CODEX PLANETARIUS

Water Quality Indicators and Metric-based Standards:

Background and Suggestions for *Codex Planetarius*

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About *Codex Planetarius*

Codex Planetarius is a proposed system of minimum environmental performance standards for producing globally traded food. It is modeled on the *Codex Alimentarius*, a set of minimum mandatory health and safety standards for globally traded food. The goal of *Codex Planetarius* is to measure and manage the key environmental impacts of food production, acknowledging that while some resources may be renewable, they may be consumed at a faster rate than the planet can renew them.

The global production of food has had the largest impact of any human activity on the planet. Continuing increases in population and per capita income, accompanied by dietary shifts, are putting even more pressure on the planet and its ability to regenerate renewable resources. We need to reduce food production's key impacts.

The impacts of food production are not spread evenly among producers. Data across commodities suggest that the bottom 10-20% of producers account for 60-80% of the impacts associated globally with producing any commodity, even though they produce only 5-10% of the product. We need to focus on the bottom.

Once approved, *Codex Planetarius* will provide governments and trade authorities with a baseline for environmental performance in the global trade of food and soft commodities. It won't replace what governments already do. Rather, it will help build consensus about key impacts, how to measure them, and what minimum acceptable performance should be for global trade. We need a common escalator of continuous improvement.

These papers are part of a multiyear proof of concept to answer questions and explore issues, launch an informed discussion, and help create a pathway to assess the overall viability of *Codex Planetarius*. We believe *Codex Planetarius* would improve food production and reduce its environmental impact on the planet.

This proof-of-concept research and analysis is funded by the Gordon and Betty Moore Foundation and led by World Wildlife Fund in collaboration with a number of global organizations and experts. For more information, visit www.codexplanetarius.org

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Abstract

Runoff from agricultural fields, pastures, plantations, and orchards, and effluents from aquaculture production facilities contain potential water pollutants such as the two major plant nutrients (nitrogen and phosphorus). Additional pollutants include other minerals, dissolved and suspended organic matter, suspended soil particles, and trace contaminants such as residues from pesticides and therapeutant agents. Concentrated animal feeding operations (CAFOs) also discharge runoff and washdown effluent that are especially high in biochemical oxygen demand (BOD_5), total suspended solids (TSS), total nitrogen (TN), and total phosphorus (TP). In addition, total dissolved solids (TDS) concentration is problematic in irrigated agriculture in arid regions, and dissolved oxygen (DO) is critical at CAFO and some aquaculture production facilities.

A consideration of the literature on the composition of runoff and effluents from food and fiber production were compared with typical river water composition given in a global database. Agricultural runoff is from slightly elevated to much higher in concentration of the key water quality variables of agricultural pollution than were those reported for river water.

Farming categories were established and some of the categories were subdivided. Water quality standards were recommended for each category and sub-category that consisted of one standard and a suggested, secondary standard. The standards include a total of four water quality variables.

Efforts to regulate non-point source pollutants from agricultural lands have been based on practices, because sampling of runoff is difficult. Methods for sampling runoff from fields and other expansive areas are discussed. Costs for making the analyses necessary for the recommended standards likely would cost between US$100-300/year for each farm. Pesticide and therapeutant analyses would be excessively expensive, and it would be desirable to prohibit the use of certain problematic pesticides and therapeutants.

The onus on small farmers by *Codex Planetarius* would be considerable, and they could not be expected to provide adequate water samples for testing unless trained and carefully audited. Governments would need to combine small farmers into blocks of farms to facilitate auditing for compliance. Some suggestions for implementing *Codex Planetarius* are included.

Introduction

Agriculture from its beginning several millennia past has required land, water from rainfall, and human effort. People learned that animals could be trained to pull plows, carts, etc. They also figured out how to use river water to irrigate crops and built irrigation systems. Livestock manure has been used as fertilizer since ancient times, but in the mid-1800s, chemical fertilizers were developed. Farm machinery was invented that relied on energy from wood or fossil fuel combustion and has replaced animal power at most farms for tilling and many other operations. Farmers in arid regions began to tap sources of underground water for irrigation. Livestock rearing options were developed to include compounded feeds, concentrated feeding operations, climatic control in animal rearing houses, etc. Thus, modern agriculture has been imposed upon nature. Today agriculture is dependent upon land, water, energy, commercial fertilizers, liming materials, compounded animal feeds, pesticides, antibiotics, and even genetically improved seed and breeding stock.

While many advances have been made, land and water remain two of the critical requirements for agriculture. The land can be reused from year to year and rainfall and surface water are in a continuous cycle, but we cannot make any more land or water. Desalinization can be employed to make seawater usable for agricultural purposes. The energy cost and carbon footprint for the process, at least by present technology, is far greater than is acceptable for providing water for most types of food production. Groundwater can be used in irrigation, but it can be used faster than aquifers are recharged by nature, and this also is true of other renewable resources used in agriculture. Non-renewable resources also are depleted through human use, and agriculture is a major contribution to fossil fuel use.

Most of the world's land that is well suited for agriculture has been put into food and fiber production. Modern agriculture has greatly increased productivity per unit of land use, and the world produces about three times more raw food and fiber products than it did in 1950, and remarkably with only 10% more land. In fact, according to a 2023 report by the Food and Agriculture Organization (FAO) of the United Nations, the world agricultural area in 2021 was 4.8 billion hectares (ha) with 1.6 billion ha of cropland and 3.2 billion ha of permanent meadows and pastures. This represents around 40% of the earth's land surface.

The FAO report also stated that since 2000 cropland increased by 6% while land in meadows and pastures decreased by 5%. Total agricultural land has remained relatively constant over the last 20 years. This has not prevented low quality farmland from being abandoned and land more suitable for agriculture being cleared for farms.

The situation with freshwater is less encouraging. In 1950 around 1 trillion cubic meters (m^3) of freshwater were used for agricultural purposes, but by 1995 agricultural water use had increased to 2.9 trillion m^3. A study made in 2013 gave a projected water use by agriculture of 3.5 trillion m^3 by 2025. Because of the great expansion of irrigated agriculture since 1950, water use has increased by approximately the same factor as food and fiber production. Freshwater withdrawals for agriculture are estimated to account for about 70% of all freshwater withdrawals for human use.

