
Distance from mouth [km]
198
232
235
234
236
231
233

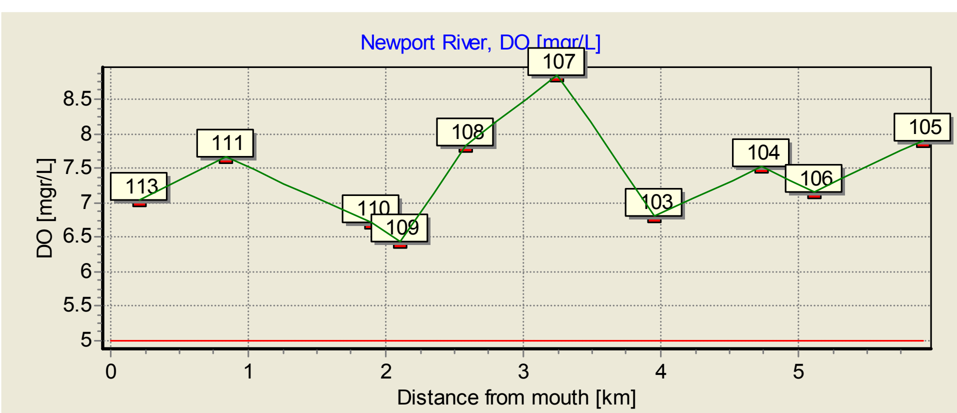

Chincoteaque apx, Ptot [microM]
Ptot [microM]
3
2.5
2
1.5
0
1
2
3
4
5
Distance from mouth [km]
232
235
234
236
231
233
198

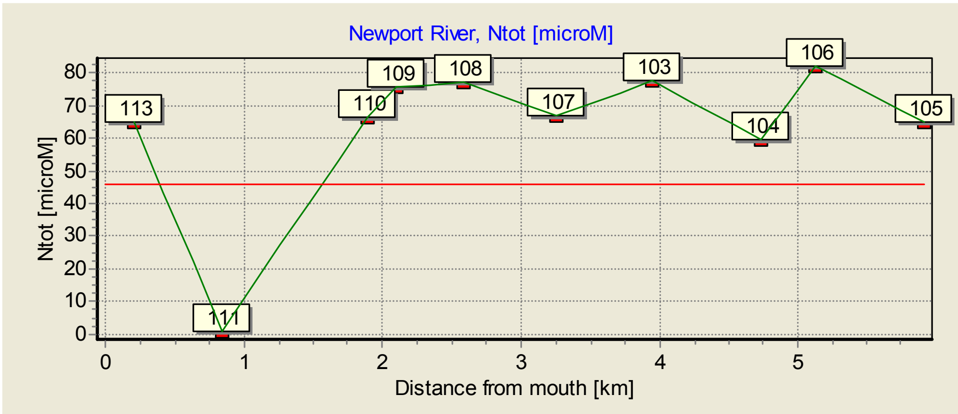

Chincoteaque apx, Secchi [m]
Secchi [m]
1
0.9
0.8
0.7
0.6
0.5
0
1
2
3
4
5
Distance from mouth [km]
233
231
234
236
198
235
232

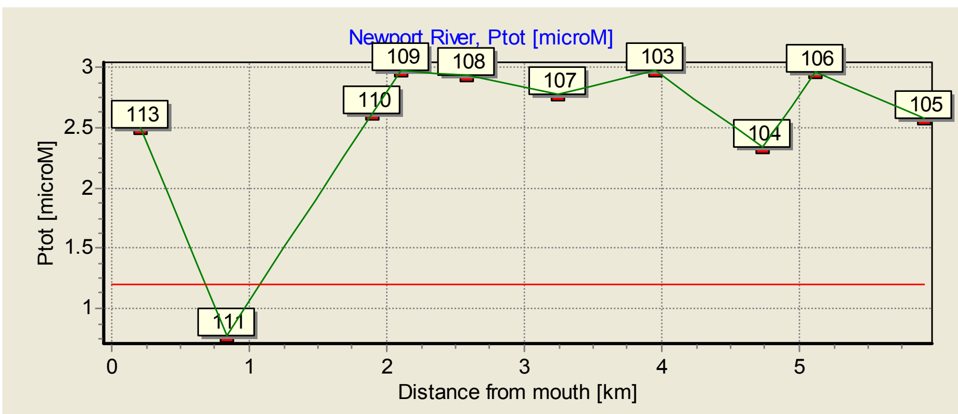
Region: Newport River

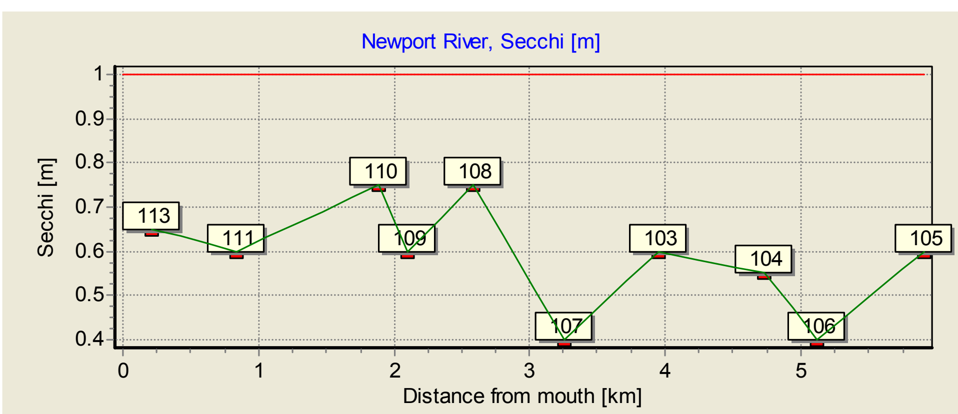




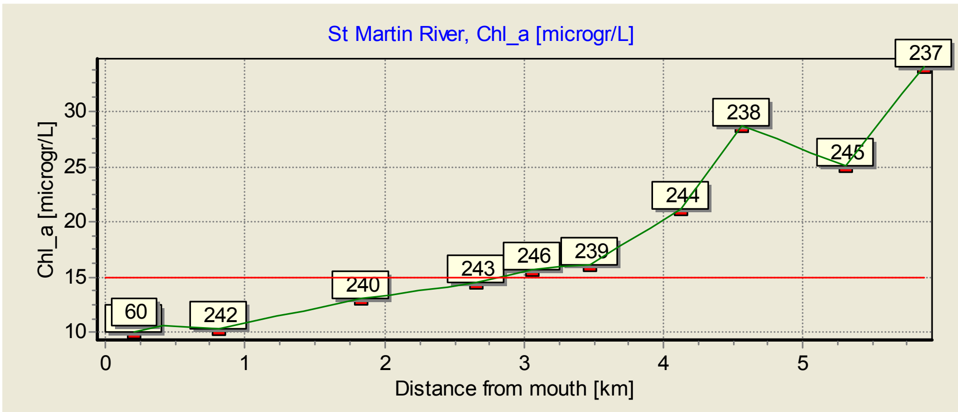


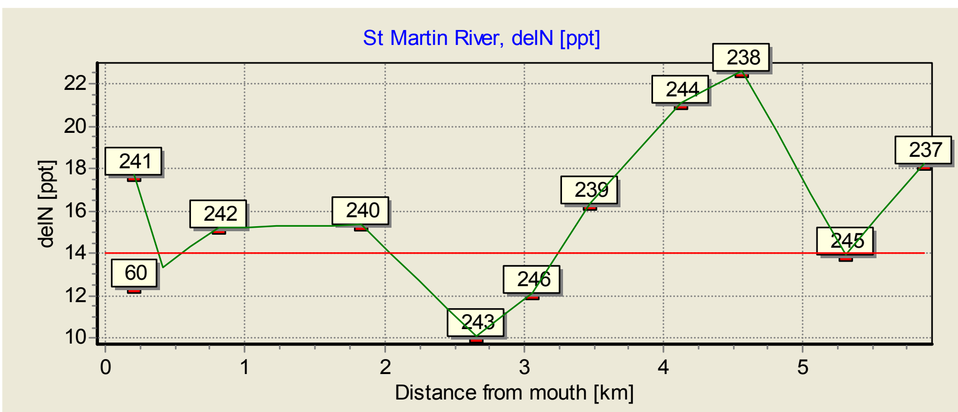

Newport River, Ntot [microM]
Ntot [microM]
Distance from mouth [km]
113
111
110
109
108
107
103
104
106
105

