Mass Balance Methods Report for the Delmarva Peninsula

Delmarva Land and Litter Collaborative

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The Delmarva Land and Litter Collaborative (DLLC) is a forum for diverse partners to identify solutions that support both healthy and productive ecosystems and farming and poultry on Delmarva. Our vision is that farming and poultry production on Delmarva are economically viable, environmentally sound and can serve as a national model.

DLLC Steering Committee

Delaware Center for the Inland Bays
Chesapeake Bay Commission
Chesapeake Bay Foundation
Delmarva Poultry Industry, Inc.
Eastern Shore Land Conservancy
Harry R. Hughes Center for Agro-Ecology
Hutchison Brothers
Maryland Department of Agriculture
Maryland Grain Producers Utilization Board
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Sustainable Chesapeake
The Nature Conservancy
Tyson Foods, Inc.
U.S. Environmental Protection Agency
University of Maryland Extension
Virginia Department of Environmental Quality
West/Rhode Riverkeeper

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Executive Summary

A mass balance study was conducted over the course of three years by members of the Delmarva Land and Litter Collaborative (DLLC), a group that formed in 2015 to develop new approaches to tackle poultry litter challenges and protect the Delmarva Peninsula's waterways. The DLLC is composed of representatives from the farming community, environmental groups, poultry companies, agricultural businesses, academic institutions, and government agencies. The purpose of the study was to determine to what extent, if any, available poultry litter nutrients exceeded local crop demand for fertilizer at a county-level on the Delmarva to inform policies and programs for poultry litter and protect water quality.

DLLC identified the need for a mass balance for several reasons. With increasing interest and support for litter to energy plants on Delmarva, there was a need for more information on the amount of litter available to meet the various options under discussion. Additionally, members wanted information specific to Delmarva to better account for nutrient application and crop uptake rates. Lastly, through outreach and internal discussions, DLLC identified the transportation of poultry litter from areas with surpluses to areas in need of organic fertilizer as a priority. A mass balance analysis was necessary to provide a roadmap for corresponding transportation programs.

The study was conducted through a collaborative process where researchers and stakeholders worked together to develop the methods, decide on assumptions, review the data, and write the report. The workgroup of seventeen people, representing environmental and agriculture interests, was led by three co-chairs also representing both interests. The data analysis team was composed of members of the Maryland Department of Agriculture, Delaware Department of Agriculture and the University of Delaware. The DLLC decided in advance to only release the results of this study if the full DLLC Steering Committee could reach a consensus in support of the final product.

The mass balance compared the amount of nitrogen (N) and phosphorus (P) applied to and utilized by crops, including biosolids, inorganic commercial fertilizer purchased for use on agricultural crops and nutrients generated from animal production. The analysis was performed for each county in portions of Maryland, Delaware, and Virginia that are on the Delmarva Peninsula.

Limitations to the analysis included limited data and the age of the 2012 USDA Agricultural Census, which was the primary dataset used for the mass balance. The analysis team applied several assumptions due to the limited data available. Ultimately, the workgroup could not find consensus on three of the assumptions and the DLLC Steering Committee made the decision to not release a report.

In lieu of a final report with results and data calculations, this report provides the background material, methods, assumptions, data sources and a brief discussion of the unresolved issues. The intent of releasing this report is to share information about methodology and lessons learned to inform future mass balance work on the Delmarva and elsewhere.

Literature Review

The nutrient balance approach has been applied at various scales throughout the world to identify areas where nutrient surpluses may be a problem and highlight the need for management solutions (see review in Sims et al. 2006). Historically, nutrient balances have been based on either a "crop removal" or "management oriented" approach. These approaches have disparate utility and should not be discussed interchangeably.

A "crop removal" approach is a measure of the nutrients leaving a field in the crop subtracted from the nutrient inputs. Where a surplus exists, more nutrients were applied than were removed by the crop, therefore the residual nutrient is either retained in the soil, immobilized, and/or lost via volatilization, denitrification, leaching, or runoff. A deficit in a crop removal approach means that after accounting for all the inputs, the removed crops contained more nutrients than the farmers applied during that growing season. Assuming no reduction in yield, this means that plants are tapping into residual soil P and N.

