NOAA Technical Memorandum GLERL-139

CONVERSION OF SPECIFIC GRAVITY TO SALINITY FOR BALLAST WATER REGULATORY MANAGEMENT

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Errata

Section 1.2, Specific Gravity (page 6): the stated reference temperature for most hydrometers used aboard ships was corrected to 60°F. Previous versions of this report had it incorrectly listed as 60°C.

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Conversion of Specific Gravity to Salinity for Ballast Water Regulatory Management

David F. Reid

ABSTRACT. To reduce the risk of new aquatic species introductions to coastal ecosystem via the ballast tanks of ocean-going ships, both the United States and Canada have established regulatory and/or policy requirements based on assuring that the salinity of incoming ballast water, including residual ballast water, is 30 ppt or greater. However, common shipboard practice for management of ballast water is to determine the specific gravity of the water, not the salinity. Thus there is a technical disconnect between the information the ship typically records and what the regulatory agencies need. In 1981 a new equation of state for seawater was established, including a highly accurate mathematical relationship between density, salinity, temperature, and pressure. The equation is valid for salinity from 2 to 42 (practical salinity) and temperature from -2 to 35^{o}C. The equation of state for seawater was used to calculate a set of tables relating salinity to density and specific gravity, which were then converted into a related series of graphs, presented in this report, that can be used by ship's crews and regulators alike to convert between salinity and specific gravity.

1. INTRODUCTION

1.1 Background and Purpose

While a universal solution to the transoceanic dispersal of aquatic nuisance species through ship's ballast water is being developed, ballast water exchange and, more recently, ballast tank flushing and the resultant potential for salinity shock to fresh- and brackish-water biota have been and are the only practical and available defense for coastal waters and internal water bodies such as the Great Lakes-St. Lawrence Seaway system. Mid-ocean ballast exchange to achieve a ballast water salinity of at least 30 ppt is required for ships coming to U.S. and Canadian ports with or in ballast (U.S.: 33 *CFR Part 151 subpart C*; Canada: Canada Gazette*, Part II, Wednesday, June 28, 2006*). In August 2005 the U.S. Coast Guard implemented a new policy aimed at ships entering the Great Lakes with no pumpable ballast (NOBOB ships) to encourage the use of ballast water exchange or ballast tank flushing on the high seas to assure that the salinity of all water in their ballast tanks, including residual water, is at or above 30 ppt (U.S. Coast Guard, 2005). Similar regulations were established in Canada in June 2006 (Transport Canada, 2006). Thus it has become important for both mariners and U.S. and Canadian enforcement officials to know or be able to determine the salinity of water in ballast tanks.

Unlike the scientific community, mariners may not typically measure salinity while ballasting. Ships are primarily concerned with and measure the specific gravity of the water in which the ship floats, not the salinity. Enforcement officials typically measure the salinity in a water sample drawn from a ballast tank, via either a Refractive Salinometer or a hand-held electronic Conductivity-Salinity-Temperature Meter. Thus there can be a technical disconnect between the information a ship records (specific gravity) and what the regulatory agencies require and measure (salinity). This report provides a means to easily convert between salinity and specific gravity (or density) for purposes related to ballast water regulation.

1.2 Specific Gravity

Specific gravity is defined as the ratio of the density of a liquid to the density of pure water at a given reference temperature and atmospheric pressure (pressure at sea level). The standard instrument used on ships for measuring the specific gravity of water is a hydrometer. Modern hydrometers are usually made of glass, although marine hydrometers may also be made of brass. A hydrometer is a hollow tube with a thin cylindrical stem marked with a calibrated specific gravity scale and a wide bulb weighted at the base to make it float upright. The hydrometer is gently lowered into the water sample until it floats freely, and the reading where the surface of the water touches the stem is the specific gravity. For most hydrometers used aboard ships, the reference temperature is 60^{o}F (15.56^{o}C), although it may be another temperature depending on where the hydrometer was manufactured. Some hydrometers include a built-in thermometer to measure the sample temperature. The temperature of the sample at the time the specific gravity is measured is an important consideration (see section 2.2, below).

Specific gravity (or density) affects the depth to which the hull of a ship will submerge and thus the amount of cargo the ship can safely carry on her voyage as well as the depth of water that the ship requires for safe navigation. In particular, specific gravity determines the weight of the volume of ballast water taken on board and its consequent effect on trim, stability, and the stresses to which the hull is subjected. Although specific gravity is a ratio and therefore technically a unitless number, it is often reported as metric tonnes per cubic meter ($t/m^3 = kg/m^3$) for ballast-related purposes.

1.3 Equation of State of Seawater

In 1978 a new definition of salinity was established by the Joint Panel on Oceanographic Tables and Standards (UNESCO, 1981) called “practical salinity.” Practical salinity is defined and measured in reference to electrical conductivity of the seawater sample compared to that of a potassium chloride solution of a specific concentration. Practical salinity is a unitless number, but is essentially equivalent to the traditional “parts per thousand” unit of salinity that was used until the new definition was adopted in 1978. Salinity is now often reported as “psu” (practical salinity units) to make it clear that what is being reported is based on the practical salinity scale, although in some uses it is still reported as “parts per thousand” (ppt).

A new equation of state for seawater was established in 1981 by the Joint Panel on Oceanographic Tables and Standards (UNESCO 1981) and is considered valid over a temperature range of -2 to 35^{o}C and a practical salinity range of 2 to 42 psu. Related equations allow calculation of the density of seawater and the corresponding specific gravity as a function of practical salinity, temperature (°C), and pressure (bars). However, ballast water is taken from approximately the sea surface, where p = 0 (bars), which simplifies the calculations. Millero and Poisson (1981) calculated a standard error of 3.6 x 10^{-3} kg/m^3 for the one-atmosphere (p=0) equation of state, which is insignificant for the present purpose.

2. RELATIONSHIP BETWEEN SPECIFIC GRAVITY, SALINITY, AND TEMPERATURE AT THE OCEAN SURFACE

2.1 Calculation of Specific Gravity

For this report, UNESCO (1981) Equations 9 and 10 were used to calculate values of seawater density (kg/m^3) for given values of temperature and salinity over the ranges 0-35°C in 2.5°C intervals and, for each temperature, 2-42 psu, in 1 psu intervals. Specific gravity was then calculated for each value of salinity by dividing the calculate density of the water sample (S) at the selected temperature (T) by the density of pure water (0) at the reference temperature of 60°F (15.56°C) and multiplying by 1000.

$$\text{Specific Gravity} = (\rho_s(T)/\rho_0(15.56)) \text{ X } 1000$$

2.2 Measuring Specific Gravity with a Hydrometer – Importance of Temperature

When specific gravity is measured with a hydrometer, a water sample is drawn into a tube or other suitable container, and the hydrometer float is placed in the water and allowed to stabilize. The specific gravity is then read as described in Section 1.2. Since density is a function of temperature as well as salinity, it is important to measure the temperature of the water sample at the time the specific gravity is measured. This is illustrated by Figure 1, which shows the relationships between salinity and specific gravity at 5°C and 35°C. Note that for the same specific gravity, the salinity of a seawater sample at 5°C would be ~8-10 psu less than a sample with the same specific gravity but at 35°C.

Figures 2-16 show salinity vs. specific gravity (x 1000) for temperatures ranging from 0 to 35°C in 2.5°C increments and salinities ranging from 2 to 42 psu. For the purpose of ballast water characterization for regulatory purposes, 1 psu = 1 ppt.

2.3 Salinity-Specific Gravity Curves - How to Use Figures 2 - 16

Figures 2-16 may be used to find the equivalent salinity of ballast water for which both the temperature and the specific gravity at that temperature are known. The charts are provided with 1 psu and 1 t/m^3 grids. Values falling between whole units can be visually interpolated with accuracy of 0.5 psu or less, which should be sufficient for ballast-related purposes. When the temperature of the sample falls between charts, the chart with the closest temperature should be used.

Example 1: ballast water at 21°C has a specific gravity (x 1000) of 1028; using the chart for 20°C, find the specific gravity grid line for a value of 1028 on the vertical axis, read across to the plotted line and then read down to the corresponding salinity on the horizontal axis, estimated as 38.0 psu (= 38.0 ppt).

Example 2: ballast water at 9°C has a specific gravity (x 1000) of 1018; using the chart for 10°C, find the specific gravity grid line for a value of 1018 on the vertical axis, read across to the plotted line and then read down to the corresponding salinity on the horizontal axis, estimated as 22.2 psu (= 22.2 ppt).

3. REFERENCES

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U.S. Coast Guard. Ballast Water Management for Vessels Entering the Great Lakes That Declare No Ballast Onboard. Federal Register, Vol. 70, No. 168, Wednesday, August 31, 2005, Notices, 51831-51836 (2005).