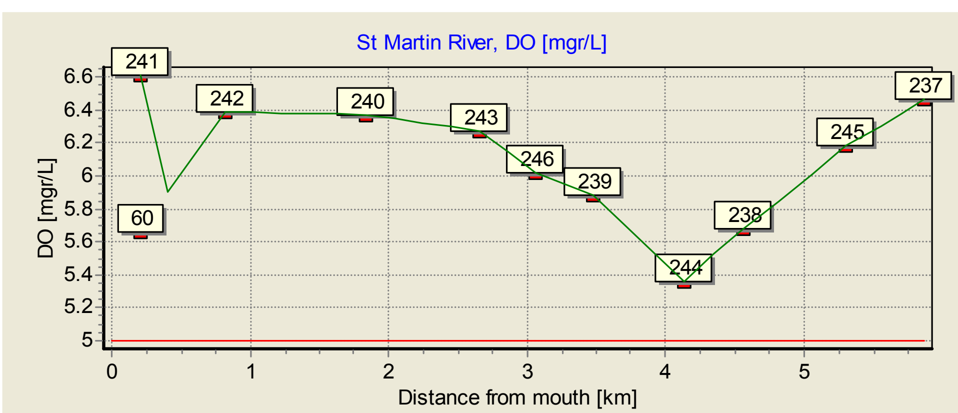

Newport River, Ptot [microM]
Ptot [microM]
Distance from mouth [km]
113
111
110
109
108
107
103
104
106
105

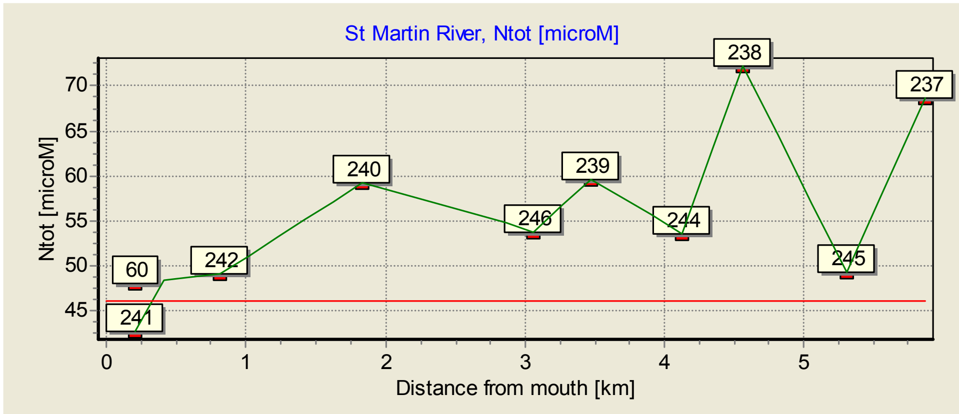

Newport River, Secchi [m]
Secchi [m]
Distance from mouth [km]
113
111
110
109
108
107
103
104
106
105

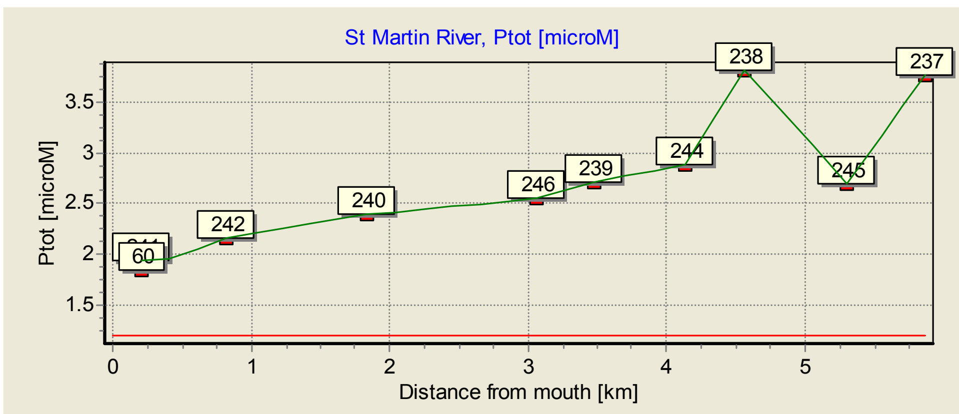
Region: St Martin River

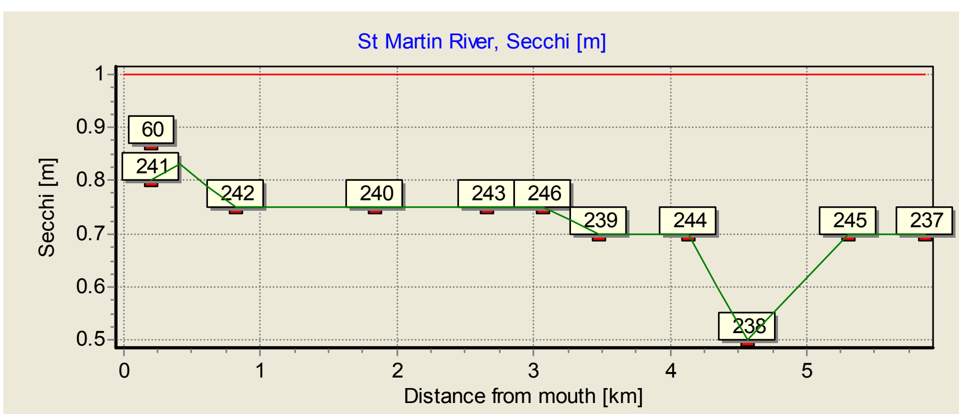







St Martin River, Ntot [microM]
Ntot [microM]
Distance from mouth [km]
238
237
240
239
246
244
60
242
245
241


St Martin River, Ptot [microM]
Ptot [microM]
Distance from mouth [km]
238
237
244
239
246
245
240
242
60


St Martin River, Secchi [m]
Secchi [m]
Distance from mouth [km]
60
241
242
240
243
246
239
244
245
237
238