A "management-oriented" approach also called a "crop need" approach approximates the surplus or deficit of nutrients if all acres were grown following a nutrient management plan (NMP). In this case, the N and P recommended to attain economically optimum crop yields are subtracted from the estimates of nutrient inputs. This approach can also include consideration of residual soil nutrient values. A surplus in a "management-oriented" balance indicates more nutrients were available in a county than there was crop capacity to utilize those nutrients during the growing season, resulting in soil storage and increasing risk for environmental loss. Conversely, a deficit indicates less nutrients were available than were needed to achieve the optimum yield under favorable growing conditions.

Several studies have assessed county-level nutrient balances that included the Delmarva Peninsula using both the crop removal and management-oriented nutrient approaches.

USDA (2000) conducted an analysis of manure nutrients relative to the capacity of cropland and pastureland to assimilate nutrients at a county scale throughout the United States. They used data from the Census of Agriculture to estimate livestock populations (beef cattle, dairy cattle, swine, and poultry), quantities of manure produced, and land available for manure application for 1982, 1987, 1992, and 1997.

USDA (2000) estimated the excess of manure nutrients in each county by taking the sum of manure nutrients available for application in the county and subtracting the "assimilative capacity" of cropland and pastureland in the county. The assimilative capacity of cropland and pastureland was estimated to be the amount of nutrients taken up and removed at harvest for cropland ("crop removal") and the amount that could be applied to pastureland without accumulating nutrients in the soil. County-level excess nutrients were estimated assuming that all acres of crops and pastureland in a county are available for land application. Inputs from commercial fertilizer were not included in this analysis. Similarly, manure transport was also not included.

The Mid-Atlantic Water Program (MAWP) developed county- and state-level N and P nutrient budgets for agricultural cropland in Delaware, Maryland, Pennsylvania, Virginia and West Virginia (http://www.mawaterquality.agecon.vt.edu/) for intervals from 1939 to 2007. These nutrient budgets were developed to demonstrate general trends in cropland nutrient flows in the Mid-Atlantic region. The budgets were based on a "crop removal" approach similar to that used by USDA, but in addition to

manure nutrients, the inputs included inorganic fertilizer, and in some instances biosolids. Like the USDA study, manure nutrients were based on the U.S. Census of Agriculture (Census) inventory of animal numbers multiplied by the nutrient excreted (per animal per production period). The MAWP also estimated the amount of manure that was deemed "recoverable." Recoverable manure was assumed to be usable for cropland application or other distribution. Manure from animals that were not kept in confinement was not considered to be recoverable. For each type of crop, the annual nutrient harvested was calculated as quantity of crop harvested from the Census multiplied by the nutrient removed per yield unit ("crop removal"). There was no consideration given to transport of manure among counties. In addition, pasture acres were excluded from being eligible to receive nutrients.

Sims et al. 2008 conducted annual nutrient mass balance analyses for Delaware for 1996 to 2006 at statewide and county scales, for N and P. They used both the "crop removal" and "management-oriented" approaches. The "crop removal" approach estimated N and P from fertilizer, manure, and soils from biological N2 fixation and compared this to the amount of nutrients that were removed by harvested crops or manure relocation. The "management-oriented" approach estimated the amounts of N and P from fertilizer and manure compared this to the N and P recommended for attaining economically optimum yields. The goals of the Sims study were to: 1) provide recommendations for research and extension that could improve nutrient management and water quality outcomes, and 2) evaluate the effectiveness of Delaware's nutrient management program over time. The "management-oriented" approach assumed that nutrients were applied at recommended rates for particular crop yield goals and considered soil P levels. Crop yield goals were taken from state and county data for 1996 – 2006, throwing out the two highest and lowest yields, so were based on a seven-year average. For P, University of Delaware soil test summaries for a given area and year were used to estimate the amount of fertilizer P that would be recommended based on the distribution of soil test P results (percentage in each category – low, medium, and optimum) with no P applied to soils deemed "excessive" with a Fertility Index Value (FIV) greater than 100.

Both approaches evaluated by Sims indicated surpluses of both N and P over the project time period. However, results indicated that surpluses were decreasing over time. For example, the management-oriented nutrient balance showed three-year average statewide total N and P surpluses for 2004-2006 were reduced by 60% (N) and 52% (P) compared to 1996-1998. The crop removal approach for the same time periods show reductions of 55% and 97% for N and P, respectively.