4. ACKNOWLEDGEMENTS

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5. COMMENTS AND CORRECTIONS

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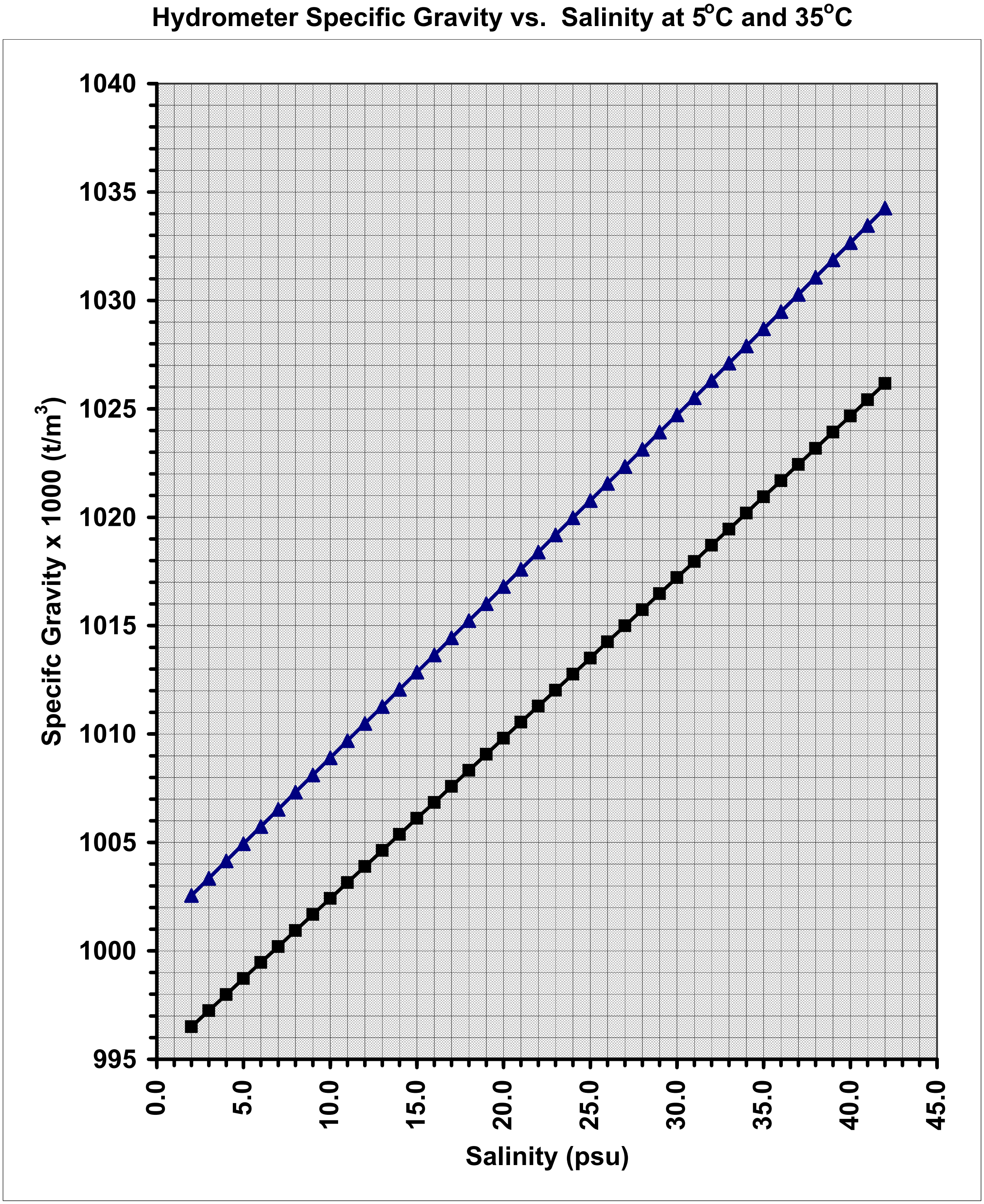

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Figure 1 **5°C and 35°C Comparison**