Appendix 2 – Water Quality Data

			SURFACE				BOTTOM									Macroalgal	
ID	LAT	LONG	TEMP	PH	SALINITY	DO	TEMP	PH	SALINITY	DO	Secchi	Chl a	fya	Tot N (µM)	Tot P (µM)	%N	del N
2	38.17536	75.21738	23.35	8	26.87	5.74	23.3	7.99	26.87551	5.34	0.7	16.248	5.558	57.7	3.13	1.99	14.08
3	38.18904	75.19593	24.32	8.21	27.34	5.24	24.28	8.22	27.35148	5.1	0.7	15.140	5.287	58.7	3.30	1.26	11.82
4	38.1906	75.19371	24.32	8.32	27.68	5.57	24.3	8.33	27.66883	5.28	0.8	11.632	3.968	54.4	2.77	1.42	12.11
6	38.20628	75.17987	22.8	8.29	28.00	10.01	22.8	8.29	28.1	9.81	0.5	8.770	2.693	46.3	2.68	3.50	11.88
7	38.19814	75.19501	23	8.23	27.80	9.73	22.9	8.24	27.8	9.65	0.4	19.480	4.826	53.7	3.13	1.89	12.19
8	38.19959	75.18553	23.5	8.47	27.90	12.93	23.5	8.49	27.9	12.99	0.5	19.387	5.005	51.1	3.04	1.56	11.75
9	38.2035	75.18536	22.4	8.24	28.30	9.86	22.3	8.24	28.3	9.68	0.6	20.218	3.657	44.0	2.645	1.14	12.47
10	38.20686	75.18825	23.2	8.22	27.20	9.22	22.5	8.17	28	8.74	0.4	24.003	6.077	52.0	3.07	1.43	12.43
11	38.20899	75.18031	22.2	8.25	28.50	9.76	22.2	8.25	28.5	9.61	0.6	18.833	3.835	42.6	2.62	1.93	11.37
12	38.20975	75.17828	22.4	8.27	28.30	9.78	22.3	8.27	28.3	9.69	0.6	19.756	3.946	47.2	2.70	1.97	9.36
13	38.21083	75.17019	21.9	8.49	27.60	11.22	21.9	8.49	27.6	11.22	0.6	9.324	2.570	48.3	2.24	1.52	10.49
14	38.21315	75.16525	23.1	8.47	27.60	12.6	23.1	8.47	27.6	12.6	0.6	12.002	3.168	45.5	2.22	1.59	10.46
15	38.21799	75.16501	22.6	8.32	28.20	10.41	22.5	8.34	28.2	10.23	0.8	12.463	3.051	34.6	1.98	1.15	9.35
16	38.22065	75.15932	21.9	8.24	28.80	10.7	too shallow				0.8	9.694	2.545	35.1	1.93	1.37	10.13
17	38.22596	75.15746	21.8	8.21	29.30	10.36	21.6	8.23	29.3	10.25	0.9	7.940	1.541	29.9	1.71	1.49	10.95
18	38.22779	75.15639	23.8	8.43	30.00	13.28	too shallow				0.4	5.059	1.250	23.4	1.36	1.48	10.61
19	38.24624	75.14193	26.6	8.37	27.40	4.39		8.38	27.4	5.16	0.75	8.124	2.563	48.7	2.46	0.88	10.02
20	38.24883	75.14132	25.9	8.2	27.30	4.71	25.9	8.2	27.3	4.67	0.65	13.109	4.129	51.7	2.98	2.24	11.75
21	38.2475	75.13871	26.1	8.3	27.50	4.14	26.1	8.3	27.5	4.05	1	7.201	2.452	38.8	1.92	0.86	9.87
22	38.25564	75.13499	26.3	8.26	27.50	4.49	26.3	8.28	27.5	4.41	0.75	9.786	3.487	44.7	2.48	0.88	14.09
23	38.26802	75.12887	25.7	8.21	27.80	3.96	22.7	8.02	29.6	4.75	1	9.140	2.582	36.3	2.11	1.07	10.43
24	38.27805	75.12652	24.7	7.92	28.00	3.38	21.3	7.95	29.7	4.99	1.1	6.370	2.852	38.7	2.21	1.02	12.50
25	38.29566	75.12283	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
26	38.32572	75.09484	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
27	38.32301	75.09031	18.3	8.03	30.70	6.48	18.2	8.04	30.7	6.41	1.75	1.763	0.000	69.5	1.44	2.59	11.85
28	38.32751	75.09155	17.9	8.01	30.80	6.28	17.9	8.01	30.8	6.28	1.75	2.262	2.565	18.0	1.05	0.28	13.94
29	38.32981	75.09095	17.9	8.03	30.80	7.74	18	8.01	30.8	7.64	1.9	1.616	1.065	14.5	0.90	1.83	14.71
30	38.33351	75.09174	17.9	8.02	30.80	8.02	nd	nd	nd	nd	nd	2.188	1.329	27.2	1.25	2.47	13.71
31	38.34523	75.09179	18	8.01	30.80	7.86	18	8.02	30.8	7.8	1.5	1.8741	1.2632	17.0	0.87	1.53	19.02

32	38.35645	75.08788	19.1	7.99	30.50	7.67	19	8	30.5	7.66		3.342	1.752	15.2	0.95	1.90	15.95
33	38.36253	75.0878	18.5	8	30.70	7.94	18.5	8.01	30.7	7.96	1.25	3.120	1.732	18.1	1.04	1.19	23.36
34	38.36638	75.09545	19.6	7.57	30.50	7.65	19.6	7.96	30.5	7.68	1.5			18.7	0.99	1.86	15.86
35	38.37187	75.09369	21.4	7.78	30.00	7.11	21.4	7.74	30	7.25	1.75	1.846	1.291	18.8	1.15	1.65	14.79
36	38.36614	75.08262	20.7	7.72	30.20	7.23	20.7	7.73	30.2	7.3	1.8	1.782	1.674	0.7	0.69	1.25	16.26
37	38.37616	75.07577	23.9	7.81	29.70	6.67	19.7	7.73	30.5	6.88	1.9	2.788	1.159	21.9	0.91	1.08	9.84
38	38.38487	75.08984	24.4	7.73	28.90	6.91	24.4	7.69	28.9	6.98	1	5.170	3.535	24.9	1.12	1.36	14.19
39	38.38778	75.08198	25.4	7.93	28.90	6.97	25.4	7.93	28.9	7.07	1.1	4.838	2.282	30.2	1.23	1.02	21.32
40	38.39471	75.081	25	7.6	28.10	6.91	25	7.67	28.1	6.93	1	5.632	2.987	33.6	1.26	1.23	12.25
41	38.40224	75.07458	24.7	7.59	27.40	6.3	24.8	7.63	27.5	6.16	1	5.622	2.230	30.9	1.09	1.93	11.33
42	38.40666	75.08444	24.7	7.54	27.30	7.17	24.8	7.59	27.4	7.23	0.8	6.555	3.874	46.7	1.77	1.42	14.58
43	38.4156	75.07837	24.6	7.49	26.20	6.78	26.2	7.54	26.2	6.9	1	6.278	2.169	46.3	1.51	0.87	11.26
44	38.41838	75.07074	25.1	7.51	27.10	6.5	25.1	7.51	27.1	6.5	1.1	8.678	0.889	45.1	1.65	1.17	15.19
45	38.43042	75.07006	25.2	7.52	26.10	6.74	25.2	7.52	26.1	6.74	1	7.386	3.647	43.7	1.38	1.20	11.67
46	38.43602	75.07692	25.1	7.54	25.90	6.95	25.1	7.54	25.9	6.95	0.8	10.801	2.213	56.2	1.83	1.24	14.47
47	38.44492	75.07083	25	7.43	25.10	6.15	25	7.44	25.1	6.14	0.75	9.786	2.453	58.4	1.73	1.44	11.62
48	38.44847	75.0796	25.3	7.43	25.00	6.61	25.1	7.48	24.9	6.54	0.75	6.832	1.701	64.1	1.58	1.45	11.23
49	38.44291	75.08488	24.8	7.44	24.70	6.76	24.8	7.44	24.7	6.76	0.8	11.632	2.244	58.0	1.64	2.08	11.63
50	38.44011	75.09263	23.9	7.33	25.10	6.62	23.9	7.33	25.1	6.62	0.75	9.786	2.108	43.7	1.30	1.79	11.33
51	38.43374	75.10467	24.1	7.47	25.00	6.62	24.4	7.5	25	6.28	0.9	10.894	2.380	43.7	1.38	1.13	17.49
52	38.4333	75.10986	25.1	7.5	24.80	6.18	25.2	7.56	24.7	6.3	0.75	10.248	1.991	55.2	1.75	1.47	10.91
53	38.42934	75.10701	25	7.47	25.40	6.56	24.9	7.5	25.4	6.64	0.8	9.324	2.570	51.1	1.73	1.58	10.49
54	38.41826	75.10213	24.7	7.38	26.00	6.27	24.7	7.43	26	6.33	0.4	10.709	1.444	55.7	2.27	1.79	11.75
55	38.42163	75.08759	24.5	7.49	26.40	7.12	24.5	7.54	26.4	7.16	0.8	12.556	2.528	52.7	1.91	1.18	10.53
56	38.3982	75.09668	24.7	7.41	27.10	6.52	24.7	7.46	27.2	6.47	0.7	9.417	4.460	36.9	1.67	1.35	17.87
57	38.38729	75.09887	24.3	7.47	27.80	6.88	24.3	7.5	27.8	6.99	0.75	9.140	3.186	34.6	1.57	1.79	13.89
58	38.3753	75.10554	23.1	7.48	28.90	5.98	23	7.52	29	7.02	0.8	5.078	3.628	32.3	1.81	1.90	14.70
59	38.38403	75.1133	24.6	7.5	27.70	6.81	24.6	7.55	27.7	6.91	1	8.863	3.204	25.0	1.25	1.17	16.99
60	38.39354	75.12345	25	7.51	26.70	5.66	25.1	7.53	26.8	6.64	0.87	10.709	3.943	48.0	1.85	2.10	12.45
61	38.38789	75.12249	24.5	7.49	27.40	6.82	24.6	7.55	27.4	6.86	0.9	10.340	6.381	38.8	2.12	1.82	14.76
62	38.37641	75.12263	23.9	7.53	28.40	6.81	23.9	7.56	28.3	6.97	0.65	8.493	4.349	37.4	2.35	1.82	15.55
63	38.37107	75.12006	22.8	7.5	29.10	6.85	23.1	7.53	29	6.53	0.5	6.555	3.012	28.4	2.34	1.95	18.44
64	38.36044	75.10722	18.8	7.62	30.60	7.51	18.8	7.62	30.6	7.38	2	1.228	1.125	15.7	1.25	1.26	15.55
65	38.35674	75.09924	18.9	7.8	30.50	8.77	18.9	7.82	30.6	8.81	1.5	3.277	2.273	17.3	1.12	2.24	15.97