In the present report, the emphasis is not on land and water use per se; the focus is on the effect of agricultural land and water use, and farming practices on water quality in bodies of water receiving agricultural effluents. Nevertheless, with respect to water pollution by agriculture, it is critical to realize that the land and freshwater are intricately related because the freshwater resides in the land. Agriculture occupies about 40% of the earth's land mass, and it tends to be mainly in areas that are better watered by rainfall. As a result, more than 40% of the annual rainfall input to the earth's land mass likely falls onto agricultural lands. Storm runoff from these lands suspend and dissolve solids of various types, many of which originate from farm operations, before flowing in natural water bodies.

Water that evaporates from the earth's surface enters the atmospheric circulation as water vapor, but soon, it is caught up in rising air, condenses into water droplets to form clouds, and falls to earth again as relatively pure liquid water in rain or in frozen precipitation. This rather pure water will fall back onto land surfaces to dissolve and suspend solids and generate contaminated runoff again. Much agriculture is done in medium to high rainfall areas where rainfall is frequent and often intense, and agriculture, which occupies much land, is the major source of contaminated runoff.

Water pollution is one of the main impacts of human activities on aquatic ecosystems. Standards for effluent water quality will be required in *Codex Planetarius* to impose environmental regulations on agricultural production through international trade agreements. The purpose of the present report is to provide some suggestions on the development of these standards.

Water Pollutants from Aquaculture

There are two basic types of water pollution. One kind is raw or treated wastewater from municipal, industrial, or other sources that is discharged at the ends of pipes or other dedicated and confined conduits. Such effluent is known as point-source pollution. The second type of water pollution results from contaminants becoming dissolved or suspended in water as it flows over land or other surfaces and as it infiltrates through the soil following rainfall events. This type of water pollution is called nonpoint-source pollution.

Agriculture causes both types of water pollution. Plant crop production in fields and livestock rearing in pastures or on rangeland are nonpoint sources of pollution. Intensive production of animals for meat, eggs, or milk usually results in point sources of pollution.

Agricultural tillage loosens the soil and makes it more susceptible to erosion by raindrops and the resulting surface runoff. As a result, agriculture is a major source of suspended soil particles that enter water bodies in runoff and lead to greater turbidity and sedimentation.

Surface runoff also removes nitrogen and phosphorus in dissolved and particulate matter from agricultural watersheds. These two plant nutrients are leading causes of eutrophication in natural waters. The sources of nitrogen and phosphorus in plant agriculture are commercial fertilizers and livestock manure applied to croplands. Common, nitrogen- and phosphorus-containing commercial fertilizers are: urea, ammonium sulfate and nitrate, di- and mono-ammonium phosphate, super and triple superphosphate, and calcium cyanamide. The amounts of nitrogen and phosphorus applied globally in commercial fertilizers in 2021 were 109.2 and 20.9 million tonnes, respectively.

A FAO study concluded that worldwide about 115 million tonnes more nitrogen are applied to global agricultural soils in livestock manure. The corresponding estimates for phosphorus input in livestock manure derived by the author was 12–20 million tonnes annually. It seems that about as much nitrogen and phosphorus are applied in livestock manures as in commercial fertilizers. Livestock manure is around 30% organic matter on an "as is weight basis." Manure typically contains 0.5–2.0% nitrogen, and several hundred million tonnes of manure are applied annually to agricultural land. It is a major source of organic matter (and oxygen demand) to natural water bodies.

Pesticides are applied in most types of agriculture. A review of 2015 pesticide use in agriculture reported that 4.1 million tonnes of pesticides were used annually and that 10 compounds (or compound groups) made up 74% (3.03 million tonnes) of the total **(Table 1, pg.9)**. The largest amounts of pesticides are used for weed control (herbicides).

Insecticides often are the most toxic of the pesticides to aquatic life. About 15–20% of pesticides applied in agriculture are for insect control. The most common insecticides are organophosphate, carbamate, and pyrethroid compounds.

Water used for irrigation in semi-arid and arid regions becomes concentrated in ionic content because of high evapotranspiration in relation to rainfall. The drainage water from irrigated fields typically has an elevated salinity. Irrigation is a leading cause of salinization of soils and freshwater bodies in certain regions.

The efforts to protect water quality in natural water bodies originally focused on treatment of point-source pollution and much improvement has resulted. On the other hand, it is not possible to confine and treat nonpoint-source effluents, and practices have been designed to lessen the amounts of potential pollutants applied in agricultural operations that are removed in runoff and infiltration through the soil from agricultural watersheds. Agriculture is considered to be the main source of nonpoint-source pollution, and is the leading cause of water pollution today. It is estimated that about 60% of the suspended solids load and around 70% of the loads of oxygen demand, nitrogen, and phosphorus entering the waters of the United States in pollution are of agricultural origin and the biggest part of the agricultural pollution is nonpoint in source. Global estimates of agriculture's contribution to loads of these three pollutants were not found, but the percentages are possibly slightly higher in some countries with much agriculture and somewhat lower in countries that import the majority of their food.

Programs directed at reducing pollution from agriculture at river basin, national, and global levels are too numerous to discuss here. These efforts and suggested approaches for improvement were discussed in a 2017 FAO publication "Water pollution from agriculture: a global review." This publication suggests greater implementation of practices on farms to lessen pollution loads, but application of water quality standards are not one of the suggestions. The main use of standards in farming relate to government-issued permits for concentrated animal feeding operations (CAFOs) that were not a focus in the FAO publication.

Major Water Pollutants

Any feature of water that influences its beneficial use by humans or by natural ecological processes either negatively or positively is a water quality variable. There are many water quality variables, but relatively few of these variables are important in water pollution. The most important ones in both point and nonpoint pollution are nutrients, suspended inorganic and organic wastes, acidity and alkalinity, and toxins. The major water quality variables of concern in agricultural effluents will be considered briefly.

Waste heat

Water temperature has a great effect on all aquatic ecosystems, because the growth rates of plants and animals are to a large extent regulated by temperature. Some industrial effluents are the recipients of waste heat from production processes. Elevated temperatures in such effluents may be harmful to aquatic life. Agricultural effluents usually are near the same temperature as found in natural water bodies into which they are discharged, and water temperature is not a common effluent feature of concern.

pH

This variable is an index of the reaction of water as an acid or base. A pH of 7 is neutral (neither acidic nor basic). The further below 7.0 the pH, the more acidic a water. The opposite is true of the basic reaction of water. Many industrial effluents may be outside the optimum pH range for aquatic life of 6–8.5. Agricultural wastewater is the result of processes in which living organisms are produced, and pH usually is within the optimum range for living things.