Kovzelove et al. (2010) compared the MAWP approach to a nutrient budget that used the "management-oriented" approach that included soil test P (STP) values. In Maryland, this comparison included the Delmarva counties of Caroline, Somerset, Wicomico and Worcester. Soil P data were obtained from the University of Maryland Soil Testing Laboratory that used the Mehlich-1 extract and presented results as the distribution, by county, of the percentage of samples within various FIV ranges for 2002. Per nutrient management guidance (Maryland Department of Agriculture's Agronomic Crop Nutrient Recommendations Based on Soil Tests and Yield Goals, 2009), additional P was not applied to soils with FIV > 100 and was applied at the midpoint of rates for soils that were in the low, medium and optimum categories. Scenarios included with and without pasture land and with and without reported manure transport. One of the purposes of the study was to compare estimates of surplus P in selected counties with intensive animal production if P applications were based on a management-oriented approach that included soil test P or annual crop removal. They found that the difference between the two approaches was relatively small (average ~9%).

Materials & Methods

Basis for Performing Nutrient Mass Balances on Delmarva

The workgroup selected a management-oriented approach for computing the mass balances for N and P on the Delmarva peninsula. Most farmers growing crops on Delmarva have a nutrient management plan (NMP), rely on university recommendations for applying nutrients as the basis for meeting crop requirements, and these recommendations use soil tests to account for current P levels in the soil.

Inputs of nutrients came from commercial fertilizer, manure, and biosolids. Additional qualifications included manure that was transported off the peninsula, estimated losses due to ammonia volatilization (for N), and nutrient applications that were recommended to meet crop yield goals. Nutrient management recommendations included STP information that was available from the Maryland Department of Agriculture; however, unlike in Sims et al. 2008 and Kovzelove et al. 2010, the threshold for no application of additional P was set at FIV>150 instead of 100. In addition, there was no tailoring of P application rates based on the percentage of soils in the low, medium, optimum and excessive STP categories. Rather, acreages with soil FIV > 150 were excluded from P applications and acreages with soil FIV < 150 were assumed crop P need as the midpoint of the medium soil P category. Current nutrient management programs in Maryland and Delaware regulate P application on soils that have an FIV >150 and require a risk management tool that governs application above FIV 150 (VA uses a Mehlich-1 soil test concentration of >135 ppm P before required to utilize a risk management tool). Using an FIV = 150 was intended to provide a "snapshot" of the nutrient balance that reflected current nutrient management programs.

Formulating N and P Balances for Crop Production on Delmarva

Using a crop management approach, the balance for N associated with crop production is expressed as:

$$N_{balance} = N_{available} - N_{losses} - N_{recommended} - N_{relocated} \quad (1)$$

where

$N_{balance}$ = the net surplus (if positive) or deficit (if negative) of N remaining in the soil
$N_{available}$ = N purchased (inorganic) and generated (organic)
N_{losses} = N lost to the atmosphere due to volatilization
$N_{recommended}$ = N recommended to meet the crop production yield goals
$N_{relocated}$ = N from poultry litter transported out of a county and off Delmarva

The balance for P associated with crop production is expressed as:

$$P_{balance} = P_{available} - P_{recommended} - P_{relocated} \quad (2)$$

where

$P_{balance}$ = the net surplus (if positive) or deficit (if negative) of P remaining in the soil
$P_{available}$ = P purchased (inorganic) and generated (organic)
$P_{recommended}$ = P recommended to meet the crop production yield goal
$P_{relocated}$ = P from poultry litter transported out of a county and off Delmarva

A difference between Equations 1 and 2 is the presence of the N_{losses} quantity in Equation 1 that accounts for the loss of ammoniacal N (NH_3) from organic sources only and occurs when organic forms of N are land applied. It should also be noted that Equations 1 and 2 apply only for agricultural crop production and do not attempt to account for (or compute balances for) nutrients associated with other activities on Delmarva including but not limited to turf and lawn management, septic systems, wastewater treatment systems, and atmospheric deposition.