66	38.35471	75.09362	19	7.82	30.50	8.6	19	7.83	30.5	8.76	1.1	3.730	2.700	18.8	1.12	1.80	13.92
67	38.33802	75.09582	19	7.8	30.50	8.68	19	7.81	30.5	8.63	0.9	3.997	0.045	17.8	1.30	2.64	11.82
68	38.33224	75.09523	19.1	8.11	30.50	8.78	19.1	7.82	30.5	8.8	1.1	4.265	3.561	15.1	1.20	2.52	13.46
69	38.32565	75.0997	18.9	7.78	30.50	8.44	18.9	7.82	30.6	8.54	1	4.182	1.739	13.1	1.08	1.68	15.52
70	38.3193	75.1059	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
71	38.31498	75.10877	18.9	7.79	30.60	8.51	18.9	7.84	30.6	8.47	1.1	4.634	2.157	15.2	1.13	1.83	14.06
72	38.30273	75.11493	18.9	7.83	30.60	8.3	18.9	7.84	30.6	8.51	1	6.176	0.297	14.1	1.11	2.26	11.55
73	38.28502	75.13027	18.6	7.79	30.70	8.16	18.6	7.81	30.7	5.1	1.1	1.985	3.023	12.8	1.00	0.94	10.92
74	38.28045	75.13419	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
75	38.26718	75.13613	18.7	7.83	30.60	8.58	18.7	7.83	30.6	8.58	1	4.330	2.574	14.8	1.11	1.15	12.80
76	38.26149	75.14286	18.7	7.73	30.70	7.75	18.7	7.73	30.7	7.63	0.9	2.345	2.939	15.3	0.98	1.18	12.24
77	38.25607	75.14272	18.7	7.8	30.70	8.23	18.7	7.81	30.7	8.21	1	2.585	2.259	16.4	0.95	1.93	10.94
78	38.25049	75.14912	19.9	7.78	30.30	8.96	19.9	7.86	30.3	8.02	0.75	4.117	2.295	24.6	1.53	1.45	10.91
79	38.24401	75.15201	17.9	7.48	30.50	7.71	18	7.63	30.6	7.74	1.25	2.807	0.796	18.5	1.23	1.82	12.74
80	38.23586	75.15668	18.6	7.61	30.20	7.3	18.6	7.61	30.2	7.3	0.6	4.524	0.000	19.9	1.36	1.14	11.85
81	38.23107	75.1605	18.5	7.72	30.30	7.56	18.5	7.72	30.3	7.56	0.6	3.951	1.065	17.1	1.25	1.58	10.48
82	38.22604	75.16624	18.6	7.76	30.20	7.45	18.6	7.78	30.2	7.32	0.8	4.976	1.324	22.5	1.48	1.44	10.42
83	38.21877	75.17702	19.1	7.77	30.00	7.6	19.1	7.8	30.1	7.67	1	7.053	0.000	24.9	1.81	0.72	13.79
84	38.22712	75.17878	18.7	7.77	30.00	7.5	18.9	7.8	30.1	7.26	1.1	5.281	2.114	24.0	1.52	1.56	11.15
85	38.22558	75.1819	20.4	7.8	28.60	6.81	19.8	7.83	29.3	7.24	0.75	14.310	3.704	40.1	2.22	1.78	12.86
86	38.22097	75.18297	20.1	7.83	28.90	7.18	20.1	7.85	29	7.41	0.75	14.679	2.818	39.2	2.15	1.39	10.39
87	38.21958	75.18965	22	7.87	27.30	6.92	22.1	7.9	27.7	6.89	0.55	23.819	2.814	56.6	3.27	1.20	10.69
88	38.2178	75.20219	23.2	7.85	25.60	5.94	23	7.89	25.6	5.89	0.65	17.356	5.312	63.2	2.74	1.52	9.67
89	38.20964	75.19736	21.6	7.92	26.60	6.52	21.8	7.94	36.9	6.64	0.3	23.726	0.407	63.2	3.12	1.57	10.26
90	38.20757	75.2007	26.6	8.07	26.64	5.57	26.09	8.09	26.67489	5.27	0.5	16.341	4.690	57.4	3.03	1.37	11.02
91	38.20783	75.20619	26.01	8.1	26.47	5.02	26.02	8.12	26.64614	5.01	0.55	20.310	5.116	59.7	3.36	0.99	13.65
92	38.20541	75.21346	26.45	8.11	25.96	5.09	26.48	8.12	26.07191	5.15	0.6	16.202	5.001	61.3	3.42	0.88	10.16
93	38.19267	75.21435	26.02	8.13	26.52	4.99	26.06	8.13	26.46654	4.95	0.55	18.141	5.001	60.4	3.58	0.71	10.28
94	38.20457	75.22983	26.39	8.12	24.92	5.58	26.33	8.12	25.02764	4.75	0.6	15.510	4.573	61.9	2.72	0.91	15.09
95	38.20991	75.2259	26.51	8.11	24.98	5.33	26.54	8.11	25.04192	5.3	0.65	14.679	4.111	63.1	2.80	1.03	9.30
96	38.2072	75.22116	26.55	8.13	25.02	5.61	26.56	8.14	25.08403	5.62	0.55	15.787	4.727	62.2	3.26	1.43	10.26
97	38.21075	75.21609	26.37	8.11	25.04	5.39	26.39	8.12	25.08474	5.43	0.65	17.172	4.721	61.9	3.12	0.43	12.02
98	38.21532	75.21227	23.1	7.87	25.50	5.97	23.1	7.87	25.5	5.91	0.6	13.109	4.560	59.5	2.75	1.42	11.38
99	38.22195	75.21101	23	7.83	25.40	6.01	23	7.82	25.4	5.87	0.6	18.279	4.992	61.5	2.68	1.13	10.57

