Basic water chemistry for hydroponic systems

Grant Kinkead
Independent Researcher, Melbourne, VIC, Australia
grant@kinkead.au

***Abstract*—Hydroponic production depends on water that functions not merely as a neutral liquid, but as the chemical medium through which dissolved nutrients and other constituents are presented to plant roots. Before nutrients are added, source water may already contain dissolved ions, weakly buffered carbonate species, hardness-forming minerals, suspended matter, and biological contaminants, all of which influence later chemical adjustment and interpretation. This paper synthesises review-based evidence on the water-chemistry concepts that matter before a hydroponic nutrient solution is prepared. It focuses on three questions: how water acts as a solvent for ionic and molecular solutes, how pure water differs from real source waters, and why both total concentration and ionic composition must be considered when assessing hydroponic source water. Across the evidence base, electrical conductivity is shown to be useful as a rapid indicator of overall dissolved load, but insufficient for identifying which ions are present or how they will influence solubility, precipitation, and nutrient management. The synthesis indicates that chemically interpreting source water requires attention to both quantity and identity of dissolved constituents. The practical implication is that hydroponic water assessment should begin with recognition that the starting water already exerts chemical effects, which shape every subsequent nutrient, pH, and management decision.**

I. Introduction

Hydroponic cultivation is built on a simple but chemically demanding premise: plant roots obtain essential mineral nutrients from a prepared aqueous solution rather than from soil, so the properties of the water medium become central to nutrient delivery and availability. Reviews of hydroponic systems consistently describe nutrient solution as the medium through which essential elements, other than carbon, hydrogen, and oxygen, are supplied, while also noting that pH affects solubility and precipitation within that solution [1]. This means water is not a passive backdrop. It is the solvent that carries ionic and molecular solutes to the root zone, and its pre-existing chemistry can either support or complicate later solution preparation. A useful interpretation of hydroponic performance therefore begins before fertilisers are mixed, at the level of the starting water itself [1], [2], [3].

The need for that starting-point analysis becomes clear when real water supplies are compared with the chemical abstraction of pure water. Reviews of irrigation and production waters identify a wide range of relevant physical, chemical, and biological parameters, including pH, electrical conductivity, total dissolved solids, sodium adsorption ratio, bicarbonate and carbonate chemistry, suspended solids, and microbial contamination [4]. In practice, then, the water entering a hydroponic system already contains dissolved and suspended constituents that are absent from ideal pure water. Those constituents matter because they alter the chemical baseline from which growers attempt to build a controlled nutrient solution. The conceptual distinction between water itself and the solutes it carries is therefore foundational to hydroponic water chemistry, not a secondary technical detail [4], [5].

A further complication is that total dissolved load does not by itself explain water behaviour. The irrigation-water literature distinguishes among EC or TDS, sodium-related indices, residual carbonate effects, hardness, pH, and specific ions, showing that similar overall dissolved loads can correspond to very different chemical consequences [4]. For hydroponics, this distinction is critical because management decisions are often made quickly from bulk indicators, yet nutrient availability, precipitation risk, and suitability for recirculation depend on which ions are present, not only on how much dissolved material exists in aggregate [4], [6]. This paper addresses that problem by synthesising evidence on the role of water as a solvent, the difference between pure water and real source waters, and the reason concentration and ionic composition must both be considered before a hydroponic nutrient solution is formulated.

The paper is intentionally limited to basic water chemistry relevant to source water before nutrient preparation. It does not present new experiments, and it does not attempt a full treatment of fertiliser recipe design, pathogen control, or advanced automation. Instead, it provides an evidence-based overview of the concepts needed to answer a practical scientific question: what chemical properties of water matter before it is turned into a hydroponic nutrient solution? The argument developed throughout is that hydroponic water already contains chemically active constituents, and that these constituents influence every later adjustment involving nutrients, pH, and operational interpretation [1], [6].

II. Background and Scope

Prior hydroponic reviews establish that plant response depends not only on the addition of nutrients, but also on the composition of the nutrient solution, its pH, and its electrical conductivity. These works further indicate that source-water conditions affect solubility and precipitation processes, which means the initial water chemistry helps determine how successfully a later nutrient formulation behaves in practice [1]. The background literature therefore supports a practical distinction between chemically simple water used as a conceptual reference and operational water that already carries dissolved constituents. For hydroponic interpretation, the important implication is that water cannot be assumed to be chemically

blank at the moment of mixing. Its prior ionic content helps define what forms remain soluble, what interactions occur, and what corrections may be required [1], [2].