Total dissolved solids (TDS)

The solids dissolved in water are either organic matter or inorganic ions. In most water over 95% of the TDS will result from ions of sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), sulfate (SO_4^{2-}), and bicarbonate (HCO_3^-) or bicarbonate and carbonate (CO_3^{2-}). As a result, the TDS concentration is usually roughly the same as the salinity when expressed in the same units of measure. Freshwater has 1,000 mg/L of TDS or less, while undiluted ocean water averages 34,500 mg/L in TDS. Freshwater organisms do best at salinities below 1,000 mg/L, estuarine species can tolerate a wide range in salinity, and marine species thrive best in ocean water. The main issue with TDS in farming relates to elevated salinity in irrigation drainage and in aquaculture effluents from farms that use a saline water source but discharge into a freshwater body.

Total suspended solids (TSS)

This variable results from particles of mineral matter (soil), living microscopic organisms, and dead organic matter suspended in water. These particles impact turbidity of water and limit light penetration to restrict photosynthesis by phytoplankton and other aquatic plants in natural waters. Suspended particles also settle and accumulate in the bottoms of water bodies. This sediment causes ecological damage to bottom-dwelling organisms, and its buildup reduces the depths and volumes of receiving water bodies. The usual limits placed on TSS in effluents is between 10 and 50 mg/L.

Most types of farm effluents, and particularly those from CAFOs and plant production associated with frequent tillage, have TSS concentrations greater than those found in receiving water bodies. Erosion of the land is the main source of suspended solids found in freshwater bodies and many estuaries, and cultivated cropland is a major source of suspended solids. Dense plankton blooms in aquaculture ponds also may cause elevated TSS concentrations in effluents. Mechanical aeration in ponds also generates water currents that can erode earthen embankments and lead to greater TSS concentrations in effluents.

Turbidity

This term refers to a reduction in water clarity related to elevated TSS concentration. Turbidity is measured by refraction of light by suspended particles by use of an instrument called a nephelometer and reported in nephelometer turbidity units (NTU). The relationship of TSS to NTU varies, and it is better to measure TSS for most water pollution assessments. Turbidity reduces primary productivity in natural waters and negatively impacts aquatic animal food webs. Turbidity sometimes is used as a way of quickly estimating TSS concentration which is more difficult to measure. The clarity of water is an important water quality indicator, and clear waters tend to be less polluted than turbid water.

Dissolved oxygen (DO)

Aquatic animals depend upon molecular oxygen (O_2) as the terminal electron acceptor in respiration. Molecular oxygen in water is known as dissolved oxygen and it is reported in milligrams per liter. A freshwater at 20°C holds 9.07 mg/L DO at 100% saturation at standard atmospheric pressure. The saturation concentration decreases with rising temperature and with greater salinity. As a general rule, aquatic life does best in water with more than 50–60% of DO saturation. The acceptable minimum concentrations usually are 5 mg/L for warmwater and tropical species and 6 mg/L for cool and coldwater species. Most farm effluents other than those from terrestrial CAFOs will contain sufficient DO for aquatic life. Of course, organic matter in effluents may impose an oxygen demand on receiving water bodies as the organic pollutants are decomposed by bacteria and other microorganisms. Examples of pollution problems include cleaning and flushing of animal rearing facilities, cleaning and flushing of sugar mills, wet pulping facilities, and coffee husking operations.

Biological oxygen demand (BOD)

This variable is an estimate of the amount of dissolved oxygen required to oxidize the organic matter in a water sample. It typically is measured over a five-day period of incubation of water samples in the dark at 20°C, and it is reported as the five-day BOD (BOD_5) concentration in milligrams of DO per liter. The BOD_5 represents the rapidly expressed portion of the oxygen demand – usually about 70% of the longer-term BOD. The usual levels of BOD_5 allowed in wastewater permits vary from 10–50 mg/L BOD_5, with 20–30 mg/L being most common.

The BOD_5 is particularly elevated in waters from concentrated CAFOs. Some countries require wastewater from CAFOs to be held in sedimentation ponds without overflow where solids settle, and the liquid evaporates. Livestock manure and CAFOs holding pond sediment are typically applied to agricultural fields. If improperly applied and especially if left exposed on the surface of fields and pastures, manure particles will be suspended in surface runoff and be a major source of organic matter contamination (increase the BOD) in natural water bodies.

Total nitrogen

Wastewaters contain ammonia, nitrate, nitrite, dissolved organic nitrogen, and particulate nitrogen. The main problem resulting from nitrogen inputs in effluent is that of stimulating excessive aquatic plant growth or eutrophication. Ammonia and nitrate nitrogen are the plant available forms of nitrogen, but the other forms are easily converted to plant available forms by microbial activity. Total nitrogen usually is the form used in assessing the eutrophication potential of effluents. Permits typically limit total nitrogen concentration to 1–5 mg/L.

Total phosphorus

Phosphorus is equally as important or often more important than nitrogen as a plant nutrient and cause of increasing eutrophication. Most phosphorus in effluents is in the form of dissolved inorganic phosphorus and particulate organic phosphorus, but the plant available form is soluble inorganic phosphorus. The particulate and soluble organic forms of phosphorus, like those of nitrogen, are rapidly converted to plant available phosphorus. Discharge permits usually restrict total phosphorus concentration to 0.5 to 1.0 mg/L.

Trace elements

A variety of minor and potentially toxic elements, particularly copper and arsenic, may be found in agricultural wastewater. These elements are used as fungicides, algicides, and insecticides. Many synthetic organic chemicals also are used widely in agriculture as pesticides of various kinds. These substances are mildly to highly toxic and some are persistent and slowly disappear from water bodies into which they are introduced in effluents. Effluent water quality permits usually limit the concentrations to some fraction of the lowest concentration not expected to cause toxicity, require in-stream toxicity testing to prove the absence of toxins, or prohibit the presence of particularly toxic compounds.

Effluent Discharge Regulations

It will be useful to look briefly at how point-source pollutant discharges have been and are regulated. The initial effort in the early years of water pollution abatement focused on limiting the concentrations of selected pollutants. For example, the BOD_5 mg/L. This protected water quality and aquatic life in the zone near the effluent outfall. It did not restrict the amount of pollution, because there were no volume limits for effluents in most instances.

Volume limits were soon imposed in some effluent permits, and with volume and concentration data available, pollutant loads could be calculated. This led to pollutant load limits, but a concentration limit was still necessary to protect aquatic life in the area of the outfall. Nevertheless, there was no means of ascertaining whether the loads assigned to pollutants would actually protect water quality and aquatic life in receiving water bodies when they are considered as entire ecological systems.