100	38.22781	75.21507	22.7	7.81	24.60	6.24	22.7	7.8	24.7	5.97	0.6	20.033	3.669	65.6	2.69	1.51	13.38
101	38.2312	75.20916	22.8	7.85	24.80	6.56	22.8	7.85	24.9	6.37	0.6	22.711	5.473	66.2	2.70	1.61	13.62
102	38.22778	75.20008	23.4	7.89	25.40	6.13	23.4	7.89	25.4	6.13	0.6	18.741	4.617	66.2	2.99	1.87	10.39
103	38.25267	75.1899	22.1	7.78	21.50	6.92	22.2	7.79	22.1	6.8	0.6	20.310	1.754	77.5	2.97	1.96	14.03
104	38.25841	75.18713	21.6	7.65	19.50	7.52	21.6	7.65	19.5	7.52	0.55	19.203	1.052	59.6	2.34	1.94	14.34
105	38.2649	75.18027	22	7.86	20.90	7.9	22	7.86	20.9	7.9	0.6	18.556	4.025	64.8	2.57	1.97	12.21
106	38.26183	75.18602	22.2	7.83	21.10	7.16	22.2	7.83	21.1	7.16	0.4	17.541	1.249	82.1	2.96	1.69	12.00
107	38.25515	75.19682	23.5	7.87	19.20	8.85	23.5	7.87	19.2	8.85	0.4	23.080	5.104	66.9	2.77	1.77	11.20
108	38.24855	75.19966	23.1	7.88	23.10	7.89	23.1	7.89	23.1	7.84	0.75	20.864	1.373	77.3	2.93	1.44	11.98
109	38.24481	75.1998	22.3	7.81	22.90	6.43	22.4	7.82	22.9	7.22	0.6	17.633	0.000	75.5	2.97	2.17	10.45
110	38.24428	75.20384	22.9	7.81	24.00	6.95	22.9	7.82	24.1	6.72	0.75	20.680	0.178	66.6	2.62	1.90	10.44
111	38.24062	75.21072	23.2	7.99	24.50	7.77	23.3	8	24.5	7.66	0.6	20.310	0.117	0.8	0.78	1.36	12.18
112	38.24024	75.21656	23.2	8	24.50	7.88	23.1	8.01	24.5	7.74	0.65	21.049	4.722	66.7	2.91	1.38	11.71
113	38.23574	75.21686	23.3	7.99	25.00	7.05	23.2	8	25	7.11	0.65	21.049	5.411	64.9	2.50	1.50	10.19
114	38.23342	75.21932	23.2	8.01	24.80	7.52	23.1	8.02	24.8	7.47	0.6	19.572	6.458	60.8	2.70	1.39	10.60
115	38.23929	75.2233	23.2	8.03	24.60	7.69	23.1	8.04	24.6	7.64	0.6	20.403	4.506	66.4	2.70	1.22	11.61
116	38.23327	75.2252	23.2	8.03	24.20	7.9	23.1	8.04	24.3	8.05	0.6	23.542	5.332	69.9	2.86	1.89	10.32
117	38.23317	75.23134	23.2	8.04	24.20	7.9	23.2	8.04	24.2	7.77	0.6	20.403	4.420	66.4	2.91	1.59	9.80
118	38.22664	75.22386	23.3	8.02	24.70	7.48	23.2	8.03	24.7	7.34	0.6	14.864	0.000	65.5	2.87	1.48	12.08
119	38.21853	75.22009	26.65	8.11	24.66	5.39	26.62	8.11	24.87071	4.39	0.65	13.940	4.332	60.9	2.82	1.07	11.06
120	38.21785	75.22125	26.58	8.11	24.73	5.41	26.59	8.11	24.72814	5.4	0.6	8.124	2.650	60.4	2.65	nd	nd
121	38.22183	75.22634	26.47	8.1	24.88	5.41	26.48	8.09	24.84932	5.12	0.65	15.048	4.517	59.9	2.81	0.82	12.65
122	38.21959	75.2276	26.42	8.1	24.79	5.14	26.42	8.09	24.87784	4.99	0.65	13.940	5.366	60.3	2.75	1.01	11.96
123	38.21835	75.23141	26.33	8.09	24.91	4.93	26.33	8.09	24.9135	4.88	0.65	14.956	4.782	60.8	2.83	1.24	12.72
124	38.22621	75.23036	25.84	8.06	24.64	4.96	25.85	8.07	24.62128	4.78	0.6	14.771	4.363	60.6	2.74	nd	nd
125	38.22705	75.23269	25.82	8.07	24.65	4.99	25.81	8.07	24.69252	5.01	0.6	12.279	3.149	61.0	2.78	1.08	12.17
126	38.22778	75.23846	25.68	8.07	24.66	5.12	25.63	8.07	24.59991	5.15	0.55	17.172	4.979	61.6	2.86	1.13	11.06
127	38.22877	75.23956	25.43	8.02	24.38	4.93	25.41	8.02	24.40059	4.96	0.5	17.541	5.558	66.4	3.10	1.22	10.08
128	38.21582	75.24618	25.19	8	24.66	4.9	25.21	8	24.72814	4.96	0.5	28.527	6.035	68.2	3.41	0.94	12.27
129	38.20711	75.24761	25.35	8.06	24.77	5.34	25.35	8.06	24.77803	5.3	0.5	23.449	6.631	68.6	3.46	1.14	12.65
130	38.20421	75.24443	25.46	8.05	24.85	5.03	25.57	8.04	24.87784	4.96	0.5	23.634	6.877	65.3	2.98	1.23	10.57
131	38.20709	75.24006	25.37	8.07	24.77	5.34	25.36	8.08	24.76378	5.31	0.5	18.556	5.749	62.0	2.91	0.99	12.19
132	38.1977	75.24268	25.41	8.06	24.88	5.89	25.48	8.07	24.92777	5.43	0.5	22.358	5.661	64.5	3.07	1.01	12.06
133	38.19009	75.25323	25.14	8.04	25.16	5.31	25.07	8.05	24.9349	5.38	0.45	23.719	9.431	70.0	3.86	1.44	14.55