Hydrometer Specific Gravity vs. Salinity at 0°C

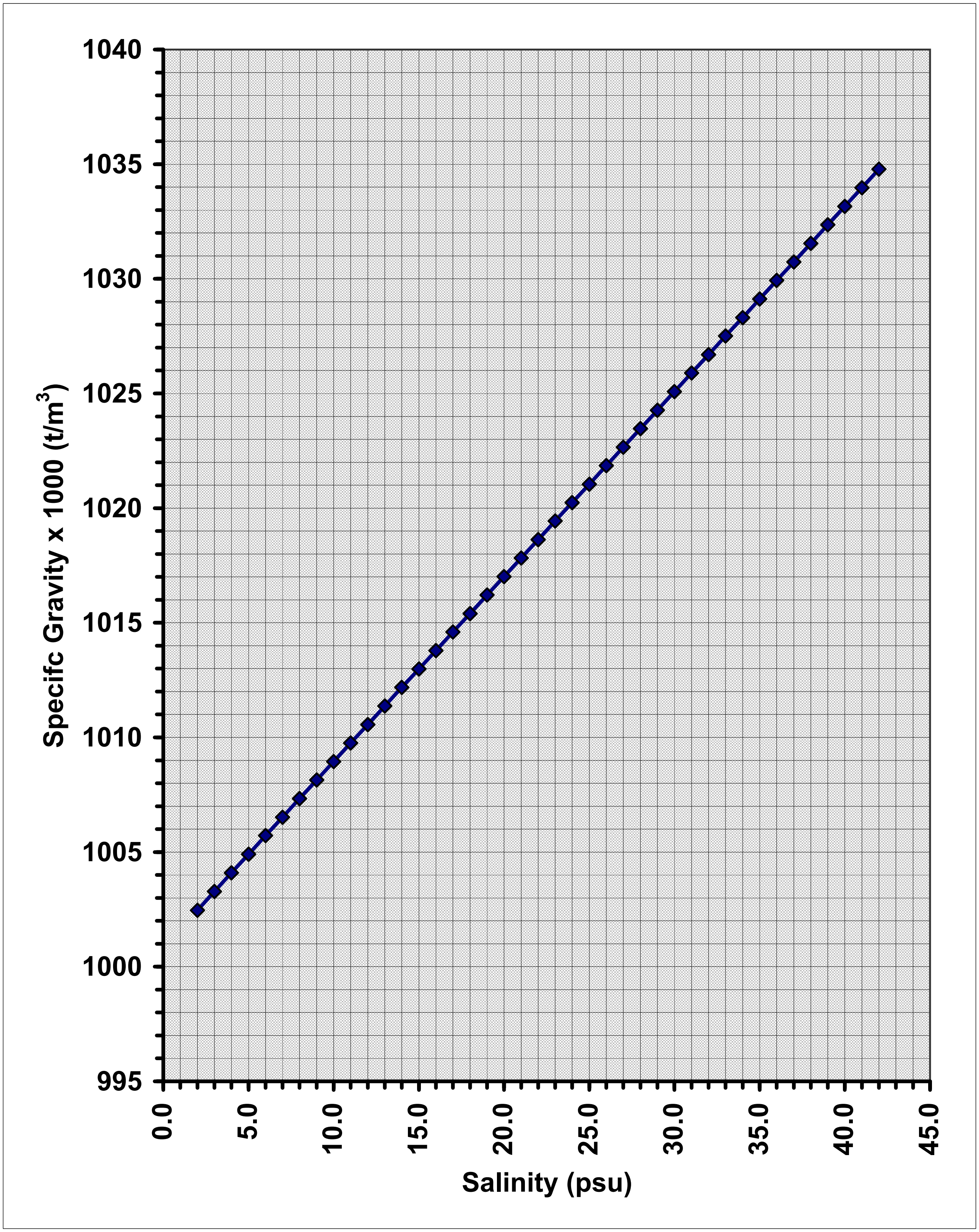

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Figure 2 **0°C**

Hydrometer Specific Gravity vs. Salinity at 2.5°C

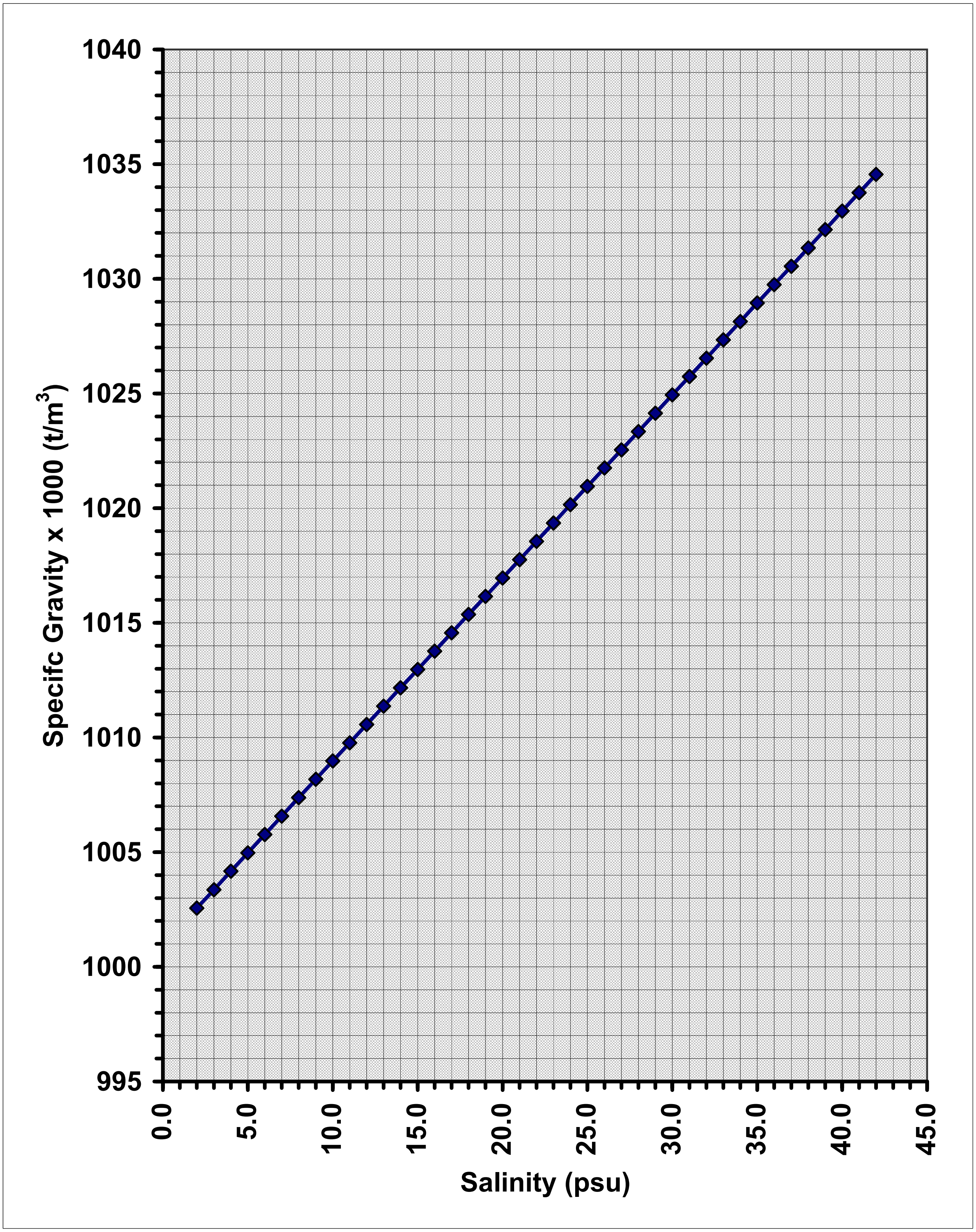

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Figure 3 **2.5°C**

Hydrometer Specific Gravity vs. Salinity at 5°C

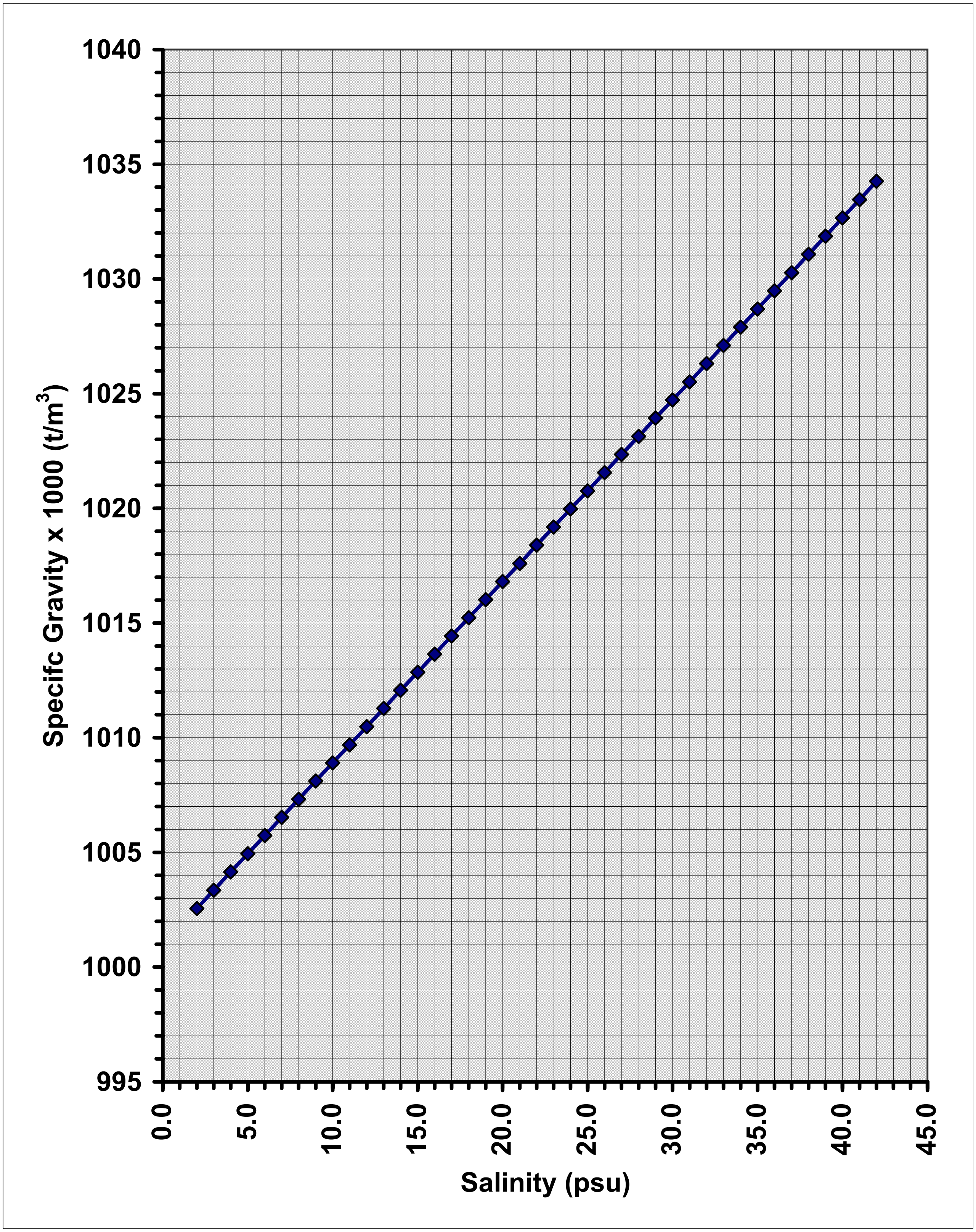