Next came what can be called delta (Δ) effluent standards. The seasonal ambient concentrations of pollutants in receiving water bodies were determined. The allowable pollutant concentrations were then assigned as a concentration less, equal to, or slightly greater than ambient. By similar reasoning, stream re-aeration models were made, and BOD_5 loads were calculated as the amounts that would not cause a sag in DO concentration downstream of effluent outfalls.

None of the methods mentioned above ensured that damage from pollution would not occur. This brought the concept of total maximum daily loads (TMDLs) of pollutants. The receiving water body is investigated and its capacity to assimilate pollutants determined. The daily pollutant inputs are assigned in amounts that should not exceed the TMDLs for the receiving water body, but concentration limits of some pollutants are still necessary to protect in areas near effluent outfalls.

The use of effluent pollutant limits is actually used in combination with stream water quality standards in the United States and some other countries. Streams and other water bodies have been classified as to their most beneficial use and water quality standards made for each use category. The purpose of the effluent discharge permit limits on pollutants is to maintain stream water quality in a state of compliance with the stream water quality limits of the stream classification standards.

Effluent water quality permits issued by governments range from simple concentration limits to rather complex analyses that result in TMDLs or even complex models of the behavior of pollutants in nature. Nevertheless, it still is not possible to be sure that water bodies do not continue to decline in their quality. It is well known that there is a tipping point at which eutrophication, or some other negative impact, will suddenly occur. This tipping point is difficult, if not impossible, to detect from water quality data.

The uncertainties with nonpoint-source pollution control efforts are even greater than for point-source pollution. There has been no effort to use water quality data in regulating nonpoint discharge. Conservation practices and other types of crop management practices have been required on agricultural watersheds to lessen the discharge of pollutants into streams and other water bodies. Studies have shown that these practices can improve downstream water quality, but not much is known about the effectiveness of the practices that have been installed on individual farms. Moreover, there is no onus on farmers to do any more than install practices, and in many countries, there likely is no auditing to assess the correctness and the extent with which the practices actually are used.

Crops and Standards

Many different food and fiber crops are produced, and the resulting effluents contribute to water pollution. Animal production results in discharge of point-source pollution at CAFOs and nonpoint-source pollution results from less intensive animal production. Plant crops typically result in nonpoint-source pollution.

Different types of farming were categorized for convenience **(Table 2, pg. 10)**. There are several categories of both terrestrial and aquatic farming, and many species make up some of the categories. Variation in production methods occurs within these categories. In traditional livestock farming, there are pasture, range, and different kinds of feed-based production. Plant crops likely present the widest range in production methodology because of the huge range of species cultivated. Aquaculture species are produced in ponds, raceways and other flow-through systems, net pens and cages, and in water-recirculating systems (RAS). The intensity of production varies from that possible through natural aquatic productivity to that possible using feeds, mechanical aeration, and other management interventions.

There likely is no workable means of developing more than rather general, broad water quality standards for *Codex Planetarius*. These standards can be customized to some extent for the categories of production. To do this, we need to consider the general quality of stream waters, because farm effluents usually will enter streams. It also will be necessary to consider the typical water quality characteristics of discharge from different types of farming.

Typical Stream Water Quality

Surface runoff that passes over agricultural land to enter streams and other water bodies is the source of renewable freshwater. Rain is relatively low in concentrations of TDS, TSS, and particularly organic solids when it falls onto the land or other solid surfaces of the earth. It may contain up to 1 mg/L or more of nitrogen in the form of nitrate, but only minute amounts of phosphorus. Rain is concentrated with carbon dioxide, and naturally would have a pH of about 5.6. Because of acidic or alkaline contamination of the atmosphere from products of combustion or dust particles from arid regions, the pH of rain can be lower or higher than the pH expected from carbon dioxide alone. The typical range in pH of rain is 3.0–7.6, but higher and lower values have been reported.

The surface runoff resulting from rainfall becomes contaminated with suspended and dissolved substances as it contacts land and other surfaces. A portion of rainfall infiltrates the land surface and moves downward into underground aquifers from which it seeps into streams or is withdrawn by wells for human use. The water that infiltrates downward dissolves substances that have been applied to agricultural soils. This can result in the pollution of underground water supplies. A well-known example for agriculture is the case of nitrate from agricultural sources contaminating wells used for human water supply. This was a leading cause of the blue baby syndrome in the midwestern US in the 1940s.

Surface waters of streams, lakes, and other water bodies in inland areas are more concentrated in suspended and dissolved substances than is rainwater. Stream water composition is effected by climate and especially the relationship between precipitation and evaporation, the nature of soil and geological formations that differ in composition, solubility, and potential for erosion. Groundwater that infiltrates into natural water bodies also varies in composition according to similar factors that influence surface water composition. Pollution can drastically increase the concentrations of nutrients, dissolved organic matter, and particulate organic and inorganic solids in water.

Data from a worldwide database on river water quality are provided in **Table 3 (pg. 10)**. The median pH was 6.89 and the median DO concentration was 8.34 mg/L (92% of saturation). Both of these variables vary naturally with time of day, because they are affected by photosynthesis and carbon dioxide concentration. During daylight, carbon dioxide decreases, and both DO concentration and pH rise. At night, photosynthesis stops, carbon dioxide increases and DO concentration and pH decline. This trend is most marked in eutrophic waters of ponds and lakes, but it also may be considerable in nutrient polluted, slow-moving streams. The issue of low DO concentration is accentuated by greater temperature, because higher temperature lessens the capacity of water to hold dissolved oxygen but increases the rate of respiration of organisms.

The TSS concentration median is 9.78 mg/L, but as can be seen from the high percentage of outliers, considerable variation can be expected. The BOD_5 is 5.88 mg/L. This suggests that rivers tend to be polluted, because relatively unpolluted waters have BOD_5 concentrations of 1–2 mg/L. The BOD_5 concentration in Table 3 is about 60% of the TSS concentration. If all of the TSS were suspended biologically available organic matter, then BOD_5 and TSS would be similar.

The median total nitrogen and total phosphorus concentrations are 1.33 mg/L and 0.105 mg/L, respectively, and the particulate nitrogen and phosphorus concentrations are 2.5-fold and 3.4-fold greater, respectively, than the dissolved fractions. Streams that are relatively free of pollutant inputs contain less than 0.5 mg/L of total nitrogen and 0.05 mg/L total phosphorus.