134	38.18763	75.24026	25.62	8.11	25.13	5.57	25.6	8.12	25.17755	5.56	0.5	15.694	4.302	64.5	3.18	0.63	10.95
135	38.18985	75.22872	26.04	8.14	25.42	5.46	26.05	8.16	25.34185	5.43	0.55	17.356	5.398	60.5	3.32	0.56	13.26
136	38.18193	75.23247	25.89	8.15	25.58	5.48	25.91	8.17	25.57779	5.46	0.5	17.927	6.050	62.9	3.32	1.03	8.94
137	38.17357	75.23425	25.56	8.14	25.55	5.49	25.51	8.16	25.56348	5.54	0.5	20.033	8.065	64.5	3.59	1.32	15.30
138	38.16325	75.22832	25.34	8.17	25.79	5.52	25.35	8.19	25.81397	5.49	0.5	19.538	6.695	61.6	3.58	1.19	11.33
139	38.17212	75.24263	25.49	8.13	25.66	5.09	25.52	8.14	25.59925	5.04	0.45	22.988	6.576	63.7	3.55	0.98	11.58
140	38.17147	75.25277	25.26	8.12	25.51	5.26	25.3	8.14	25.6064	5.19	0.45	15.048	4.345	62.3	3.44	0.97	11.79
141	38.1586	75.2553	25.3	8.14	25.86	5.21	25.32	8.17	25.89276	5.16	0.5	25.480	7.617	63.7	4.11	0.87	11.89
142	38.15389	75.2535	25.31	8.16	25.87	5.35	25.34	8.19	25.94291	5.27	0.55	26.477	6.413	63.9	3.97	0.72	10.29
143	38.14176	75.26765	25.15	8.14	26.57	5.12	25.19	8.17	26.63177	4.99	0.5	28.435	7.421	63.5	4.04	nd	nd
144	38.13087	75.27813	25.4	8.16	26.78	5.1	25.43	8.18	26.8043	5	0.5	25.480	7.272	64.5	4.18	nd	nd
145	38.12075	75.28352	25.16	8.13	27.06	5.13	25.19	8.15	27.07774	5.08	0.4	29.912	8.098	63.9	4.69	0.82	13.15
146	38.10817	75.29149	24.42	8.11	27.08	5.03	24.37	8.11	27.04894	5.06	0.4	34.026	10.743	68.8	5.52	1.68	12.43
147	38.1027	75.28299	25.34	8.02	27.96	4.77	25.38	8.08	27.95769	4.76	0.45	31.435	13.556	64.3	4.83	0.74	9.29
148	38.09935	75.26868	25.17	8.15	27.79	5.15	25.2	8.16	27.806	5.17	0.45	27.327	7.236	58.9	4.19	1.06	11.29
149	38.09684	75.26441	24.8	8.17	27.86	5.28	24.88	8.18	27.76267	5.3	0.45	30.909	7.980	61.3	4.57	0.95	16.29
150	38.09844	75.2615	24.88	8.18	27.60	5.32	24.8	8.19	27.78434	5.35	0.45	26.773	7.445	60.0	3.81	1.48	10.23
151	38.10586	75.25398	25.06	8.21	27.93	5.46	25.04	8.23	27.87822	5.35	0.55	24.834	6.108	58.8	3.72	1.40	11.09
152	38.11559	75.2601	24.9	8.18	27.28	5.15	24.9	8.2	27.28662	5.05	0.45	31.241	7.958	62.4	4.14	1.15	10.67
153	38.12532	75.24334	25.35	8.2	26.78	5.11	25.37	8.23	26.84026	5	0.45	23.726	7.733	60.4	3.63	0.74	10.75
154	38.12716	75.23733	25.52	8.19	27.09	5.61	25.55	8.22	27.14254	5.15	0.5	24.003	6.336	59.2	4.02	0.70	10.76
155	38.12098	75.23043	24.94	8.25	27.31	5.73	24.95	8.26	27.30103	5.74	0.5	24.280	6.662	58.9	3.96	0.91	11.27
156	38.10763	75.24662	25.05	8.21	27.52	5.8	25.08	8.24	27.59667	5.54	0.5	25.942	7.931	59.6	4.02	1.16	11.82
157	38.10164	75.24767	25.05	8.21	28.07	5.58	25.05	8.24	28.0661	5.43	0.5	24.188	6.496	58.5	3.39	0.85	11.07
158	38.08296	75.26757	25.19	8.17	29.26	4.92	25.2	8.2	29.35606	4.74	0.6	12.556	5.027	53.2	2.96	1.00	11.16
159	38.05708	75.28186	25.25	8.12	29.44	4.95	25.32	8.15	29.27616	4.57	0.5	18.741	5.823	51.3	3.13	1.22	10.70
160	38.05473	75.28631	25.24	8.13	29.99	5.38	25.26	8.13	29.99614	4.94	0.55	15.971	6.266	48.8	2.89	0.77	10.96
161	38.05671	75.2974	25.11	8.06	29.82	4.88	25.14	8.07	29.78504	4.73	0.6	19.941	6.174	51.8	3.32	1.10	9.78
162	38.08138	75.29115	25.1	8.07	28.48	4.93	25.12	8.08	28.18902	4.83	0.45	27.419	9.212	63.7	3.97	1.06	11.33
163	38.09421	75.29278	22.24	8.02	27.09	5.66	22.33	8.02	28.39884	5.32	0.4	37.790	9.787	62.9	4.15	1.72	12.41
164	38.09819	75.31121	21.73	7.85	28.25	4.82	21.8	7.82	28.30476	4.66	0.6	21.049	9.549	52.8	2.72	1.04	13.33
165	38.08757	75.32906	20.93	7.89	28.39	5.72	20.91	7.9	28.50019	5.65	0.6	29.081	9.791	51.5	3.27	0.53	12.04
166	38.07552	75.32113	21.24	7.91	28.67	5.65	21.29	7.91	28.87701	5.59	0.5	29.635	11.650	56.8	3.55	1.16	10.39
167	38.07311	75.34922	21.49	7.78	29.49	5.23	21.57	7.74	29.5741	5.12	0.5	4.579	2.092	49.2	1.83	0.90	17.82