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Figure 4 **5°C**

Hydrometer Specific Gravity vs. Salinity at 7.5°C

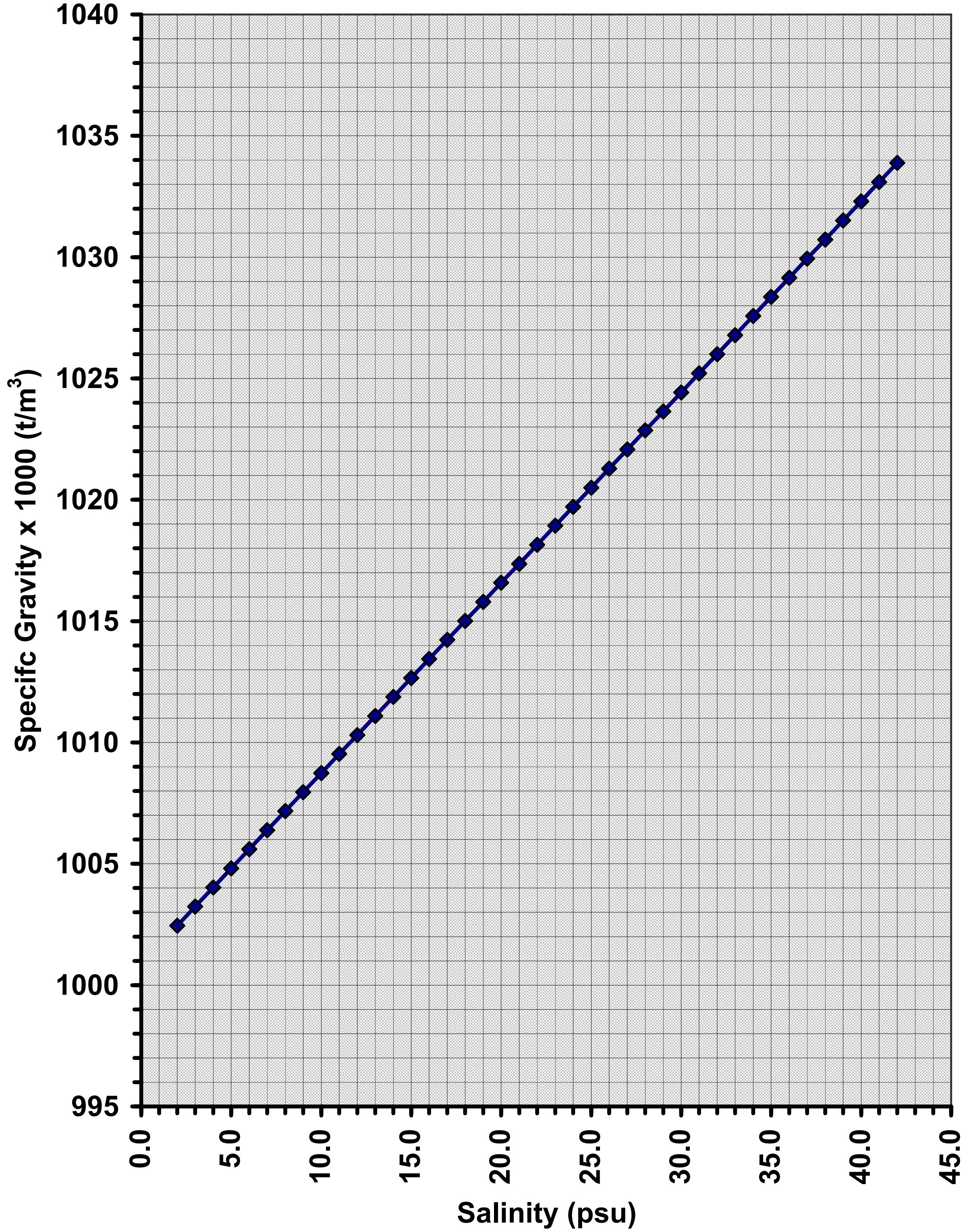

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Figure 5 **7.5°C**

Hydrometer Specific Gravity vs. Salinity at 10°C

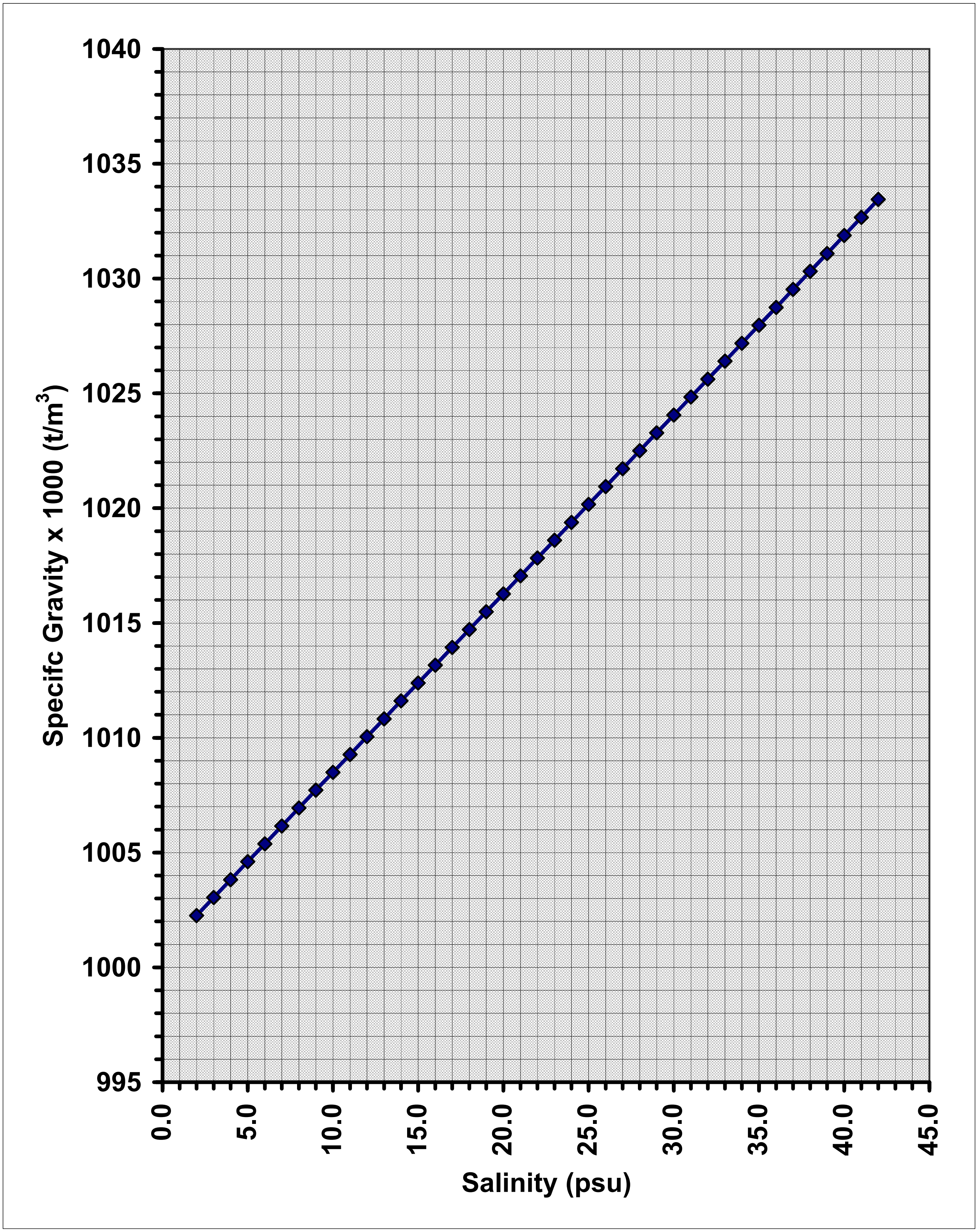

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Figure 6 **10°C**