Although river waters may be quite different in concentrations of water quality variables, the median values give us a basis for comparison with the concentrations of the key variables in different types of farm effluents.

Farm Effluent Quality

Typical concentration ranges for key pollutants in farm effluents are provided **(Table 4, pg. 11).** The data were taken from an online search and personal reference material that included examination of over 150 individual studies. These studies covered a range of crops, production methods, climatic zones, soil types, and terrain. There were generally no striking correlations related to individual categories of crops (see Table 2 for categories), and the data have been grouped in accordance with the above-mentioned categories as much as practical.

The most striking differences in the data of Table 4 are between terrestrial CAFOs and terrestrial plant crops. The concentrations of TSS, BOD_5, total nitrogen, and total phosphorus are many times, even orders of magnitude greater for the CAFOs in some instances than for extensive pasture production of animals and for plant crops.

Surface runoff from irrigated agriculture was similar in composition to that from non-irrigated agriculture and the two are not separated in Table 4. Irrigation drainage water was low in TSS concentration and similar in concentrations of BOD_5, total nitrogen, and total phosphorus to surface runoff, but it had an elevated TDS concentration range.

Aquaculture effluents were much lower in concentrations of the four pollutants of Table 4 than were the terrestrial CAFOs. When RAS is not included, aquaculture effluents were not greatly different in pollutant concentrations than were surface runoff and irrigation drainage from plant crops.

Dissolved oxygen concentration was not included in Table 4, but the literature review suggested that low DO concentration would be of major concern only in effluents from terrestrial CAFOs. Elevated salinity (elevated TDS concentration) can be expected in irrigation drainage and in aquaculture systems that are filled from the sea, estuaries, or inland sources of saline water. The discharge of such effluent into freshwater bodies could cause salinization.

All types of farm effluents present a pollution potential, because they often contain greater concentrations of certain potential pollutants (see Table 4) than usually found in river water (compare Table 3 and Table 4) and other inland water bodies, estuaries, and the sea.

Water Quality Standards for Farms

The data in Table 4 for terrestrial CAFOs were mainly for wastewater resulting from washdown of facilities for sanitary purposes. Much of the waste is usually removed and applied on cropland or pastureland as fertilizer. The washdown water is highly polluted and should not be released directly into natural waters. The common practice in many countries is to hold the wastewater from CAFOs in retention ponds designed not to overflow following the largest rainstorms expected in the specific localities. These sediment ponds are cleaned out periodically and the sediment is applied on fields as fertilizer. Some CAFOs may treat all or a portion of their wastewater in order to discharge it, and *Codex Planetarius* should have a standard for such facilities.

Aquaculture farms discharge effluent daily where water exchange is routine. In other facilities, water is discharged after heavy rains in response to water exchange applied in water quality emergencies, and for harvest. Standards for discharge from aquaculture farms are imperative other than for cage culture. Uneaten feed, feces, and metabolic waste enter water bodies in which the cages are installed, but there is no effluent stream to sample.

Seaweed and mollusk that filter particulates from water are planted in nature, usually on artificial structures, and fertilizer or feeds are not used. Cultivation of these species is not considered to be sources of nutrients, dissolved or suspended organic matter, or suspended mineral matter. There has occasionally been concern over reduced plankton abundance in water bodies because it is removed for food by large stocks of molluscan species at farms in certain estuaries. In general, seaweed and mollusk farms are considered benign or beneficial with respect to eutrophication.

One unique feature of *Codex Planetarius* will be to set water quality standards on nonpoint-source effluents. With conventional crops, the potential for pollution is ever present, but more likely after heavy rainfall events during the growing season. In the case of wood pulp, the critical time will be at harvest when the soil surface usually is disturbed by harvest operations resulting in high TSS concentrations in surface runoff from tree plantations. Studies have revealed post-harvest TSS peaks in runoff, from 25 mg/L to over 1,000 mg/L. Trees for pulp often are fertilized, and nitrogen and phosphorus concentrations in surface runoff may be elevated, but not to the extent that fertilizer nutrients are removed in runoff from row crops.

The factors influencing concentrations of pollutants in nonpoint discharge are varied, and different farms located in close proximity and producing the same crops exhibit variation in storm runoff composition. It would be impractical to attempt to customize standards for individual farms or even individual crop species.

Minor elements and synthetic organic pesticide standards likely would pose a problem in *Codex Planetarius*. The main reason being that the large expense of measuring pesticide concentrations, because single analysis of most compounds cost from $100–200 US dollars up to around $1,000 each **(Table 5, pg. 11).** *Codex Planetarius* could require practices to be installed to minimize pesticide use and reduce the concentrations of pesticides in runoff. It might also be wise to prohibit certain pesticides such as DDT, chlordane, aldrin, dieldrin, endrin, murex, heptachlor, and BHC.

The author was advised that *Codex Planetarius* should ideally require only one standard for the key negative environmental impact to be considered.[1] In the case of water effluent quality of the present report, it has been mentioned above that several of the variables are closely related under usual circumstances, and one variable may serve as a surrogate for one or more other variables. But there is the problem of exceptions that may be rather common. For example, in many cases the five-day BOD and the TSS concentration are closely related. However, there are situations where the TSS can be related to suspended inorganic matter and not closely related to the BOD. Because of this, the author feels compelled to give a suggested additional standard in most of the terrestrial crops **(Table 6, pg. 12)** and aquatic crops **(Table 7, pg. 12)**. This is the author's personal conviction but neglecting this suggestion would certainly not detract tremendously from the potential usefulness of *Codex Planetarius*.

The attempt at establishing standards for terrestrial crops is presented (Table 6) and for aquaculture (Table 7). These should be carefully reviewed by a group made up of individuals knowledgeable about the different types of crops. The author is more confident with the standards for animal production than with the others.

Relationship to Certification Effluent Standards

Aquaculture certification programs such as the Aquaculture Stewardship Council (ASC) and the Best Aquaculture Practices (BAP) certification of the Responsible Seafood Alliance impose effluent standards. No evidence of the use of effluent standards was found among the several certification programs for terrestrial agriculture. One purpose of certification programs is to require more rigorous standards for voluntary adoption than are required by national governments or international trade rules.

Codex Planetarius will be noticed by certification bodies that certify all types of food and fiber products for the international market. The certification bodies will be behooved to add effluent standards that are stricter than those of *Codex Planetarius*. This reasoning also will apply to all other standards in the *Codex. Codex Planetarius* will set minimum standards for effluents and several other negative environmental impacts of food production. Once *Codex Planetarius* has been implemented, it would be difficult to justify certification programs with lesser standards.