168	38.04916	75.35472	20.48	7.83	30.52	5.43	20.48	7.8	30.56474	5.35	0.55	10.617	4.984	45.2	2.46	1.27	16.84
169	38.04647	75.35181	20.37	7.87	30.10	5.5	20.38	7.86	30.17825	5.47	0.45	20.495	8.034	48.2	2.92	1.01	17.04
170	38.05972	75.3388	21.62	7.92	30.08	5.56	21.69	7.94	30.09082	5.36	0.5	24.096	8.743	52.1	3.57	0.83	17.15
171	38.04967	75.32148	nd	nd	nd	nd	nd	nd	nd	nd	0.4	26.627	11.841	53.6	3.64	1.35	11.88
172	38.03964	75.3221	nd	nd	nd	nd	nd	nd	nd	nd	0.4	28.158	9.766	49.9	3.60	1.05	10.71
173	38.03074	75.33023	22.51	7.93	32.18	5.39	22.52	7.93	32.21863	5.3	0.5	27.696	8.590	41.2	3.50	0.92	11.18
174	38.02797	75.34146	22.4	7.92	32.23	5.51	22.43	7.92	32.20396	5.39	0.55	29.727	10.007	42.0	3.50	1.04	9.45
175	38.02784	75.3492	22.31	7.93	31.65	5.45	22.33	7.93	31.71269	5.35	0.55	29.542	9.416	45.7	3.84	0.97	12.63
176	38.02357	75.36078	21.99	7.94	31.54	5.67	22.02	7.95	31.69071	5.37	0.55	26.588	7.802	45.5	3.93	0.63	11.60
177	38.02511	75.37399	21.74	7.88	31.16	5.32	22	7.87	31.31002	5.15	0.5	20.864	7.665	42.1	3.12	1.14	10.55
178	38.00596	75.37214	22.69	7.89	31.96	5.33	22.79	7.89	31.94723	5.14	0.5	27.973	10.985	45.6	4.17	1.09	11.71
179	38.00074	75.38816	22.26	7.87	31.28	5.32	22.43	7.86	31.31002	5.21	0.45	24.981	9.191	46.2	3.44	1.02	16.37
180	37.98061	75.40104	22.03	7.88	31.24	5.23	22.06	7.86	31.32466	5.12	0.5	9.786	4.866	31.8	2.82	1.20	17.31
181	37.97063	75.41979	21.65	7.85	31.10	5.32	21.65	7.83	31.11986	5.21	0.4	4.293	3.249	31.8	2.50	1.19	18.27
182	37.95963	75.4211	21.15	7.85	31.54	5.36	too shallow for bottom readings				0.5	15.510	6.296	37.7	3.75	1.89	13.14
183	37.96358	75.40454	21.68	7.85	31.05	5.9	21.67	7.84	31.05407	5.73	0.5	6.278	4.496	30.6	2.63	1.04	17.34
184	37.96062	75.39085	21.81	7.84	31.13	5.5	21.8	7.84	31.14911	5.41	0.5	4.524	4.612	28.4	2.35	1.79	13.21
185	37.9571	75.39169	21.61	7.84	31.07	5.65	21.63	7.82	31.05407	5.53	0.5	4.616	5.037	28.5	2.32	1.18	24.19
186	37.95446	75.37245	22.47	7.86	31.93	5.61	too shallow for bottom readings				0.6	5.170	3.535	26.5	2.98	1.56	13.95
187	37.94674	75.37773	22.16	7.87	31.81	5.78	22.15	7.85	31.41979	5.76	0.5	6.001	4.514	29.4	2.96	nd	nd
188	37.95511	75.36191	23.46	7.93	32.24	6.57	23.36	7.9	32.18928	6.38	1.1	5.364	1.437	15.8	2.09	1.36	19.46
189	37.94739	75.36224	23.48	8.12	32.20	7.87	too shallow for bottom readings				2	0.822	0.394	16.0	1.49	1.11	14.23
190	37.9499	75.37985	22.4	7.87	31.67	5.78	22.42	7.87	31.9179	5.8	0.5	5.262	4.219	30.1	2.89	1.14	24.28
191	37.96912	75.38009	23.85	7.99	32.54	5.97	23.75	7.98	32.5417	5.72	0.7	4.838	2.109	26.3	2.42	0.95	24.01
192	37.97915	75.38569	23.89	7.93	32.42	7.18	23.88	7.94	32.45356	6.92	0.6	16.987	4.905	28.6	2.86	1.12	26.39
193	37.97781	75.36416	23.42	8.09	32.27	7.57	23.46	8.11	32.29937	7.65	1	4.930	1.155	19.3	2.02	1.02	11.10
194	37.97558	75.36332	23.01	8.06	31.30	7.27	23.01	8.06	32.15259	7.29	0.9	4.893	1.227	19.9	2.05	1.18	12.22
195	37.96473	75.36038	23.25	8	32.32	6.32	23.25	7.99	32.30671	6.23	0.7	3.665	1.058	19.0	1.88	0.93	13.20
196	37.96831	75.33801	23.79	8.1	32.63	8.06	23.79	8.11	32.76953	8.04	2	1.523	0.606	22.6	1.42	1.12	19.25
197	37.98243	75.33026	24.4	8.14	nd	nd	too shallow for bottom readings				1.5	1.911	0.485	18.1	2.12	1.16	15.07
198	37.99037	75.31161	23.99	8.09	26.53	7.2	24	8.13	32.62987	8.26	0.6	11.817	4.387	35.0	1.91	1.53	20.54
199	37.9889	75.32451	24.8	8.21	nd	8.19	too shallow for bottom readings				1.5	2.363	0.645	23.7	2.10	1.01	10.77
200	37.98886	75.33321	nd	nd	nd	nd	nd	nd	nd	nd	1.1	2.197	0.664	19.2	1.83	1.00	12.41
201	37.99704	75.35688	22.7	8.05	32.48	5.4	22.82	8.08	32.50497	5.27	0.55	3.951	3.220	27.7	2.49	1.29	20.57

202	38.00456	75.33708	22.55	8.03	32.69	5.67	22.48	8.05	32.76953	5.64	0.7	8.401	2.804	28.7	2.80	1.53	12.38
203	38.0059	75.3108	nd	nd	nd	nd	nd	nd	nd	nd	0.7	11.817	3.870	33.2	2.70	1.08	11.84
204	38.00728	75.28996	nd	nd	nd	nd	nd	nd	nd	nd	0.8	6.573	2.029	31.2	2.04	0.71	9.47
205	38.01548	75.30059	nd	nd	nd	nd	nd	nd	nd	nd	0.55	16.618	5.964	35.5	2.44	1.37	13.73
206	38.02263	75.30383	nd	nd	nd	nd	nd	nd	nd	nd	0.7	22.434	9.198	43.1	3.00	1.20	10.60
207	38.02299	75.30763	nd	nd	nd	nd	nd	nd	nd	nd	0.5	22.157	8.182	44.0	3.65	0.95	11.35
208	38.03644	75.30801	nd	nd	nd	nd	nd	nd	nd	nd	0.5	26.311	9.027	43.5	3.51	1.11	12.39
209	38.02849	75.29803	nd	nd	nd	nd	nd	nd	nd	nd	0.6	20.587	8.028	42.6	3.22	1.41	12.02
210	38.02596	75.29027	nd	nd	nd	nd	nd	nd	nd	nd	0.6	13.294	5.151	42.0	2.90	0.85	13.34
211	38.03062	75.27772	nd	nd	nd	nd	nd	nd	nd	nd	0.6	9.232	3.438	38.1	2.40	1.31	9.82
212	38.04678	75.26563	nd	nd	nd	nd	nd	nd	nd	nd	0.7	8.586	3.308	40.5	2.50	1.64	10.55
213	38.04117	75.27449	nd	nd	nd	nd	nd	nd	nd	nd	0.7	13.202	4.984	43.8	2.76	0.84	11.24
214	38.06855	75.26093	24.04	8.15	30.61	5.25	too shallow for bottom readings				0.9	7.201	2.625	42.7	2.57	1.21	9.96
215	38.05914	75.26822	25.36	8.21	30.03	4.96	25.4	8.19	30.34591	4.5	0.8	9.140	4.047	44.6	2.66	1.26	10.78
216	38.07161	75.28426	25.03	8.09	28.88	5.18	25.03	8.09	28.91327	4.87	0.5	25.850	6.558	59.9	4.20	0.70	10.60
217	38.08049	75.2571	25.17	8.28	29.96	5.28	25.16	8.31	29.96701	5.11	0.7	12.832	3.975	50.0	2.75	0.96	11.06
218	38.08839	75.27821	25.02	8.16	28.10	5.48	24.98	8.17	28.02996	5.37	0.5	25.388	7.450	59.8	4.04	0.77	11.07
219	38.09809	75.28525	24.87	8.1	27.86	5.34	24.91	8.11	27.79878	5.05	0.5	28.988	10.314	63.3	4.46	0.68	11.74
220	38.09581	75.22051	24.52	8.32	30.00	5.61	24.51	8.33	30.11996	5.18	1.1	9.324	3.001	49.4	2.52	1.43	11.58
221	38.10681	75.21622	23.88	8.3	28.84	5.03	too shallow for bottom readings				1	8.124	3.081	53.2	2.76	1.21	10.10
222	38.11574	75.22007	24.9	8.28	27.88	5.45	24.93	8.3	27.93601	5.32	0.7	23.357	6.465	57.8	3.56	nd	nd
223	38.11762	75.2171	24.95	8.3	28.05	5.39	24.97	8.32	27.94324	5.19	0.6	21.049	6.877	55.1	3.22	nd	nd
224	38.12168	75.19824	25.12	8.25	28.65	5.52	too shallow for bottom readings				0.6	14.402	5.163	61.5	2.79	1.19	9.26
225	38.14162	75.22814	25.23	8.19	27.13	4.71	25.46	8.21	26.50964	4.64	0.55	19.018	5.632	60.7	3.70	1.11	11.51
226	38.14395	75.21521	25.14	8.17	27.08	4.95	25.18	8.19	27.15695	4.79	0.55	15.325	5.878	58.0	3.33	0.75	11.23
227	38.14284	75.21294	24.87	8.16	27.42	4.89	24.87	8.17	27.38031	4.72	0.7	10.801	4.368	57.0	3.29	1.01	14.28
228	38.14701	75.2139	24.72	8.16	27.31	4.98	24.74	8.17	27.23546	4.76	0.8	14.494	5.329	61.5	3.42	0.96	11.89
229	38.15894	75.20428	23.23	8.2	27.88	5.34	too shallow for bottom readings				0.75	12.186	3.414	57.3	3.23	0.87	12.22
231	37.96475	75.3257	24.23	8.1	31.59	7.63	24.35	8.13	31.55888	9.42	0.9	6.195	0.520	21.0	2.70	1.71	11.84
232	37.98523	75.30817	24.04	8.11	32.64	7.23	24.04	8.12	32.65192	7.19	0.5	18.372	5.762	39.8	3.19	1.39	17.62
233	37.95589	75.32513	23.82	8.07	31.38	7.79	21.14	8.13	31.41979	8.59	1	2.142	0.918	20.0	2.82	1.72	10.24
234	37.97545	75.30887	24.03	8.03	32.54	6.99	24.02	8.03	32.03449	6.98	0.8	5.428	1.225	27.1	2.61	1.35	11.71
235	37.97974	75.30824	24.44	8.07	32.56	7.32	24.51	8.08	32.60783	7.17	0.6	14.956	5.299	33.9	2.91	1.08	13.90
236	37.97189	75.32061	24.55	8.12	31.73	7.74	24.59	8.12	31.83727	7.38	0.8	2.650	1.005	20.0	2.65	1.41	13.22