Hydrometer Specific Gravity vs. Salinity at 12.5°C

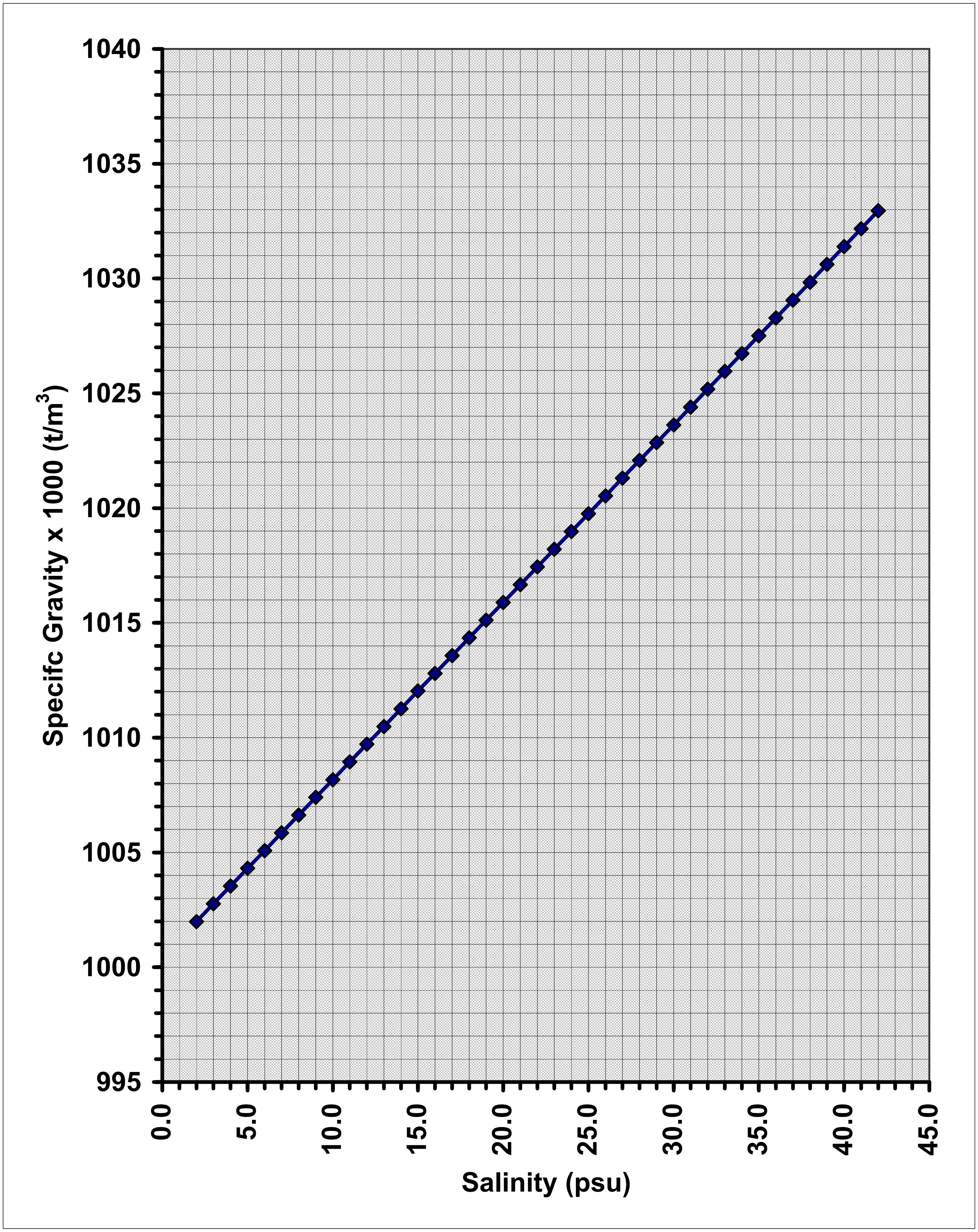

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Figure 7 **12.5°C**

Hydrometer Specific Gravity vs. Salinity at 15°C

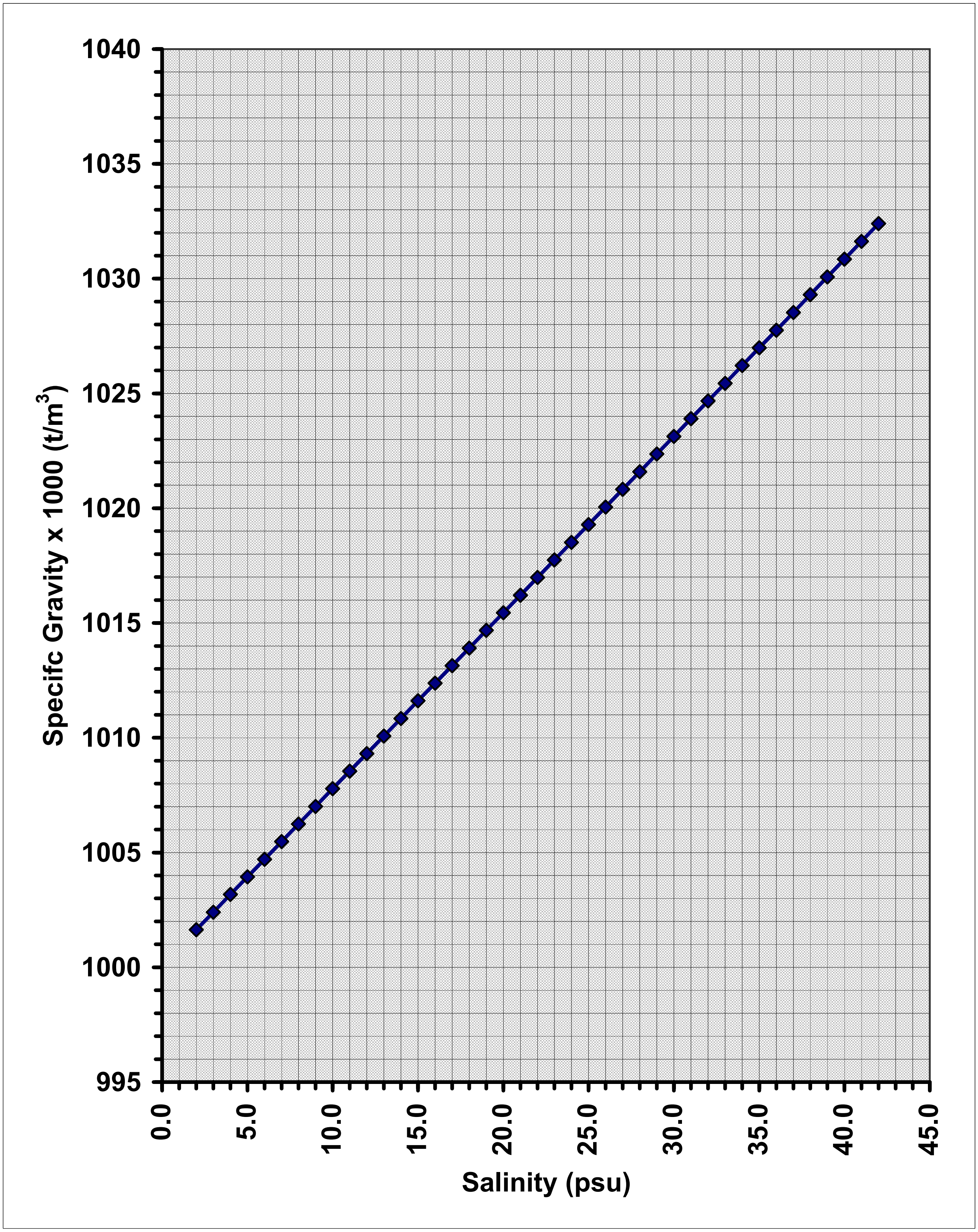

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Figure 8 **15°C**

Hydrometer Specific Gravity vs. Salinity at 17.5°C