Equations 1 and 2 can be applied at both the county and peninsula-wide levels. The *available* N and P can be thought of as the *inputs* to crop production, and the *recommended* N and P are the *outputs* utilized to grow crops. The inputs (or sources) include fertilizer N and P purchased within each county as well as the N and P in poultry litter and manures generated within each county. Details regarding various sources for N and P data – for both as inputs and outputs - are described below.

Assumptions and Limitations

At the time of the analysis, the 2012 USDA Agricultural Census (Census) was the most recent census data available and was used for much of the data in the study. Therefore, the analysis that follows generally pertains to the practices, recommendations, production numbers and other data available in 2012.

The following generation sources were included and quantified for the inorganic and organic N and P inputs ($N_{available}$ and $P_{available}$ terms in Equations 1 and 2):

- Commercial N and P fertilizers sold
- Broiler/roaster litter
- Swine manure
- Beef manure
- Dairy manure and slurry
- Sheep manure
- Biosolids

The following management assumptions were made regarding the land available to receive N and P nutrients for crop production:

- N: all land used for non-legume crop production in 2012 received N. Land used for growing legume crops received no N in 2012. In other words, all the N requirements for legumes were satisfied from biological N-fixation.
- P: only land used for crop production in 2012 with an expected P FIV value less than 150 received any P.
- Land that was double-cropped in the same year received the recommended N and P required to grow both crops in that year.
- All land growing crops were available to receive manures.

- Based on previous discussion regarding P soil thresholds, soils within a county with P FIV values greater than or equal to 150 received no (zero) inorganic or organic P applications.

The following assumptions were made regarding poultry litter and manure transport on Delmarva

($N_{relocated}$ and $P_{relocated}$ terms in Equations 1 and 2):

- The only poultry litter and manure relocation considered in the mass balance was transport of poultry litter and manure off the Delmarva peninsula that was cost-shared through state programs. Manure transport from Delaware was assumed to be equal tonnage for both Kent and Sussex counties.
- No transport of poultry litter or manures occurred between counties. In other words, all manure generated within a county remained in that county (except for poultry litter and manures that were part of an aforementioned relocation program). There was not sufficient information to account for, and quantify, poultry litter transport between counties.
- All poultry litter and manure in a county not relocated was land applied. In other words, all N and P from these generation sources were used for crop production, and there was no storage or alternate uses of poultry litter or manure within a county.

Regarding the N_{losses} term in Equation 1, the only loss was ammonical (NH_3) volatilization losses to the atmosphere from land applied poultry litter and manures. Inorganic fertilizer losses were not calculated.

Other important considerations for the mass balance included:

- ❖ Nutrients from wastewater treatment (both municipal wastewater treatment and manufacturing and processing plants) used for the irrigation of agricultural crops were not included in the mass balance due to the lack of data for this practice. Biosolids were included.
- ❖ No crop residues were harvested or removed from any cropland. For example, straw from small grain production was not removed, nor was any corn stalk residue.
- ❖ No N deposition from precipitation was considered in the mass balance.
- ❖ The correlation observed between county-level poultry populations and soil P FIV values in Maryland counties on Delmarva was assumed to be the same for all Delaware and Virginia counties.

Data Sources Used in the Mass Balances

As mentioned previously, the 2012 USDA Agricultural Census (Census) was used as the source for many data sets in this analysis. The discussion that follows describes how the Census, as well as other data sources were used in the computations associated with the N and P balances.

Land available for crop production for Delmarva counties with farms and major cropland acreages (corn, soybeans, wheat, barley, sorghum, forages/hay and vegetables) came from the Census. Harvested cropland accounted for only the land harvested, and not for double-crop production. Total harvest cropland included harvested cropland from seven different crop categories (corn, soybeans, wheat, barley, sorghum, forages/hay, and vegetables) as well as for double-crop harvested cropland.

The mass balance contained crop yields for each of the crops considered in the mass balance and total acreage on Delmarva for each crop. The acreages reflected double-crop production, meaning both wheat and soybeans would be grown and fertilized so total crop acreage will be higher than actual farmed land available. Yields were based on typical crop production in Maryland and Delaware and therefore reflected that some land in each county was irrigated. These yields, in conjunction with the University of Maryland and University of Delaware N recommendations for crop production, were used

to determine the total N required per acre for the yield goals for each crop. The resulting N requirements for each crop were then totaled to determine the $N_{recommended}$ and terms in Equations 1 and 2 at both county and peninsula-wide scales.