The same literature also clarifies an important measurement limitation. Electrical conductivity is widely used because it provides a rapid estimate of total ion concentration, yet reviews note that EC does not specify the concentrations of individual elements, nor does it reveal how pH-dependent reactions may alter solubility or absorption [1]. As a result, two waters with similar EC values may not be chemically equivalent for hydroponic purposes. One may contain ions that integrate readily into nutrient management, while another may contain ions that shift pH behaviour, encourage precipitation, or accumulate in recirculating systems. This gap between bulk concentration and chemical identity motivates the present synthesis, because growers and interpreters need concepts that move beyond a single-number description of water quality [1], [6].

Broader reviews of soilless agriculture reinforce this framing by describing nutrient solution as the primary medium delivering essential nutrients in place of soil, with pH, EC, and nutrient formulation treated as core operational variables [2]. That evidence supports the role of water as the solvent platform on which hydroponic chemistry depends. At the same time, it reveals a recurrent limitation in the literature: many sources explain nutrient-solution management or system performance at a high level, but fewer isolate the preliminary question of what source-water chemistry means before nutrients are added. This paper addresses that explanatory gap through synthesis rather than new experimentation. Its scope is confined to solvent role, dissolved substances, ions, concentration, and the distinction between pure water and real source waters, because those concepts are the necessary foundation for all later hydroponic chemical control [2], [7].

III. Core Concepts and Mechanisms

The first core concept is that hydroponic systems rely on nutrient-rich water rather than on soil as the immediate chemical environment of the roots. Reviews of soilless systems describe EC and pH as operational indicators and note that recirculating designs require monitoring of both nutrient and water balance over time [2]. This points to a basic mechanism: once dissolved, ions move within the aqueous phase and are presented to roots through the solution medium. Water is therefore the carrier that makes nutrient delivery possible, while the measurable condition of that water provides indirect evidence about the state of the dissolved phase. The design implication is that hydroponic water chemistry begins with recognising water as a managed chemical medium, not simply a transport fluid that becomes relevant only after fertiliser addition [2], [8].

The second core concept is the difference between pure water and real source waters. Evidence from water-chemistry review work shows that pure water in equilibrium with atmospheric carbon dioxide contains only a low dissolved solute load, whereas natural waters commonly contain bicarbonate, carbonate, calcium, magnesium, dissolved carbon dioxide, alkalinity, and hardness that vary with geology and biological processes [9]. This distinction matters because hydroponic source water is almost always drawn from real supplies rather than from chemically ideal water. Its pre-existing carbonate species and dissolved minerals can influence buffering behaviour, apparent hardness, and the chemical baseline against which added nutrients are interpreted. The implication is not that every source water is unsuitable, but that its dissolved composition is part of the nutrient-solution problem from the outset [9].

A third concept concerns the kinds of solutes that matter. Hydroponic reviews describe the system as depending on controlled mineral nutrient solutions and routine monitoring of pH, EC, and dissolved oxygen [8]. This evidence supports a solvent picture in which water carries both ionic species, such as nutrient salts dissociated into charged forms, and molecular solutes, such as dissolved gases relevant to root-zone conditions. From a chemical perspective, the solution is defined not only by the presence of water molecules but by the identities, proportions, and interactions of the dissolved substances within them. That is why water chemistry before nutrient addition remains important: source-water constituents can alter the environment into which later ionic and molecular solutes are introduced, thereby affecting interpretation and control even before plants experience the final solution [1], [8].

IV. Evidence Synthesis

Across the accepted sources, a consistent theme is that hydroponic management depends on operational indicators, but those indicators must be interpreted cautiously. Reviews discussing pH, EC, and dissolved oxygen treat them as central variables for controlled mineral nutrient solutions, and some provide indicative operating ranges for hydroponic practice [8]. Yet the same evidence also implies that total concentration is only one dimension of solution chemistry. EC may suggest that dissolved ions are present in low or high overall quantity, but it does not establish whether the ionic balance is appropriate, whether non-target ions are present, or whether chemical interactions will favour continued solubility. The synthesis therefore supports a layered interpretation of source water: bulk metrics are useful entry points, but they are not substitutes for understanding composition [1], [8].