Application of Effluent Standards

Arrangement of farms for auditing

The farms in countries participating in *Codex Planetarius* must be audited. This effort would ideally be conducted on each farm, but it may not be possible in some countries with many small farms. Some possible ways of arranging the procedure for assessing compliance follow:

1. Each farm could be checked individually for compliance, and this certainly should be the procedure for larger CAFOs with over 50t live weight production each per year or at other farms with 5 ha or more of active production area each. Each farm would deal with non-compliance individually as required.

2a. In areas with many small farms, i.e., CAFOs less than 50t/yr of production and other farms each with less than 5ha in active production area, the farms might be arranged in blocks of 10 or more farms each. A random sample of 20% of the farms within a block, but not less than three farms, could be assigned to be audited each year. The farms selected for sampling on a given year could be excluded from sampling the next year, but only for one year.

2b. Where two-thirds (67%) of the farms chosen for sampling are found to be in compliance, the block could be considered compliant, but the non-compliant farm or farms would be issued a compliance schedule and excluded from the block until regaining compliant status.

3. Where farms in an area all discharge into a common first order, permanent stream, the stream water quality could be used as a method of determining compliance by all farms on the catchment. The stream sample could be analyzed for all water quality variables included in the standards for all categories of standards applicable to farms contained in the first order catchment. The problem in this option is that the cause of any instance of non-compliance could probably not be traced to an individual farm.

Sampling

Sampling of point-source effluents is relatively easy. Discrete grab samples can be secured by filling sample bottles directly from effluent streams. The sample bottle itself or some type of dipper can be used to collect the sample manually. Some CAFOs and particularly those for aquatic animals will have continuous or periodic discharge which can be sampled directly. Many farms for plant crops will have one or more places where a confined stream of water exits the lower edges of farms via a natural drainage channel, ditch, canal or pipe following rainfall events.

Water samples may be dipped from such farm outflows. Where there are multiple outflows for the same farm, samples should be collected from each and equal volumes from each individual outflow combined into a single sample for analysis.

Some farms will not have a well-defined runoff exit point. In such instances, samples can be collected from flow across the land surface. There may be depressions in fields or pastures where this can be done during a rainstorm or soon afterwards. At least three such places should be selected on each farm and water sampled at each. Equal volumes of these subsamples can be combined to provide a single sample for analysis. At farms where there are no depressions suitable for sampling, shallow collection pans installed so that their tops are level with the ground surface could serve to capture runoff. The pans could be simple, shallow, flat-bottomed plastic pans, e.g., 20-cm wide x 40-cm long x 10- to 15-cm deep. These pans should be kept covered until immediately before the rainfall begins. This type of collection method has frequently been used in research to collect surface runoff from cultivated fields and pastures.

Automated runoff samplers are available to collect continuous or discrete samples of runoff. The continuous samplers often collect samples in proportion to water flow to provide an unbiased sample taken over time. These samplers also can be set to sample according to a time schedule. The disadvantage of automatic samplers is their initial cost. A single, automated runoff sampler usually costs $2,000 to $3,000 US dollars. Manual, grab sampling will be the only feasible type of sampling that can be considered practical at most farms.

Sampling frequency

Where a more or less continuous discharge from farming operations occurs, four samples per year spaced about three months apart would be sufficient. Some aquaculture farms produce two or more crops per year, and they may not discharge except during crop periods. For two crops per year, two samples should be secured per crop, one at one-third crop duration and the other at two-thirds crop duration. Where three or more crops are produced annually, at least four samples should be taken each year with two at one-third and two at two-thirds of crop duration.

The number of sample dates per year of nonpoint-source effluent (surface runoff) cannot be planned in advance according to the calendar, because rainfall events do not follow the calendar other than in seasonal patterns. Rainfall events also are less common in some regions than in others, and particularly with respect to events that result in surface runoff. As a general rule, if it has not rained for the past five days, a rainfall intensity of 1- to 2-cm depth over a period of two or three hours or less is necessary to generate water flow over the land surface. The timing of rainfall at a particular location varies both with time of year and hour during a given day. Some regions have well-defined wet seasons and rainy seasons that would limit the sampling opportunities primarily to the wet season.

Farmers would have to be aware of impending rainfall events in advance from local weather forecasts and be prepared to take samples. Individual farmers cannot be expected to take advantage of each sampling opportunity that nature provides because of unexpected or unscheduled events that demand immediate attention as common to us all. A sampling effort must be imposed on farmers, but in view of the uncertainty involved, the annual number of required sampling dates should not exceed three or four. These dates should be spread across the year, or the rainy season in some areas, with at least one month between sampling dates. The farmer will by necessity be the only one who can determine when to take samples.

In the case of irrigated agriculture, irrigation drainage could be an allowable surrogate for storm runoff sampling. The best approach would be collection of both storm runoff and drainage samples, because the main variable of interest, the TDS concentration, will usually be much greater in the drainage water than in the stormwater runoff from the irrigated field.

In the event that first order stream sampling is adopted for *Codex Planetarius*, the total number of samples would be much less than for farm sampling by a block arrangement or by individual farms. The best approach would be to secure monthly stream samples for analysis.

Handling samples

The sample volume collected should exceed the minimum required for the analyses of the variables of concern (Tables 5, 6, and 7). Suggested volumes for individual variables are: BOD_5, 600 mL; TSS, 300 mL; TDS, 200 mL; total phosphorus, 200 mL; total nitrogen, 300 mL. A 1.6-liter sample would be needed if all these analyses must be made from a single water sample bottle. Individual farms will not be required to have all the analyses made, and a 1.0-liter sample should be adequate in most cases, but the actual situation should be the guide. If the sampling is done according to the first order stream sampling option, all the analyses might be required. Dissolved oxygen was not included in the sample requirement volume, because it must be done onsite and in situ with a dissolved oxygen meter.

The sample bottles must be clean, and plastic bottles are preferable over glass bottles for safety reasons. The samples should be held in the dark, on ice, but not frozen. The analyses, especially for BOD_5, must be initiated within 24 hours of collection.

The bottles must be carefully labeled as to date and farm, and the laboratory must be informed as to the desired analyses. *Codex Planetarius* should develop some type of bottle label unto which the farmer can write the information needed by the laboratory.