All livestock populations, including broilers, were taken from the Census. Values used for poultry litter projections are described in the *Recommendations to Estimate Poultry Nutrient Production in the Phase 6 Watershed Model*. The approved results of that report, assuming 1.5 tons of poultry litter produced per year per 1,000 broilers with an average nutrient content of 57.3 pounds N and 20.2 pounds of P per wet ton. The net N was based on 20% volatility of ammoniacal N; which was subtracted as N_{losses}.

For animal species other than broilers, county-level animal populations were obtained from the Census, where available. Nutrient content for cattle, hogs and sheep were taken from either the *Penn State Extension Agronomy Guide* or the *Natural Resources Conservation Service's Animal Manure Management 1995 Brief #7*. The net N generation amounts reflected volatilization losses and was the net N in each county available to meet crop nutrient needs.

Data for biosolids was a reportable value to the Chesapeake Bay Program's Phase 6 Model, and personal communication with Maryland and Delaware environmental agencies confirmed the quantities of land applied biosolids permitted by the states within the Delmarva region in 2012. The data reflected the corresponding biosolids applications of N and P by county. County-level commercial fertilizer allocations were taken from the Phase 6 Model Beta version 4. Both the Maryland Department of Agriculture (MDA) and the Delaware Department of Agriculture (DDA) provided data from their poultry litter alternate uses and relocation programs to determine poultry litter generated on the Delmarva Peninsula and exported outside the region.

Due to the lack of publicly accessible soils data in Delaware and Virginia, Maryland's soil data was used to estimate soil P concentrations in Delaware and Virginia counties. Based on the data collected by MDA, the team developed a relationship between soil P FIV values (as a percentage of total harvested cropland in a county) and the concentration of P from poultry litter in that county . A linear regression model was fit to the data and provided a relationship between soil P levels in a county and the concentration of broiler production in that county as follows: (% Land > P FIV of 150) = 1.632 * (P concentration, lbs. P/acre) + 10.294. Since the coefficient of determination value was relatively high (R^2 = 0.894), there was a good correlation in Maryland between the concentration of broilers in a county and the corresponding levels of soil P FIV values in that county. Since no P FIV data was publicly available for Delaware or the Eastern Shore of Virginia, the equation noted above was applied to these states based on the known concentrations of broilers in each Delaware and Virginia counties. For the mass balance, acreage with P FIV values greater than or equal to 150 received zero fertilizer or organic P.

External Review Process and Recommendations

Upon the initial completion of the calculations associated with Equations 1 and 2 at both the county-level and peninsula scales, a three-person peer review team external to the Mass Balance

Workgroup was formed to review the analysis and provide answers to five review questions posed by the workgroup:

1. Should the workgroup apply both the "crop removal" and "crop need" approach.
2. Are the proposed assumptions regarding crop yield goals, crop N and P removal rates, and application recommendations for N and P for crops appropriate?
3. Are the assumptions regarding N fixation appropriate?
4. Does the approach to extrapolate Maryland data for poultry litter P, available cropland and soil FIV to Delaware and Virginia make sense?
5. Do you agree with choosing an FIV of 150 as the threshold for lands not eligible for more P?

The review recommendations included:

- Choose either crop removal or crop need approach, not both.
- Account for current soil P levels as part of the assessment of the P balance.
- Account for N volatilization for land applied poultry litter and manures.
- Regarding the P FIV threshold of 150, perform a sensitivity analysis to understand how changes to the land available to receive P impacts P surplus or deficit at both the county and the peninsula-wide levels.

The review team's feedback was evaluated by the Mass Balance Workgroup and incorporated into the analysis.

Discussion

The DLLC is a forum that brings together diverse stakeholders to both share and learn about different perspectives and views. The strength of DLLC is bringing together these diverse perspectives and expertise to collectively support or oppose information and approaches to advance the mission of identifying solutions that support both healthy and productive ecosystems, farming, and poultry on Delmarva.