A second pattern emerges when hydroponic evidence is compared with literature on irrigation water and non-ideal water sources. Reviews of wastewater hydroponics and production water show that actual waters may contain salts, nutrients, metals, microbes, pharmaceuticals, suspended matter, and other pollutants or contaminants [5]. Even where those sources are not centred on ordinary hydroponic feed water, they strongly reinforce the core distinction between pure water and practical source waters. Their value for the present topic is conceptual: they demonstrate that water entering cultivation systems can already carry multiple chemical and biological burdens. The limitation is that such literature often addresses contaminated or recycled waters rather than routine fresh

supplies. Even so, it confirms that interpreting hydroponic source water requires attention to what the water is carrying, not just to the volume of water available [5], [10].

The strongest hydroponic-specific synthesis comes from nutrient-solution management reviews that state directly that EC alone does not reveal individual ion concentrations and that pH and ion-specific monitoring improve solution management [6]. This is decisive for the present argument. If overall conductivity cannot identify macro- or micronutrient concentrations, then two chemically different waters may appear similar when assessed only by a bulk concentration measure. Source water interpretation must therefore consider both concentration and ionic composition, because nutrient availability, accumulation patterns, and management responses depend on which ions are present and how they change over time. In hydroponic chemistry, quantity without identity is an incomplete description, and identity without concentration is equally insufficient for sound interpretation [4], [6].

Additional contextual sources support this synthesis while also showing its limits. Soil-root and aquaculture reviews both describe water as a carrier of dissolved species involved in nutrient movement, alkalinity, hardness, and related reactions [9], [11]. An aeration study that used tap water rather than ideal pure water also lightly illustrates that experimental and operational waters commonly begin with measurable conductivity and dissolved constituents [12]. However, these sources are not hydroponic-specific explanations of source-water chemistry. Their contribution is therefore supportive rather than definitive. Taken together with the hydroponic reviews, they strengthen the general chemical logic that water in cultivation systems is a solvent medium populated by dissolved substances whose quantity and identity both matter [9], [11], [12].

V. Practical Implications and Limitations

For hydroponic practice, one implication of the evidence is that source water should be understood as chemically active even before nutrient stock is added. Nutrient-solution management reviews explain that hydroponic source and recirculating waters can accumulate sodium, chloride, and unequal nutrient concentrations over time, while EC alone cannot specify individual ions [6]. Although accumulation is often discussed in operating systems, the same principle begins at the source-water stage: if the starting water already contains dissolved constituents, these become part of the solution inventory from the first mixing event. The practical consequence is that later adjustments are never made to water alone, but to water plus its inherited solute load. This does not dictate a single treatment response, but it does require chemically informed interpretation of the baseline [6].

A second implication is methodological. Because EC is fast and useful but cannot identify individual macro- or micronutrient concentrations, and because different ions can change differently over time, the evidence supports combining bulk indicators with more composition-sensitive assessment where accurate interpretation matters [6]. Irrigation-water and production-water reviews point in the same direction by showing that no single metric captures all relevant contaminant or suitability risks, since distinct chemical classes can create different operational outcomes [4], [10]. The limitation, however, is that the present evidence base is more consistent in establishing the principle than in specifying a universal measurement protocol for all hydroponic contexts. The safest supported conclusion is therefore conceptual: concentration and composition must both be considered, even if the exact analytical depth required will vary by water source and system design [6], [10].

The evidence also places boundaries on generalisation. Reviews of hydroponics define the system as plant growth without soil using mineral nutrient solution, with pH, temperature, oxygen, and nutrient concentrations identified as core parameters [7]. This strongly supports the role of water as the solvent carrying hydroponically relevant dissolved nutrients, but it does not mean all water-quality concerns can be reduced to the same hydroponic significance. Some supporting sources arise from aquaculture, wastewater treatment, or container production, and those contexts differ in purpose, contaminant profile, and operational priorities [5], [9], [10]. Their relevance lies in clarifying fundamental chemical distinctions, especially between pure and real waters, rather than in supplying hydroponic-specific thresholds for every constituent. The main validation need for future work is therefore more hydroponic-specific source-water evidence that links particular dissolved compositions to subsequent nutrient-solution behaviour [6], [7].

Another practical lesson concerns interpretation of apparently similar waters. Aquaculture chemistry evidence shows that waters with similar alkalinity or overall dissolved load can differ substantially in hardness, dissolved carbon dioxide, calcium, and magnesium [9]. Translated cautiously into the hydroponic context, this means a single bulk descriptor may conceal chemically meaningful differences in source water. Such hidden differences matter because they can alter buffering behaviour, interact with added nutrients, and shape the interpretation of later pH or conductivity measurements. The limitation is that the evidence does not quantify these effects specifically for hydroponic source water in this paper's dataset. Nevertheless, it provides strong conceptual support for avoiding overconfidence in simplified screening metrics when the underlying ionic composition may differ materially [4], [9].