Laboratories and analytical methods

The analyses should be made by a commercial, university, or governmental laboratory holding one or more internationally recognized laboratory certifications. There must be insistence upon a single methodology of analysis for each variable across all laboratories. The procedures to be used should be those described by the most recent or second most recent edition of the book *"Standard Methods for the Examination of Water and Wastewater"* published as updated editions at intervals of a few years by the American Public Health Association.

Every two or three years, *Codex Planetarius* should contract with a reliable laboratory that is not involved in the program to make standard concentrations of the water quality variables. These samples should be sent to participating laboratories to assess the performance of each laboratory.

Implementation

Farms that will participate in *Codex Planetarius* should be allowed a period of up to a year to install or improve existing practices for lessening the pollution potential of farm effluent or runoff. There should also be a period of possibly two years, to determine if the standards which are initially adopted are of sufficient rigor yet not unreasonable with respect to effort for compliance.

Once the program is initiated, a schedule for correcting non-compliance will be necessary. A period of six months to one year should be sufficient. Farmers will be responsible for sampling, but oversight must be provided by some governmental agency in each participating country. The results of the sample analyses should go to the governmental authority that would keep farms informed of their status. Periodic and unannounced visits by an auditor to take samples for analysis independently of the farmer's samples and to check the practices in place at farms would seem a necessity.

Cost to farmers

The expense of taking samples and sending them to a laboratory will be highly variable and vary by location, but it must be imposed on the farmers. Farms that will require DO concentration measurements would need to spend \$500–\$1,000 US dollars for a portable dissolved oxygen meter. This device, if taken care of, should perform well for at least five years. It also is easy to operate, but it must be calibrated before taking readings of DO concentrations.

The cost estimates for analyses, including the purchase of a DO meter, are listed in **Table 8 (pg. 13).** The cost of the required analyses in terrestrial farming ranged from \$100 US dollars/yr for irrigated crops to \$400 US dollars/yr for intensive CAFOs. In aquatic farming, no analytical cost would be incurred for mollusk and seaweed farming. The cost for other categories ranged from \$160 US dollars/yr for fertilized ponds to \$560 US dollars/yr for feed-based ponds. The cost of water clarity analyses for cage and net pens could be reduced from \$300 US dollars per year to a few dollars per year if a Secchi disk that costs about \$75 US dollars and lasts for many years is used to measure water clarity as a surrogate to laboratory turbidity analyses.

The farms will have to be audited, and auditing by internationally accredited auditing firms is expensive. While larger farms could afford such costs, it would not be possible for small farmers to bear the cost of auditing. Some type of block auditing could possibly be arranged, but it seems more reasonable for governments to bear the auditing responsibility.

Cost to governments

Effective oversight by national governments will be essential in *Codex Planetarius.* The program could result in smaller quantities of agricultural products for export where farmers fail to comply with effluent and other *Codex* standards. The problem is that effective auditing and oversight will be a significant expense. It likely would be several to many millions of US dollars annually depending upon how many farms and how much production is realized in a particular country.

The desirability to export agricultural products and to lessen cost to governments could lead to lax governmental oversight. As a result, if *Codex Planetarius* is eventually implemented, the World Trade Organization would likely incur costs in efforts to confirm the effectiveness of government oversight.

Conclusions

The information given here should be useful to those charged with developing the initial working standards for the water effluent quality impact of agriculture and aquaculture if for no more than as a framework around which to base their initial deliberations. For those with little previous involvement in water pollution abatement efforts, this report should serve as a primer on effluent water quality and on the ways in which point-source pollution standards have been formulated.

The development of water quality standards for *Codex Planetarius* will be a minimalist approach by necessity. This does not imply that it will not be a notable step forward in improving effluent regulations and other environmental regulations in agriculture. It will represent the first step in applying metric-based water quality standards to nonpoint-source pollution in agriculture. It also will bring water quality and other standards to bear on food and fiber crops intended for international trade. The necessity to comply with these standards would put a greater onus on national governments to move forward with effluent and other environmental regulations on agriculture and aquaculture.

Water quality standards proposed here and suggestions for water quality sampling and analyses are intended as background material for use in developing *Codex Planetarius*. The writer personally feels that one standard is really not enough to afford sufficient environmental protection, and generally suggested a second standard. The main thrust was to consider how metric-based standards might be applied to nonpoint-source water pollution. The application of metric-based standards to agricultural runoff would be a major accomplishment. ■

Footnotes / Citations

[1] The key negative impacts initially proposed for the Codex Planetarius: biodiversity loss; habitat loss (land use); soil health (soil quality); water intake quantity (freshwater use); water effluent quality (water pollution); and greenhouse gas emissions (energy use primarily); agrochemical toxicity (primarily pesticide use).

Tables

Table 1. The 10 pesticides used in greatest quantities worldwide and their uses

Pesticide	Approximate amount[1] (tonnes)	Uses[2]
Metam phosphate	800,000	F, H, I, N
Glyphosate	800,000	H
Metam	500,000	F, H, I, N
Dichloropropene	350,000	H, N
Petroleum oil	110,000	A, F, H, I
Chlorothalonil	100,000	F
2, 4 D	98,000	H, P
Metolachlor	90,000	H
Chloropicrin	80,000	N
Atrazine	75,000	H
TOTAL	**3,003,000**	**---**

[1] Estimated from a graphic with $\log_{10}$ scale of concentrations.
[2] **F** = Fungicide; **H** = Herbicide; **I** = Insecticide; **N** = Nematicide; **A** = Acaricide; **P** = Plant growth regulator

Source: Maggi, et al., 2019. Scientific Data. https://doi.org/10.1038/s41597-019-0169-4

Table 2. Farming catagories

Terrestrial crops	Aquatic crops
Fiber • Pulp • Cotton Animals • Dairy and beef • Swine • Chicken Oil seed • Palm • Soy and others Cereal and other grains Roots and tubers Sugar	Seaweeds Mollusk Fish and crustaceans • Without feed • With feed – Carp, tilapia, etc. – Salmon and trout – Shrimp and other crustaceans – Tuna – Other

Table 3. Median concentrations of water quality variables in world river water from the GRQA: Global River Water Quality Archive – ESSD Copernicus (https://essd.copernicus.org/articles/13/5483/2021)

Symbol	Variable (concentration unit)	Sites	n	Median	Outliers (%)
BOD	Biochemical oxygen demand (mg/L)	295	163,551	2.630	13.4
BOD_5	5-day biological oxygen demand (mg/L)	13,285	278,629	5.880	8.3
DO	Dissolved oxygen (mg/L)	48,072	1,487,724	8.340	2.2
DO sat	Dissolved oxygen saturation (%)	34,949	953,274	92.160	8.7
pH	Negative log H^+ activity (pH)	27,577	1,372,794	6.890	14.1
TN	Total nitrogen (mg/L)	18,507	575,887	1.330	11.9
NO_3-N	Nitrate nitrogen (mg/L)	45,422	1,229,584	0.468	11.1
TAN	Total ammonia nitrogen (mg/L)	27,980	717,776	0.065	13.3
TP	Total phosphorus (mg/L)	44,990	1,914,538	0.105	11.8
TDP	Total dissolved phosphorus (mg/L)	3,325	169,297	0.031	11.3
TSS	Total suspended solids (mg/L)	68,592	1,958,429	9.780	20.5
TDS[1]	Total dissolved solids (mg/L)	---	---	118.0	---

[1] The Open University 2016, Understanding water quality (https://www.classcentral.com/course/openlearn-environmental-studies- understanding-wat-95983).