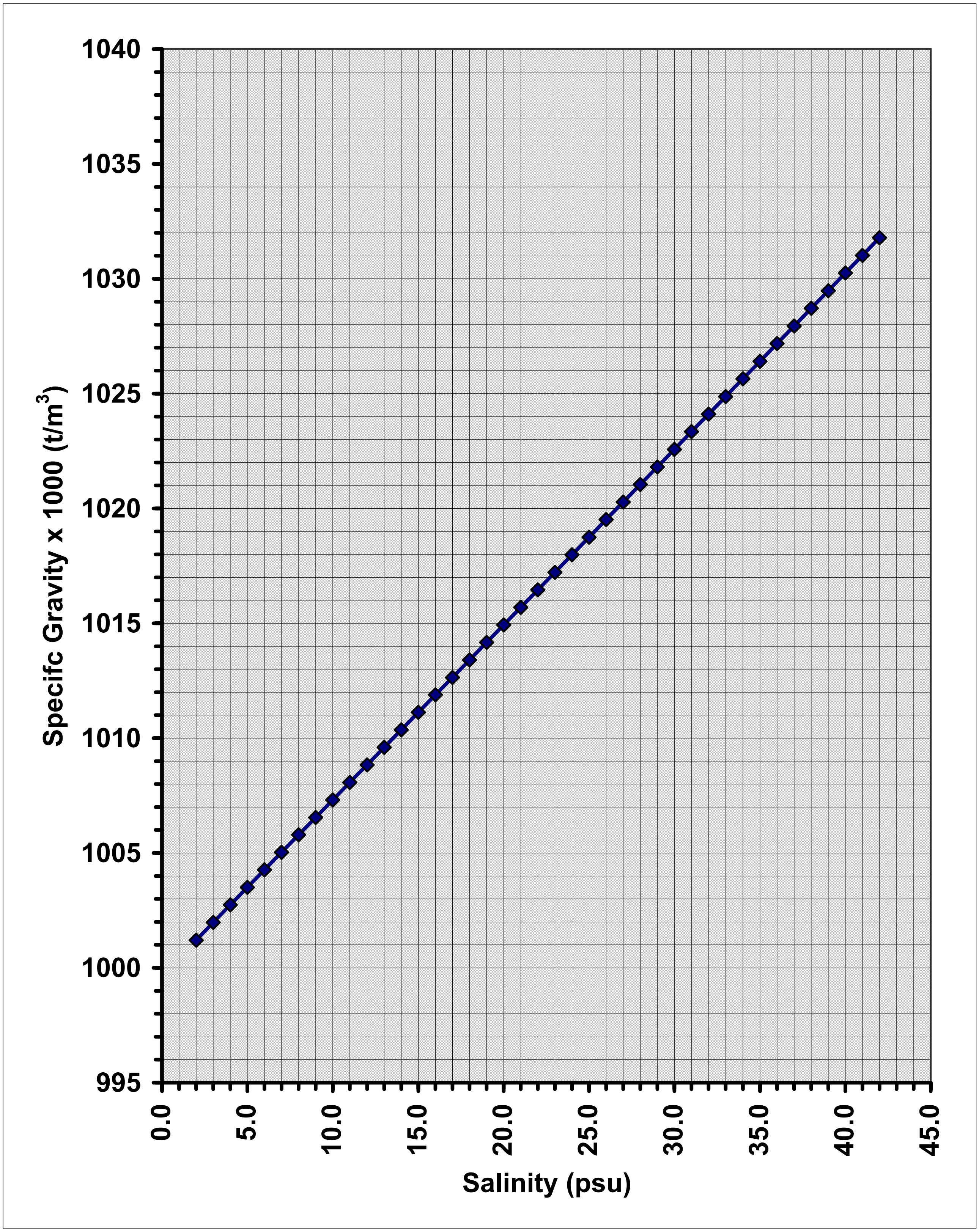

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Figure 9 **17.5°C**

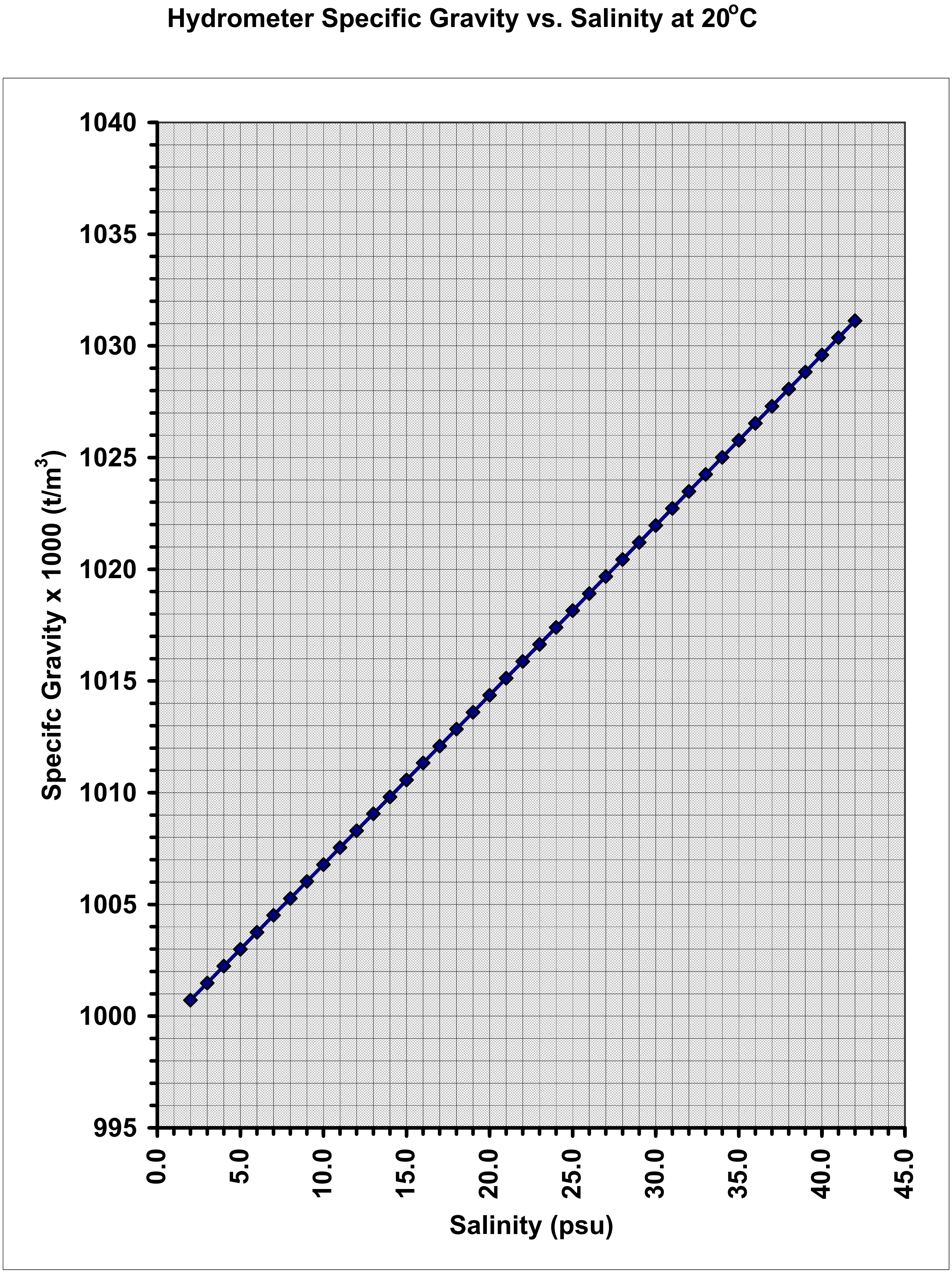

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Figure 10 **20°C**

Hydrometer Specific Gravity vs. Salinity at 22.5°C

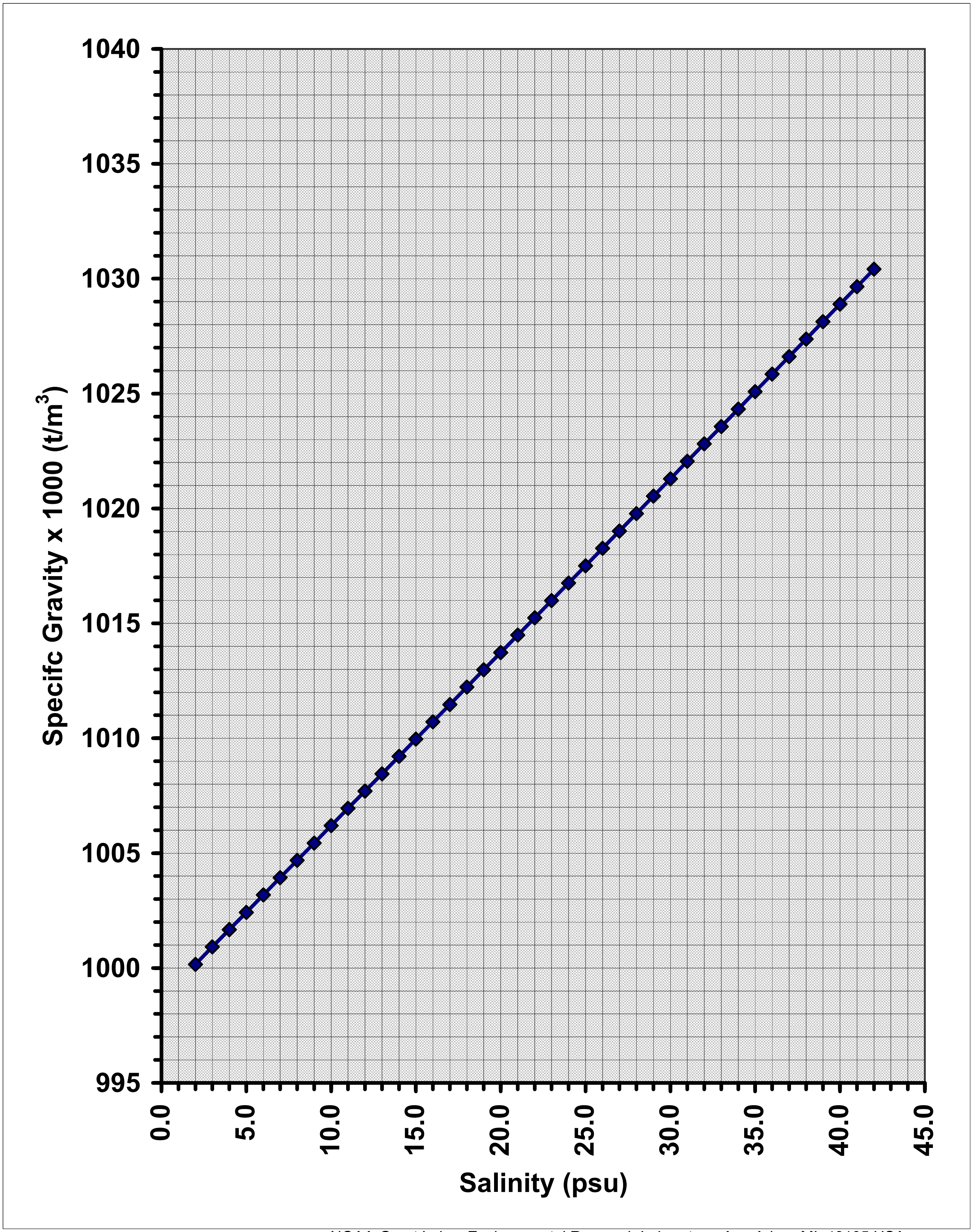

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Figure 11 **22.5°C**