The Mass Balance Workgroup was a representation of the diverse stakeholders of DLLC that ranged from environmental activists to farmers and from individuals who were experts at agronomics and data analysis to those without a science background. The group worked within a complex collaborative research process and dedicated their time over a three-year period and came to an agreement on the project goals, methods, and data sets to be used for the mass balance. Upon final review, there were three outstanding items on which the group could not reach consensus. Given the lack of consensus and the original agreement not to publish results unless a consensus was reached by DLLC Steering Committee members, the DLLC elected not to release results from the study. Rather, the DLLC supported a report that detailed the process, methods, data sources, and a discussion of the aspects of the study that resulted from the lack of consensus. Below is a brief discussion of assumptions where DLLC could not reach a final agreement:

1. *Soils eligible to receive P:* Initial soil P concentration is a major factor in determining appropriate poultry litter application rates. Currently, there is no publicly available soil test data for cropland that is below FIV150, which makes it difficult to determine appropriate P application rates. The mass balance assumed one application rate for all soils that were eligible to receive P. This application was based on the "medium" soil test P category (FIV of 26-50). Alternatively, a value

of "optimum" could have been chosen (FIV of 51-100). Some felt optimum was a more appropriate value based on publicly available soil information, consistency with previous mass balance reports, and the fact that the midpoint value of soils between 0 and 150 FIV would be 75. The difference between assuming application rates for medium or optimum soil P was more than 6,000 tons.

2. *Yield Goals:* Yield goals used in the mass balance drive the N application rate. Census yield goals were based on 2012 data which was a drought year. Additionally, the three states provided different yield recommendations. Original documentation for the external review indicated the yield goals were taken from the midpoint yields published on University of Delaware factsheets. The draft report did not match the factsheet data or the Census data. The data analysis team indicated that they used best professional judgement for the final yield goals. Consensus could not be reached on what data to use.
3. *Nutrient application rates*: The nutrient application source referenced in the materials for the external review process did not align with the draft mass balance report. Several members of the workgroup were not comfortable with the rationale for using the P application rates for wheat and barley from the MD regulations which were significantly higher from the P application recommendations used in Delaware and Virginia.

Recommendations

After the decision to not release the mass balance report, a committee was formed to evaluate the mass balance process and make recommendations to move forward. The committee developed the following recommendations based on a review of the original Mass Balance Committee meeting minutes and draft products.

<u>Recommendations for additional data needs to conduct a mass balance</u>

- Soil P data by county for Delaware, Virginia and Maryland, converted to similar units and extracts and soil P concentrations for cropland <FIV150.
- Comprehensive poultry litter transport data (i.e. coming into and leaving a county).
- The most recent Census data.
- Amount of litter applied by county by crop.
- Amount of commercial fertilizer applied by county by crop.
- A more robust yield goal average per county.
- Estimates of double-cropped acres by county.

<u>Recommendations for future Delmarva mass balance efforts:</u>

- Clearly define the objectives of the work.
- Identify and obtain critical sources of data before beginning the process. Engage academics and external experts in the subject area to address data gaps and/or develop robust assumptions.
- Decide on assumptions up front and get full consensus before running the analysis.
- When assumptions are used, consider performing a sensitivity analysis to identify the influence of each assumption on the outcome.
- Clearly communicate to stakeholders (during and after) about the limitations of the approach and assumptions employed in the analysis.

- Consider funding a team of qualified experts to do this work on a contract basis to address time requirements and potential bias.
- If changes to the data sets or methods are needed, seek feedback and gain support for changes from participants and external reviewers prior to moving forward.
- Make all data and spreadsheet analysis available to the full workgroup to allow for transparency, accountability and quality assurance of the data and analysis.

Recommendations for collaborative projects with diverse stakeholders

- Define the team, their level of understanding of the subject, and their stake in the outcome.
- If the work will be performed by an internal team, define roles and clearly outline time commitments.
- Develop a clearly defined objective and scope of work at the beginning of the process.
- Review the scope on a regular basis to assure that the scope has not changed, and work is still on track to meet the objective.
- Allow for disagreement as an opportunity to understand diverse stakeholder perspectives and data gaps.
- Use publicly available data and if it needs to be changed, describe exactly how and why.
- Maintain a running document of methods, assumptions, data sets, citations and decision points that is accessible to the whole team.
- Determine a process up front for how decisions will be made and accepted by the team regarding methods, assumptions, data, final products, etc.
- Provide periodic status reports to external stakeholders.

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