Table 4. Summary of concentrations of selected water pollutants in effluents from different types of farm effluents

Effluent source	Concentration range (mg/L)			
	TSS	BOD_5	Total nitrogen	Total phosphorus
Animal rearing:				
Houses (CAFOs)	2,000–10,000	700–7,000	300–2,000	50–500
Feed lots (CAFOs)	2,500–5,000	1,500–2,500	50–500	10–100
Milking parlors	2,000–3,000	1,200–2,000	200–300	35–45
Surface runoff from less intense production	800–1,600	500–200	---	---
Extensive pastures and rangeland	30–60	25–50	1–3	0.25–0.75
Plant crops:				
Grains and oil crops	50–1,000	25–100	1–5	0.5–1.5
Rice	50–100	1–6	1–10	0.1–0.6
Vegetables and tubers	2–24	1–3	4–16	0.6–2.7
Cotton	---	---	2–5	0.8–1.1
Forage crops	30–50	6–18	0.6–1.0	0.25–0.5
Palm oil	20–40	5–6	0.02–0.69	0.01–0.24
Irrigation drainage[1]	1–3	1–5	1–6	0.1–1.2
Aquaculture:				
Fertilized ponds	10–50	5–10	1–2	0.05–0.1
Feed-based ponds	25–150	10–50	2–10	0.5–1.0
Flow-through	10–20	5–10	1–2	0.2–0.5
RAS	50–100	60–150	5–10	1–2

[1] Salinity or TDS concentration ranges from <500 mg/L to >5,000 mg/L.

Table 5. Typical costs of wastewater pollutant analyses by commercial laboratories

Variable	Cost (US$)
pH	5–10
Total dissolved solids (TDS)	15–20
Electrical conductivity	5–10
Total suspended solids (TSS)	20–40
Turbidity	10–25
5-day biochemical oxygen demand (BOD_5)	40–50
Total nitrogen	20–50
Total phosphorus	15–25
Metals (includes all common metals of concern)	50–100
Synthetic organic compounds	
• Range for single compounds	20–1,200
• Typical for common, single compounds	100–200

Table 6. Suggested standards for effluents from terrestrial farming. Unless otherwise indicated, the standards are maximum allowable limits.

Farming type	Standard	Suggested additional standard
Intensive CAFOs	30 mg/L BOD_5	5 mg/L DO or above[1]
Extensive animal lots with feeding	20 mg/L BOD_5	5 mg/L DO or above[1]
Pastured or range animals without feeding	20 mg/L BOD_5	
Pulp plantations:		
• Without fertilizer	15 mg/L TSS[2]	0.5 mg/L TP
• Fertilized	15 mg/L TSS[2]	0.5 mg/L TP
Palm oil	15 mg/L TSS	0.5 mg/L TP
Grain, oil seed, vegetable, tuber, and flower crops:		
• Without irrigation	50 mg/L TSS	0.75 g/L TP
• With irrigation	1,000 mg/L TDS	0.75 mg/L TP
Hay crops and orchards	15 mg/L TSS	1.0 mg/L TN

[1] 6 mg/L DO or above when receiving water body contains cool or coldwater fish species.

[2] Measurements must be continued following harvest to verify that harvest practices were sufficient to maintain compliance.

Table 7. Suggested standards for aquaculture effluents. Unless otherwise indicated, the standards are maximum allowable limits.

Culture system	Standard[1]	Suggested additional standard
Aquaculture ponds:		
• Fertilized	25 mg/L TSS	
• Feed applied	30 mg/L BOD_5	30 mg/L TSS
Raceways and other flow-through units:		
• Cool or coldwater	5 mg/L TSS increase	6 mg/L DO or above
• Warm water or tropical	10 mg/L TSS increase	5 mg/L DO or above
Cages and net pens: • Inland waters • Estuaries and ocean	– No decrease in average, annual water clarity[2] – FCR of 1.3 for salmonids and of 1.7 for other fish species	FCR[3] of 1.6
RAS	– BOD_5 for 30 mg/L unless discharged into a treatment system	
Seaweed and mollusk[4]	None	

[1] In cases where culture systems contain saline water and discharge into freshwater bodies, the effluent must not increase salinity above 1,000 mg/L in the mixing zone.

[2] Water clarity measured monthly in situ with standard Secchi disk or on a sample by nephelometry.

[3] FCR = feed conversion ratio (annual feed input ÷ annual harvested biomass).

[4] Should be no interference with navigation by farms and a plan for avoiding loss of ropes, floats, lines, or other gear that might lead to entanglement of fish and other species.

Table 8. Estimated analytical cost for *Codex Planetarius* standards.[1]

Type of farming	Four samples per year	DO meter[2]
Terrestrial		
Animal crops:		
• Intensive CAFOs	200	200
• Extensive feed lots	200	200
• Pasture or rangeland with feeding	200	
Plant crops:		
• Pulp and palm oil	260	
• Non-irrigated row crops	260	
• Irrigated crops	180	
• Hay crops and orchards	360	
Aquatic:		
• Fertilized ponds	160	
• Ponds with feeding	360	200
• Flow-through	100	200
• RAS	300	
• Net pen and cages	300[3]	
• Mollusk and seaweed	---	

[1] Based on high end of ranges of analytical costs in Tables 5 and 6.

[2] Based on $800 US dollars for DO meter, $40 US dollars/yr maintenance, and five-year service life.

[3] FCR = feed conversion ratio (annual feed input ÷ annual harvested biomass).

[4] Based on using laboratory to analyze water clarity in NTU.