237	38.41028	75.17236	25.4	7.67	23.40	6.46	25.4	7.6	23.4	6.6	0.7	34.066	7.995	68.6	3.76	1.20	18.27
238	38.41028	75.16034	25.6	7.63	23.80	6.01	25.6	7.65	23.8	5.68	0.5	28.712	6.713	72.2	3.81	1.14	22.61
239	38.40505	75.15232	25.3	7.56	24.90	6.06	25.3	7.55	25	5.88	0.7	16.156	3.926	59.6	2.71	1.40	16.34
240	38.40121	75.13645	25.2	7.56	25.40	6.37	25.2	7.56	25.4	6.37	0.75	13.109	3.698	59.2	2.39	1.37	15.35
241	38.39406	75.12337	25	7.51	26.70	6.64	25.1	7.52	26.7	6.61	0.8	10.063	4.762	42.7	1.94	1.19	17.74
242	38.39703	75.12895	25.1	7.51	26.00	6.39	25.1	7.54	26.1	6.47	0.75	10.340	4.399	49.1	2.16	1.94	15.21
243	38.40313	75.14412	25.2	7.54	25.10	6.41	25.2	7.56	25.2	6.27	0.75	14.494	4.209	nd	nd	2.13	10.09
244	38.40766	75.15598	25.6	7.5	24.20	5.36	25.6	7.54	24.2	5.59	0.7	21.141	6.698	53.6	2.88	1.05	21.09
245	38.41062	75.16591	25.6	7.69	23.40	6.41	25.6	7.67	23.4	6.18	0.7	25.111	4.883	49.2	2.70	1.62	13.91
246	38.404	75.14813	25.3	7.54	24.80	6.02	25.3	7.57	24.8	6.07	0.75	15.694	6.887	53.8	2.55	1.38	12.14
Ayers	38.29443	75.16294	26.7	7.51	7.70	6.47	25.4	7.07	8.7	3.86	0.03	25.757	7.857	76.7	2.73	5.14	13.33
Deals	38.31391	75.19192	20.3	6.9	0.00	6.54	too shallow				0.1	2.908	2.953	113	3.04	1.46	13.45
Hayes	38.28565	75.20675	27.5	8.75	2.70	11.53	25.8	7.93	3.6	9.82	0.25	49.760	9.969	98.5	4.15	1.57	11.66
Marshall	38.25296	75.26946	16.7	6.86	0.00	6.92	too shallow				0.3	0.247	0.504	417	3.20	2.50	13.88
Poplar	38.29045	75.22869	18.7	6.45	0.00	1.16	too shallow				0.05	1.025	2.242	174	2.69	2.71	18.41

Appendix 3 – Photos

Plate 2. Close up of the macroalgal $\delta^{15}N$ incubation rig with buoy, perforated macroalgal chamber, sinker and bricks.

Plate 3. The Maryland Coastal Bays receive nutrient inputs from a variety of non-point (diffuse) and point sources such as this golf course.

Plate 4. Parts of the Maryland Coastal Bays are choked with blooms of macroalgae, in particular, the Chincoteague Inlet.

Plate 5. Parts of the Maryland Coastal Bays contain healthy seagrass beds – these beds are on the eastern side of Chincoteague Bay.

Plate 6. Comparison of natural eroding coastlines in Chincoteague Bay (top) and the highly modified coastline near Ocean City (bottom).

Appendix 4 – Other resources for assessing nutrient sources and ecosystem health and development of environmental report cards

All these resources, including this report, are available on the Integration and Application Network website http://ian.umces.edu. In particular, visit our 'Maryland Coastal Bays', 'Chesapeake Bay Report Card' and 'Assessment and Prediction' pages – found in the 'Chesapeake Projects' section. There are also several related PowerPoint presentations under 'Publications / Presentations'.

Developing a Chesapeake Bay Report Card

November 2003

http://ian.umces.edu/newsletters.htm

This newsletter details the importance of developing a scientifically rigorous, spatially explicit ecosystem health report card on Chesapeake Bay and its watershed to facilitate coordination and feedback between monitoring, management and research. A pilot study was conducted in July 2003 on the Patuxent and Choptank Rivers using a novel stable isotope technique (see "Assessing Nutrient Sources" newsletter below) together with more traditional water quality monitoring techniques. Spatial statistical analysis and mapping was conducted and an Ecosystem Health Index (EHI) developed. From these, report card values (A to F) were determined for various reporting regions within the rivers and compared to a region near the mouth of Chesapeake Bay. A spatially explicit index of ecosystem health such as this is a useful monitoring tool which can help focus management and research efforts by providing rapid, effective and timely feedback on the health of Chesapeake Bay.

Developing a Chesapeake Bay Report Card

Jan 29-30th, 2004 4th National Conference on Science, Policy and the Environment 'Water for a Sustainable and Secure Future', Washington, DC

http://ian.umces.edu/posters.htm

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Assessing Nutrient Sources

Feb 2003

http://ian.umces.edu/newsletters.htm

This IAN newsletter explores the assessment of nutrient sources using stable isotope signatures of various marine organisms. This technique was developed in Moreton Bay, Australia for mapping sewage plumes, and was also used to determine the extent of aquaculture effluent (shrimp ponds) and to distinguish agricultural runoff (sugar cane) from other sources. The stable isotope ratio of nitrogen in organisms can be used to determine the influence of different nitrogen sources. A high ^{15}N signature (the ratio of ^{15}N to ^{14}N) typically indicates influence by sewage, septic or animal waste, whereas a low or negative $\delta^{15}N$ identifies fertilizer inputs. The technique, unlike traditional water quality measurements, detects only bioavailable nutrients and integrates nutrient history over time. This technique will be used in the Choptank and Patuxent Rivers during the Spring and Summer of 2003, with results made available on the IAN website.

Healthy Chesapeake Waterways

May 2002

http://ian.umces.edu/newsletters.htm

This science newsletter focuses on the role of the Integration and Application Network (IAN) in achieving healthy Chesapeake waterways. This is the first in a series of IAN newsletters on topical issues and is directed towards the scientific and technical audience. This newsletter identifies IAN's vision for *Healthy Chesapeake Waterways* and includes an overview of environmental problem solving, through transfer of data into information into knowledge and ultimately into problem solving. Fundamental to IAN's problem solving approach is the achievement of a balance between management, monitoring and research. The newsletter provides the scope for the core IAN projects for 2002-3, and begins to define what IAN will and will not attempt to accomplish, and identifies some of the challenges facing Chesapeake Bay.