Hydrometer Specific Gravity vs. Salinity at 25°C

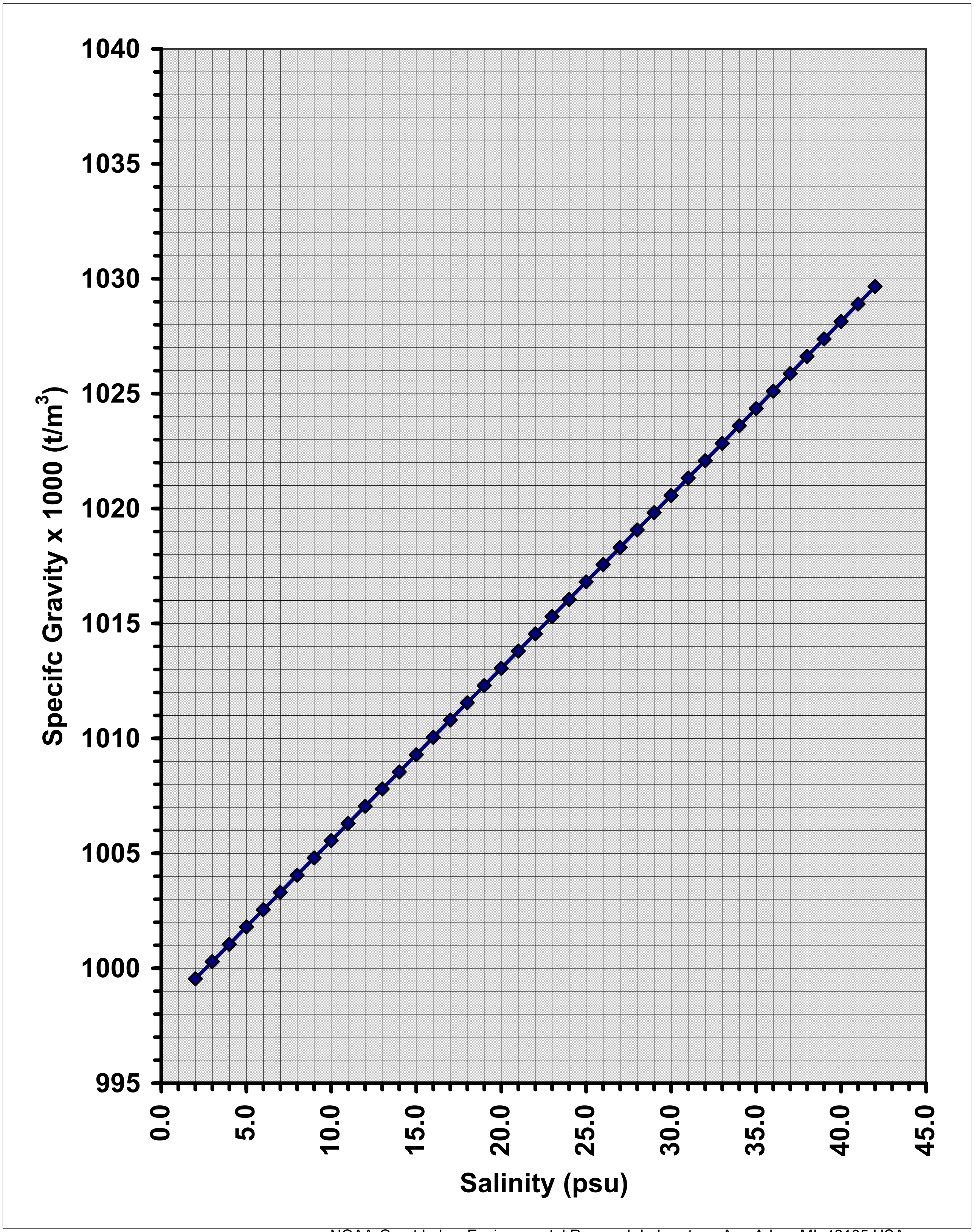

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Figure 12 **25°C**

Hydrometer Specific Gravity vs. Salinity at 27.5°C

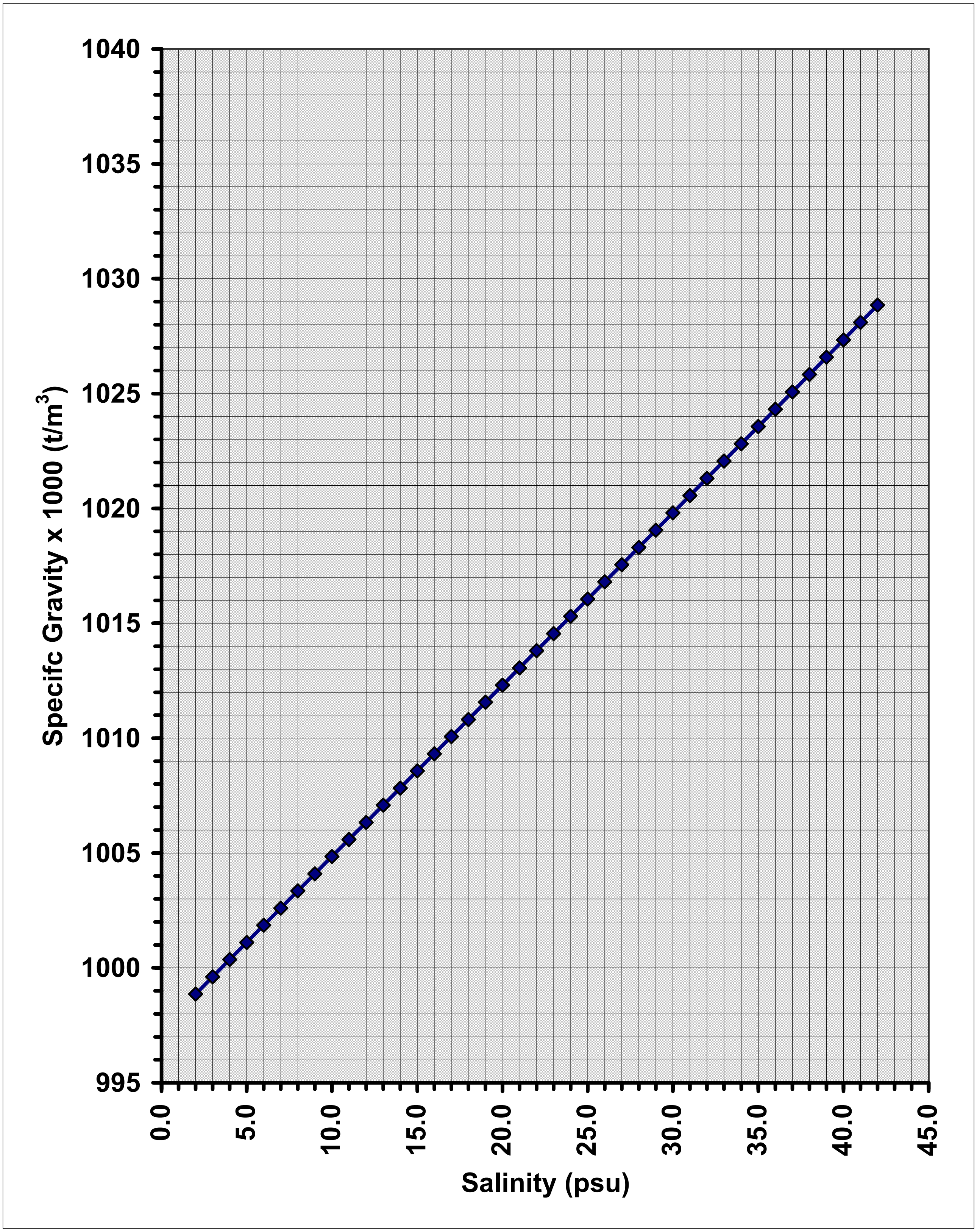

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Figure 13 **27.5°C**

Hydrometer Specific Gravity vs. Salinity at 30^{o}C

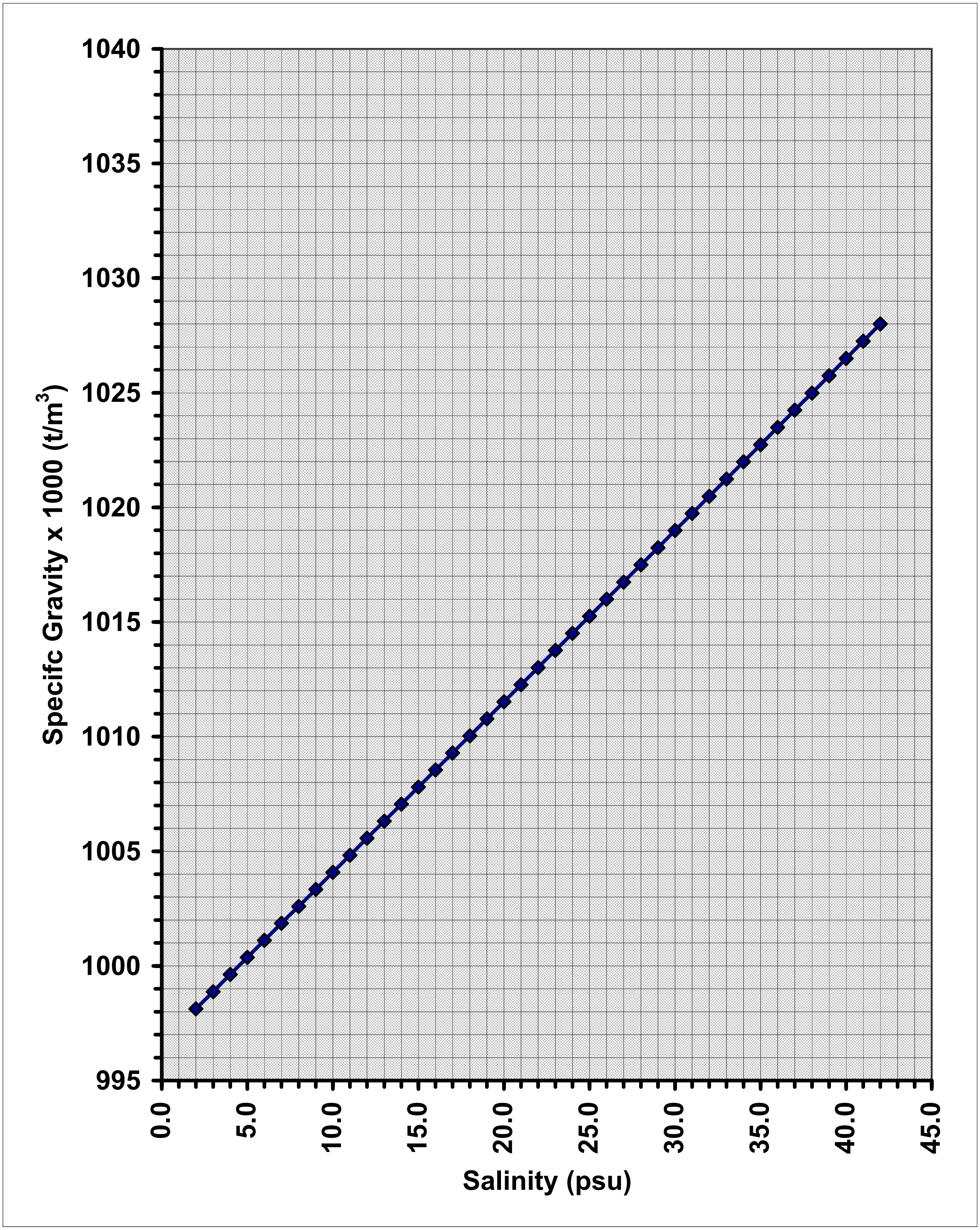