VI. Conclusion

The evidence synthesised in this paper supports a clear answer to the central question of what chemical properties of water matter before it is turned into a hydroponic nutrient solution. Water matters first as the solvent that carries dissolved ionic and molecular solutes to plant roots, but it also matters as a pre-existing chemical medium whose own dissolved constituents influence later adjustment [1], [2], [8]. Real hydroponic source waters are not equivalent to pure water. They may already contain carbonate species, hardness-forming

ions, salts, nutrients, suspended matter, or contaminants, and these constituents shape how nutrient solutions are interpreted and managed [4], [5], [9].

The central analytical conclusion is that neither total concentration nor ionic composition is sufficient on its own. Bulk indicators such as EC are valuable because they quickly reflect dissolved load, but the literature is equally clear that they do not identify which ions are present or how those ions may affect solubility, precipitation, and nutrient management [1], [6]. The highest-value next work, within the limits already identified by the evidence, is more hydroponic-specific investigation of how particular source-water compositions influence subsequent nutrient-solution behaviour under operational conditions. Until such evidence is expanded, the most defensible scientific position is that hydroponic water should always be treated as chemically consequential before any nutrients are added [6], [7].

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REFERENCES

[1] R. S. Velazquez-Gonzalez, A. L. Garcia-Garcia, J. O. Barceinas-Sanchez, E. Ventura-Zapata, and J. C. Sosa-Savedra, "A review on hydroponics and the technologies associated for medium- and small-scale operations," *Agriculture*, 2022.

[2] I. A. Lakhiar, H. Yan, T. N. Syed, C. Zhang, S. A. Shaikh, M. Rakibuzzaman, and R. B. Vistro, "Soilless agricultural systems: Opportunities, challenges, and applications for enhancing horticultural resilience to climate change and urbanization," *Horticulturae*, 2025.

[3] O. V. Obayomi, D. C. Olawoyin, O. Oguntimehin, L. S. Mustapha, S. O. Kolade, P. O. Oladoye, S. Oh, and K. S. Obayomi, "Exploring emerging water treatment technologies for the removal of microbial pathogens," *Current Research in Biotechnology*, 2024.

[4] G. W. Anyangoa, G. D. Bhowmicka, and N. S. Bhattacharyab, "A critical review of irrigation water quality index and water quality management practices in micro-irrigation for efficient policy making," *Desalination and Water Treatment*, 2024.

[5] C. Mai, A. Mojiri, S. Palanisami, A. Altaee, Y. Huang, and J. L. Zhou, "Wastewater hydroponics for pollutant removal and food production: Principles, progress and future outlook," *Water*, 2023.

[6] E. Fathidarehnijeh, M. Nadeem, M. Cheema, R. Thomas, M. Krishnapillai, and L. Galagedara, "Current perspective on nutrient solution management strategies to improve the nutrient and water use efficiency in hydroponic systems," *Canadian Journal of Plant Science*, 2024.

[7] A. Fussy and J. Papenbrock, "An overview of soil and soilless cultivation techniques-chances, challenges and the neglected question of sustainability," *Plants*, 2022.

[8] M. Elakrouch, M. Mohaddab, A. Rachid, and M. H. Jijakli, "Soilless agriculture at a crossroads: Strengths, challenges, and prospects of hydroponics, aquaponics, and bioponics in relation to precision farming," *Sustainability*, 2026.

[9] C. E. Boyd, C. S. Tucker, and B. Somridhivej, "Alkalinity and hardness: Critical but elusive concepts in aquaculture," *Journal of the World Aquaculture Society*, 2016.

[10] J. C. Majsztrik, R. T. Fernandez, P. R. Fisher, D. R. Hitchcock, J. Lea-Cox, J. S. Owen, Jr., L. R. Oki, and S. A. White, "Water use and treatment in container-grown specialty crop production: A review," *Water, Air, & Soil Pollution*, 2017.

[11] N. Joshi, R. Kaur, and T. Nawaz, "The soil-root nexus: how soil health shapes plant nutrient uptake and food nutritional security," *Plant and Soil*, 2026.

[12] C. D. Mihaela Constantin and M. Oprea, "Thermodynamic analysis of oxygenation methods for stationary water: Mathematical modeling and experimental investigation," *Thermo*, 2025.