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Figure 14 **30^{o}C**

Hydrometer Specific Gravity vs. Salinity at 32.5°C

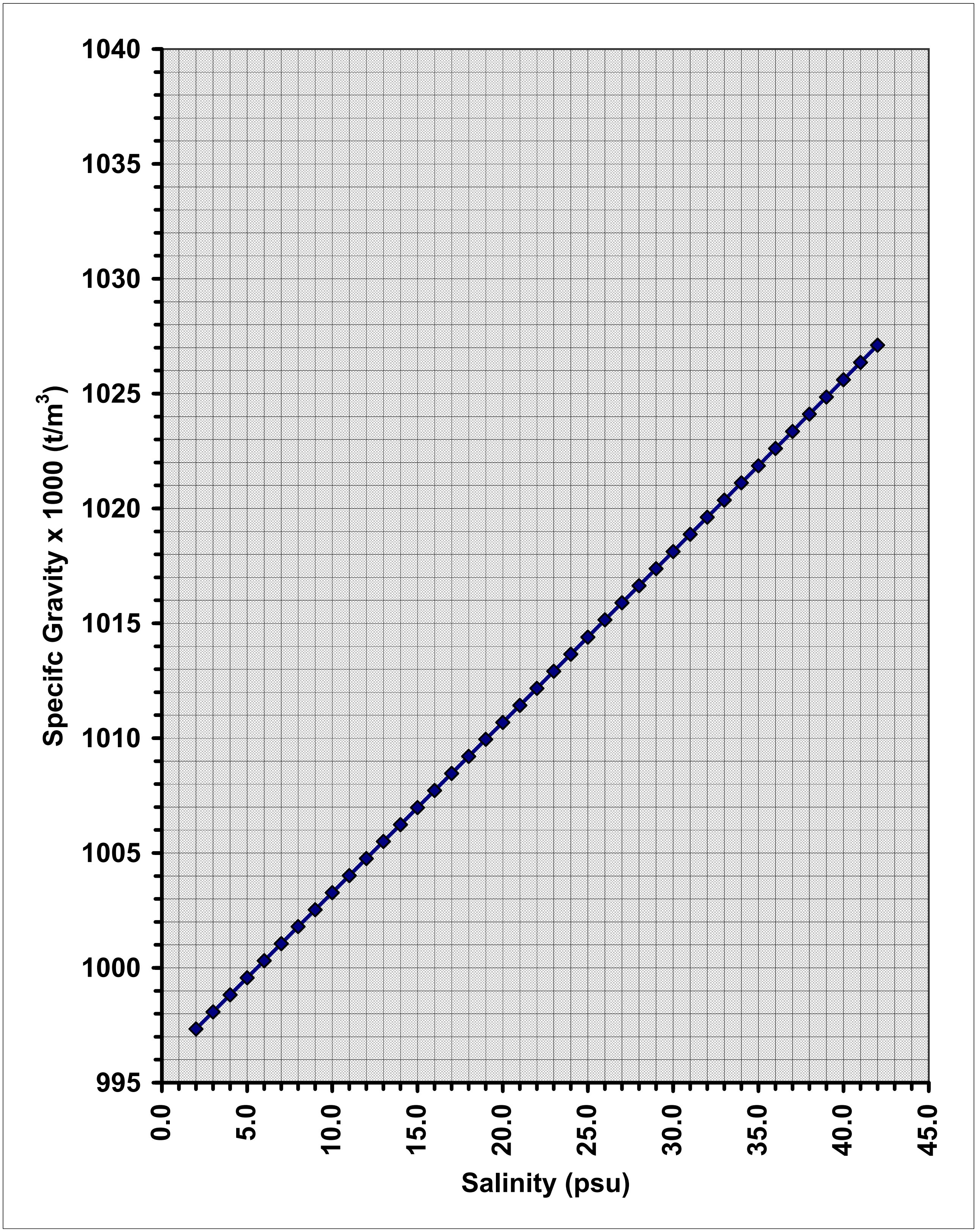

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Figure 15 **32.5°C**

Hydrometer Specific Gravity vs. Salinity at 35°C

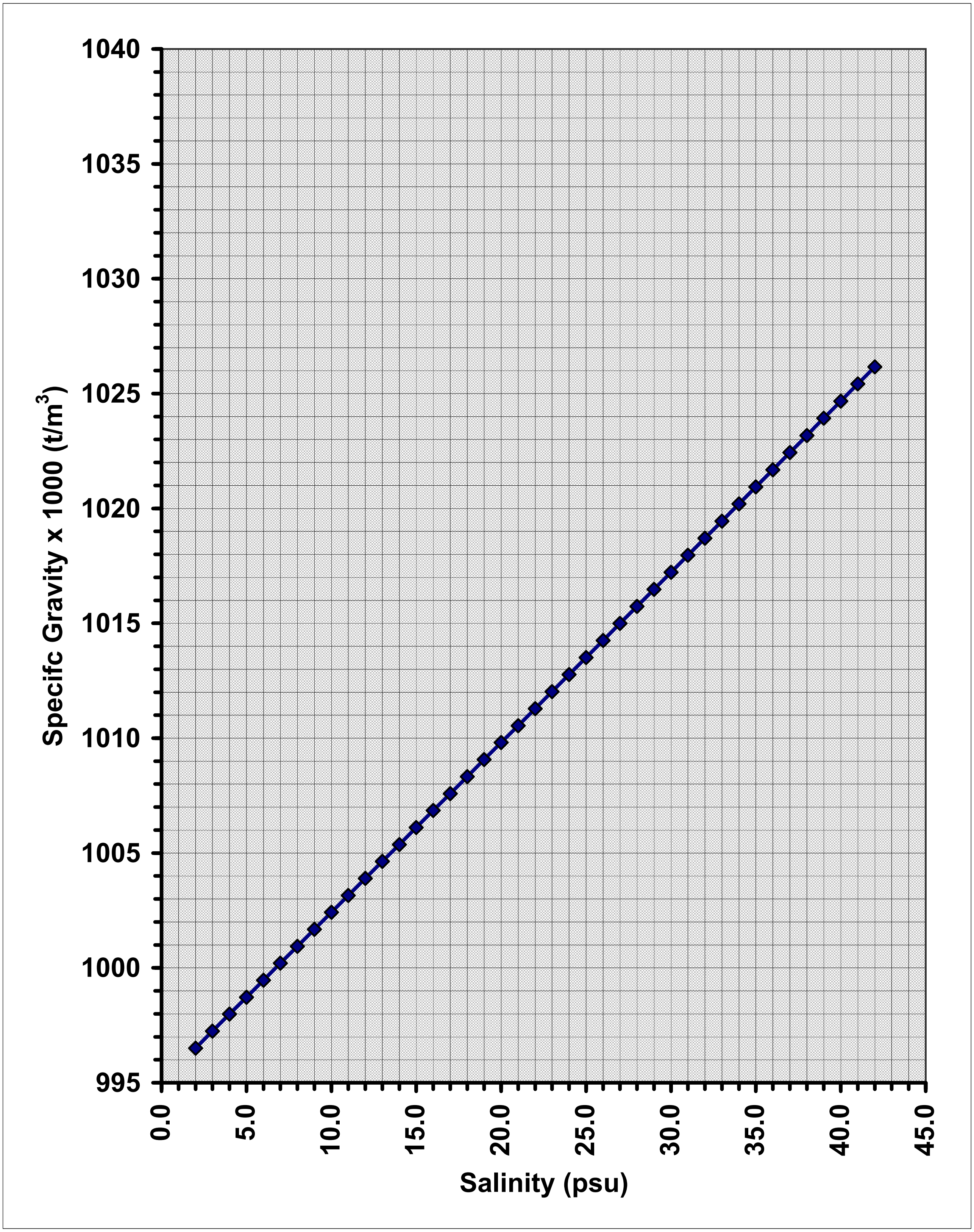

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Figure 16 **35°C**